Campbell River Project Water Use Plan

Upper and Lower Campbell Lake Fish Spawning Success Assessment

Implementation Year 5

Reference: JHTMON-3

JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment Year 5 Annual Monitoring Report

Study Period: 2018

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

November 22, 2019

JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment

Year 5 Annual Monitoring Report

Prepared for:

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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process and have implemented monitoring to address outstanding management questions. To address uncertainty around factors limiting fish abundance, 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 *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3) comprises one component of the wider effectiveness monitoring studies within the Campbell River WUP. The overall aim of JHTMON-3 is to test the assumption that recruitment of salmonids (trout and char) in Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir is limited by availability of effective spawning habitat. The three species of primary interest are Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarki*) and Dolly Varden (*Salvelinus malma*). JHTMON-3 involves assessing the extent of spawning habitat both within and above (i.e., in tributaries upstream of) the drawdown zone, evaluating overall habitat utilization and spawning success, and determining whether the area of functional spawning habitat is sufficient to allow the salmonid populations to fully seed the reservoirs.

ESH Model Results

The Effective Spawning Habitat (ESH) Performance Measure Model quantifies the amount of spawning habitat within the drawdown zone that is available to fish, and is not inundated by rising reservoir levels during the egg incubation period. Because life histories and the timing of spawning and incubation vary among species, separate ESH models were run for Cutthroat Trout, Rainbow Trout and Dolly Varden.

ESH values for both Lower and Upper Campbell reservoirs were highly variable among years for all three species, particularly in the Upper Campbell Reservoir, and particularly for Cutthroat Trout. We explored the effect of effective spawning habitat on the dynamics of Cutthroat Trout in the Upper Campbell Reservoir through the implementation of a population model.

Gill Netting Surveys

Gill netting surveys between August 20 and August 22, 2018 in Upper Campbell Reservoir resulted in the capture of 37 Cutthroat Trout, 127 Rainbow Trout, 0 Dolly Varden, 6 sculpin, and 7 Cutthroat Trout/Rainbow Trout hybrids. Catch per unit effort (CPUE) ranged from 0.07 to 0.37 fish/net hour for Cutthroat Trout and 0.24 to 0.66 fish/net hour for Rainbow Trout.

Species-specific inverse von Bertalanffy growth functions were developed and implemented to assign ages of unaged fish, based on their fork length. These functions use all available data from the monitoring program (Years 1 to 5), and therefore will progressively improve as more data is collected through this monitoring program.

Cutthroat Trout were captured in sinking nets, suggesting a benthic life style. Rainbow Trout were most abundant in floating gill nets, suggesting a pelagic life style.

Snorkel Surveys

Snorkel surveys were undertaken to enumerate spawning Cutthroat Tout in the Lower Campbell Reservoir during March and April 2018, and to enumerate Rainbow Trout in the Buttle Lake and Upper Campbell Reservoir in June 2017. The survey results for Rainbow Trout were incorporated into the existing enumeration of adult spawning fish in the six tributaries of Buttle Lake and Upper Campbell Reservoir since 1990.

Snorkel surveys were undertaken at three tributaries of Lower Campbell Reservoir for adult Cutthroat Trout spawners in 2018. Miller Creek and Fry Creek were sampled on March 9, 2018; Greenstone River was sampled on April 16, 2018 due to colder water conditions. Adult Cutthroat Trout were observed in Miller Creek (*n* = 5) and Greenstone River (*n* = 92), but not Fry Creek. However, Cutthroat Trout redds were observed in all three tributaries and were most abundant in Miller Creek (*n* = 117), followed by Fry Creek (*n* = 59) and Greenstone River (*n* = 18). Juvenile Cutthroat Trout were not observed during Spring snorkel surveys.

Cutthroat Trout densities were highest in Greenstone River (38.3 fish/km), followed by Miller Creek (12.5 fish/km). The majority of adult Cutthroat observed were either bright or moderately coloured, indicating spawning activity at the time of the surveys.

Snorkel surveys targeting adult Rainbow Trout spawners were undertaken in tributaries to Buttle Lake and Upper Campbell Reservoir during low flow conditions from June 4 to 7, 2018. Rainbow Trout redds were recorded in all sampled tributaries. The highest number of redds was observed in Thelwood Creek (1,519 redds), followed by Lower Elk River (1,235 redds), upper Elk River (875 redds), Wolf River (623 redds), and Ralph River (198 redds). The majority of adult Rainbow Trout observed were in mid-spawning or moderately coloured condition, and highest numbers were recorded from the lower Elk River and Thelwood Creek. Low numbers of adult Rainbow Trout were recorded from Henshaw Creek. Observed densities of Rainbow Trout were greatest in Wolf River (2,083 fish/km), Ralph River (721 fish/km) and Thelwood Creek (628 fish/km). This pattern was similar to that observed during previous years of this monitoring program (2014-2017).

Spawning Habitat Availability

Spawning habitat availability field surveys were carried out in Year 4 of the monitoring program. Given that spawning habitat is determined by physical characteristics of the riverscape that we assume are relatively consistent among years of the monitor, we assume that metrics calculated in Year 4 are applicable to Year 5 and present them for completeness.

Spawning habitat availability was assessed across the entire length of accessible stream reaches entering the Lower Campbell Reservoir, Upper Campbell Reservoir (Elk River and associated tributaries) and Buttle Lake. A combination of UAV (Unmanned Aerial Vehicle - drone) aerial surveys and ground-based field gravel surveys were used to generate a series of spawning habitat indicator metrics. These metrics include georeferenced linear and area-based summaries as well as a qualitative classification of reach-level spawning habitat potential. Summaries were generated within the drawdown zones and upstream sections of each tributary where applicable. Spawning habitat availability summaries were generalized for target fish species (i.e., Rainbow Trout, Cutthroat Trout, Dolly Varden).

Overall, approximately 80% of all accessible spawning habitat was located in upstream areas above the drawdown zones; however, results varied between each reservoir. The drawdown zone reaches of the Elk River and all streams within the Lower Campbell Reservoir were characterized as having a lower quantity of spawning habitat relative to upstream reaches, whereas tributaries to Buttle Lake all had large portions of spawning habitat within the drawdown relative to upstream reaches. Buttle Lake tributaries were characterized as having a larger portion of their spawning habitat located in the drawdown zone relative to tributaries themselves, whereas the upstream sections of the Elk River and Elk River tributaries accounted for over 70% of all accessible spawning habitat within the Upper Campbell/Buttle Lake Reservoir.

The methods used in this study to quantify spawning habitat within and above the drawdown zones were developed to integrate data sources from different field programs as well as quantify spawning habitat over a large area (over 31 km of streams covering a total area of 115 ha). Although the metrics used to quantify spawning habitat were relatively simple (e.g., linear distance, wetted area, channel width) the consistency of our results across linear and area-based metrics suggests that results would be relatively similar with the addition of other more specialized spawning habitat indicator variables. Habitat availability in the drawdown zones is also variable between years as a result of changing reservoir water levels. A comparison between 2017 and 2018 suggests that spawning habitat availability in the drawdown zones was lower in 2017 as a result of higher reservoir levels during the spawning period and subsequent lake backwatering over spawning channel habitat.

Spawning Habitat Use

Spawning habitat use was inferred from the abundance of redds located within the drawdown zones relative to reaches upstream of the drawdown zones. Spawning habitat use was assessed throughout unobstructed stream reaches entering the Lower Campbell Reservoir, Upper Campbell Reservoir (including the Elk River and its tributaries) and Buttle Lake. Similar to spawning habitat availability results, spawning habitat use summaries were also generalized for target fish species (i.e., Rainbow Trout and Cutthroat Trout). Overall, we identified a greater total number of redds (n = 7,989) located in upstream reaches relative to drawdown zones areas (n = 1,854).

The abundance and distribution of redds for both Rainbow and Cutthroat Trout (habitat use) were largely consistent with estimates of habitat availability. Within drawdown zones of the Elk River and all tributaries to the Lower Campbell Reservoir, we found a much larger portion (97%) of redds located in upstream reaches relative to areas within the drawdown zones. Conversely, for tributaries to Buttle Lake approximately 78% of redds (n =1,605) were located within the drawdown zones relative to upstream areas (n = 453).

Based on habitat availability, we expected that a large number of redds would be located within the drawdown zone of the Elk River; however, almost all redds within this waterbody were located further upstream in what appeared to be higher quality spawning habitat. Redds located within the drawdown zones predominantly occupied the upstream margins of the drawdown zones along the mainstem channel thalweg in deeper fast-moving water where large gravel substrates were abundant. In upstream reaches above the drawdown zones, redds were located in shallower water, in side channels or along the margin of the mainstem. Across most tributaries, redds occupied the full surface of accessible spawning habitat downstream of barriers/obstructions preventing upstream fish passage, suggesting that spawning habitat use was not limited by distance upstream of the reservoirs. Between the 2017 and 2018 field seasons the distribution of redds upstream and within the drawdown zones were similar; however, in 2017 redds were deposited at higher elevations within the drawdown zone, possibly reflecting the higher reservoir levels during the 2017 spawning period.

In future phases we suggest that additional work be undertaken to quantify uncertainty relating to the potential for a difference (offset) between the water surface elevation reported at the WSC (Water Survey Canada) reservoir gauging stations and the local water surface elevation recorded at each site with installed benchmarks. For example, wind setup could cause an offset between the local observed water surface at a site and the value reported by the gauging station.

Incubation Experiments

During the development of the WUP, it was assumed that reservoir inundation led to complete and instantaneous death of incubating Rainbow Trout embryos. To test this assumption, we carried out incubation experiments in spring 2018 at three sites on Elk River and three sites at Ralph River, at elevations above reservoir level, 1 and 3 meters below water level. Each site had 5 cassettes buried with 50 eggs per cassette. Survival and hatch rates differed among streams and depths, from almost no effect of inundation (close to 100% hatch and survival rates in Ralph River) to a substantial effect of inundation (0% hatch and survival rates at 3 m below reservoir water level in Elk River). This suggests that incubator depth and stream conditions affect egg survival.

To support the incubation test study, we measured seepage and collected substrate, water quality, and hydrology data to evaluate the influence of groundwater movement on incubation conditions and egg survival. Groundwater exchange on its own was not enough to explain the patterns observed during the incubation experiments; we observed nil or very low exchange rate at two sites (based on data from the temperature array located at each site), but only one of those sites (3 m below reservoir water level in Elk River) showed high egg mortality. A combination of 3 factors was observed at this site: very low groundwater exchange rate, low surface water flow, and a high percentage of fines in the substrate. At the second site with low groundwater exchange rate (1 m below reservoir water level in Ralph River) we measured a similar percentage of fines in the substrate, but higher surface flow, which may have improved oxygen circulation around the incubator, thereby improving survival.

The incubation tests suggest that the modeling assumptions used during the WUP were conservative and likely overestimated the effects of reservoir inundation. However, the high mortality observed at the site 3 m below water reservoir level in Elk River lends some support to the assumption. The magnitude of the effect of egg inundation on survival is influenced by stream conditions, and its true realized value is probably lower than the assumed effect, but cannot be disregarded.

Population modelling

The effect of reservoir elevation on the dynamics of Cutthroat Trout in the Upper Campbell Reservoir was assessed through the development of a statistical catch-at-age model, implemented within an Information-Theoretic approach. Given the limited data set (describing the dynamics of fish stocks requires time series much longer than 5 years), results from this modelling exercise should be considered preliminary.

The stock dynamics model captured reasonably well the time series of total catch and gill netting effort. Three scenarios were tested: *i*) recruitment to age 1+ is constant, *ii*) recruitment to age 1+ is variable, and *iii*) recruitment is a function of the effective spawning habitat. The most parsimonious model was the variable recruitment scenario. Recruitment parameters from this model were highly correlated with effective spawning habitat (accounting for the appropriate time lag). Therefore, notwithstanding the results of the incubation tests that suggest that the assumption of the Campbell River WUP were conservative and likely overestimated the effects of reservoir inundation on embryo mortality, results from the population model suggest that these effects are strong enough to affect the dynamics of Cutthroat Trout in the Upper Campbell Reservoir. The approach appears to have a reasonable likelihood of providing robust results with respect to the effect of reservoir elevation on the dynamics of salmonids in the Campbell River System by the end of the planned monitoring program.

MON-3 Status of Objectives, Management Questions and Hypotheses after Year 5.

Study Objectives	Management Questions	Management Hypotheses	Year 5 (fiscal year 2018) Status
The aim of JHTMON-3 is to test the assumption that recruitment of salmonids (trout and char) in Upper and Lower Campbell reservoirs is limited by availability of effective spawning habitat. The Monitor involves assessing the extent of spawning habitat both within and above the drawdown zone;	Following implementation of the Campbell River WUP, does the population of Rainbow Trout, Cutthroat Trout and Dolly Varden in Upper and Lower Campbell reservoirs increase as a result of the expected gains in functional spawning habitat?	H_01: Following implementation of the Campbell River WUP the abundance of adult trout does not change in Upper and Lower Campbell Reservoirs.	Data were collected as planned, from standardized snorkel surveys of spawning fish in tributaries, and gill netting of multiple cohorts in reservoirs. Trends in adult trout abundance require a long period of monitoring to test this management hypothesis. However, a preliminary population model was developed and

Study Objectives	Management Questions	Management Hypotheses	Year 5 (fiscal year 2018) Status
evaluating overall habitat utilization and spawning success; and determining whether the area of effective spawning habitat is sufficient to allow the salmonid populations to fully seed the reservoirs. Implementation of the WUP in the Upper and Lower Campbell Reservoirs is predicted to increase the area of effective spawning habitat for both Cutthroat Trout and Rainbow Trout. Analysis of fish abundance and spawning success before and after the WUP implementation will test the assumption that salmonid recruitment is limited by availability of effective spawning habitat.			implemented as part of the Year 5 summary. The approach is sound is expected to answer the hypothesis.
	Are the trout populations in Upper and Lower Campbell reservoirs limited by the availability of effective spawning habitat?	$H_0$2: Following implementation of the Campbell River WUP the abundance of adult trout in Upper and Lower Campbell Reservoirs is not correlated with ESH at the time of the cohort's emergence.	Preliminary results from population modelling indicate that the availability of effective spawning habitat may be a limiting factor to recruitment of salmonids in the Upper Campbell Reservoir. Robust analysis of the effects of ESH on population abundance will require data collection over a longer time frame. The current study design is appropriate to address this hypothesis.
	Is the ESH performance measure a reliable measure of spawning habitat, and therefore useful in the present Monitor, as well as in future WUP investigations?	$H_0$3: The proportion of mature adults that spawn in the drawdown zones of Upper and Lower Campbell reservoirs is not biologically significant.	$H_0$3: Data were collected on spawning habitat use, and integrated with information on spawning habitat availability collected during Year 4. The majority of spawning takes place in areas upstream of the drawdown zone, but it is highly variable among waterbodies. In some tributaries a considerable portion of spawning

Study Objectives	Management Questions	Management Hypotheses	Year 5 (fiscal year 2018) Status
		H_04: There is insufficient groundwater movement in areas of the drawdown zone suitable for trout spawning to replenish local oxygen supply and flush away metabolic waste.	occurs within the drawdown zone. H_04: An experimental incubation test to asses mortality rate of eggs in relation to inundation by rising reservoir water elevation was carried out. Hydrology and water quality data were also collected to support interpretation of the experimental results. Survival and hatch rates differed among streams and depths, from almost no effect of inundation to a substantial effect of inundation. High mortality rate was tentatively linked to stream conditions (i.e. groundwater exchange rate, surface water flow, and percentage of fines in the substrate).

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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 BC Hydro, 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 may be monitoring to address outstanding management questions in the years following the implementation of a WUP.

As the Campbell River Water Use Plan (BC Hydro 2012) 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 human activities in the watershed affect fisheries, and in effectively managing water uses to protect and enhance aquatic resources. To address uncertainty in our understanding of the factors that limit fish abundance and biomass, 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.

Salmonid (trout and char) recruitment (i.e., number of fish surviving to enter a particular life history stage) is assumed to be limited by the availability of suitable spawning habitat. BC Hydro affects the amount of spawning habitat through reservoir filling and drawdown. The drawdown zone refers to the area within the elevation band of the reservoir between the high and low waterlines that is susceptible to becoming either inundated or exposed from water use operations. Each tributary draining directly into the reservoirs can be divided into an upstream section above the upper limit of the drawdown zone and a lower section within the drawdown zone. Observations suggest that some resident Rainbow Trout and Cutthroat Trout spawn in tributaries and alluvial fans within the drawdown zone of Upper Campbell Lake and Buttle Lake Reservoir and Lower Campbell Lake Reservoir (Lough 2000). During the Campbell River WUP development, it was hypothesized that rising reservoir water levels during spring freshet inundate and thereby kill incubating eggs, effectively limiting the area of effective spawning habitat[1] for salmonids, and ultimately recruitment to populations in Upper Reservoir and the Lower Reservoir. The main premise for the impact hypothesis is that these fish typically dig their redds during late winter and spring when reservoir levels are low, and are then susceptible to inundation from rising reservoir levels during the freshet period (Anon. 2004). In the absence of groundwater upwelling, standing water (i.e., non-flowing water) above

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[1] The term 'effective spawning habitat' refers to spawning habitat that remains 'suitable' for the duration of the spawning and following incubation periods.

a redd is thought to kill incubating embryos in the pre-eyed stage because it prevents replenishment of oxygen at the egg-water interface.

The *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3) is one of a number of effectiveness monitoring studies within the Campbell River WUP. The objective of JHTMON-3 is to test salmonid recruitment (trout and char) in the Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir to help resource managers better understand the potential biological effects of BC Hydro operations. JHTMON-3 assesses the relationship between salmonid recruitment in the reservoirs and drawdown, specifically assessing whether population abundance of salmonids is limited by spawning habitat within the drawdown zone.

During the Campbell River WUP, an "Effective Spawning Habitat" (ESH) Performance Measure (PM) was devised for trout spawners in the Upper Reservoir and the Lower Reservoir, which calculated the amount of spawning habitat inundated during the spawning and incubation period of different salmonid species. During the WUP, the ESH PM was used to evaluate reservoir operations by assuming that more spawning habitat would result in greater recruitment to Campbell River reservoirs and their tributaries. In essence, this PM assumed that recruitment of trout in the reservoirs is limited by functional spawning habitat. The aim of the JHTMON-3 monitoring study is to test this assumption.

1.2. Campbell River Watershed - BC Hydro Infrastructure, Operations, and Monitoring Context

1.2.1. Overview

The Campbell River WUP project area is complex and includes facilities and operations in the Campbell, Quinsam and Salmon watersheds. The Upper and Lower Campbell reservoirs are located due west of the city of Campbell River on the east coast of Vancouver Island, British Columbia (Map 1). Details of BC Hydro's Campbell River infrastructure and operations are provided in the Campbell River System WUP (BC Hydro 2012).

1.2.2. Upper Campbell Reservoir

Buttle Lake and Upper Campbell Reservoir are effectively a single reservoir that is the largest in the Campbell River hydroelectric system. The largest tributaries are Thelwood Creek, entering the system at the south end of Buttle Lake, and the Elk River, which enters the west side of Upper Campbell Reservoir. Upper Campbell Reservoir is impounded by the Strathcona Dam, which was constructed between 1955 and 1958 and had a second generating unit installed in 1968. The dam also provides primary flow regulation for the Ladore and John Hart Dams, which are located downstream. Upper Campbell Reservoir's historic operational water elevation has been between 221.0 m and 210.0 m. The storage licence for operations in Buttle Lake and Upper Campbell Lake Reservoir are between 212.00 m to 220.98 m and 192.00 to 220.98, respectively (BC Hydro 2012).

1.2.3. Lower Campbell Reservoir

Lower Campbell Reservoir is located 15 km east of Campbell River. It is located to the east, and at the outflow of, the Upper Campbell Reservoir (Map 1). Lower Campbell Reservoir is impounded by the Ladore Dam. The Ladore Dam was originally completed in 1949, and two generating units were added in 1957. The reservoir's historic operational water elevation has been between 178.3 m and 174.0 m, while the current storage licence limits for operation are between 178.3 m and 163.65 m (BC Hydro 2012).

1.3. Historical Reservoir Elevations, and Implementation of the Interim Flow Management Strategy

The Upper Campbell Reservoir experiences water levels fluctuations of 4 to 10m within years. (Figure 1). Fluctuations differ among years depending on hydrological conditions; however, in general, the reservoir is drawn down in late winter and early spring and recharges during late spring and early summer. A second drawdown typically occurs in late summer and early fall, prior to recharge due to fall rainfall. Seasonal changes are much less pronounced in Lower Campbell Reservoir, which is operated within a narrower range of elevations (Figure 2).

BC Hydro implemented an Interim Flow Management Strategy (IFMS) in October 1997, with the aim of balancing power generation with fisheries and wildlife habitat, shoreline conditions, flood control, and recreation interests. The IFMS was later replaced by the WUP (BC Hydro 2012), although impacts on reservoir elevations were minimal with respect to those outlined in the IFMS. Figure 1 and 2 show the impact that the implementation of the IFMS had on elevations of the Upper and Lower Campbell Reservoirs. Following implementation of the IFMS, seasonality in elevation of the Upper Campbell Reservoir remained relatively stable, except for an increased duration of the period of high elevations during the summer. In general, the mean, 10th and 90th quantiles of reservoir elevations were ~2 m lower post-implementation of the IFMS (Figure 1). The implementation of the IFMS did not have any impacts on the elevation of the Lower Campbell Reservoir (Figure 2).

1.4. Management Questions and Hypotheses

The overall objective of JHTMON-3 is to test the assumption that recruitment of salmonids (trout and char) in Upper and Lower Campbell reservoirs is limited by availability of effective spawning habitat. Testing this assumption was conducted by: 1) assessing the extent of spawning habitat both within and above the drawdown zone; 2) evaluating overall habitat utilization and spawning success; and 3) determining whether the area of functional spawning habitat is sufficient to allow the salmonid populations to fully seed the reservoirs. The three species of primary interest for the study are Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarki*), and Dolly Varden (*Salvelinus malma*).

Project Overview

Legend

— Dam

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		10/02/2015 1230_JHT_ProjectOverview_2015Feb10_LB	CGA
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Date Saved: 10/02/2015
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_JHT_ProjectOverview_2015Feb10_LB.mxd

The JHTMON-3 monitoring program aims to address the following three management questions (BC Hydro 2015):

1. Following implementation of the Campbell River WUP, do the populations of Rainbow Trout, Cutthroat Trout, and Dolly Varden in the Upper Reservoir and Lower Reservoir increase as a result of the expected gains in functional spawning habitat?

And, by corollary:

2. Are the trout populations in Upper Reservoir and the Lower Reservoir limited by the availability of functional spawning habitat?
3. Is the ESH Performance Measure a reliable measure of spawning habitat, and therefore useful in the present monitoring study, as well as in future WUP investigations?

In addressing these questions, the monitoring study is designed to test the following four null hypotheses:

$H_0$1: Following implementation of the Campbell River WUP:

a. The abundance of adult trout does not change in Upper Reservoir.

b. The abundance of adult trout does not change in Lower Reservoir.

$H_0$2: Following implementation of the Campbell River WUP:

a. Abundance of adult trout in Upper Reservoir is not correlated with ESH at the time of the cohort's emergence.

b. Abundance of adult trout in Lower Reservoir is not correlated with ESH at the time of the cohort's emergence.

$H_0$3: The proportion of mature adults that spawn in the drawdown zones of Upper Reservoir and the Lower Reservoir is not biologically significant.

$H_0$4: There is insufficient groundwater movement in areas of the drawdown zone suitable for trout spawning to replenish local oxygen supply and flush away metabolic waste.

1.5. Scope of the JHTMON-3 Study

The current JHTMON-3 TOR proposes a 10-year study with the following study components:

1. Annual (Years 1-9) trap and gill net surveys of fish abundance and biomass in the reservoirs;
2. A two-year survey of spawning distribution in reservoir tributaries; and
3. A two-year detailed analysis of flow and incubation conditions within the drawdown zone of tributaries.

Methods for this multi-year study have changed in accordance with results from previous years. Results from the Year 1 studies (Hatfield *et al.* 2015) indicated that hydro-acoustic surveys provide coarse estimates of adult population, but do not yield age-specific abundances and therefore are not useful for assessing the effects of varying Effective Spawning Habitat values over time. Trap netting was found to be most effective at catching sculpin and stickleback, while gill nets are most effective at catching salmonids including Cutthroat Trout and Rainbow Trout. The additional sampling effort and cost associated with calibration of the gill net catches with trap net catches was determined to be not feasible. Trap net sampling was therefore discontinued for the 2016 (Year 3) monitoring program and only gill net sampling was continued.

The implemented Year 5 program followed the approach adopted for Year 3 and Year 4, with the addition of analysis of flow and experiments of egg incubation conditions within the drawdown zone. Methods related to H_01 and H_02 in Year 5 involved:

1. Estimating fish abundance for salmonid species in Upper Campbell Reservoir, using sampling with gill nets.
2. Estimating abundance of spawning adfluvial trout (Cutthroat and Rainbow) using snorkel surveys in tributaries to Buttle Lake and Upper and Lower Campbell reservoirs.

Methods related to H_03 involved:

1. Estimating spawning habitat availability using redd surveys.

Methods related to H_04 involved:

1. Measuring seepage rates and collecting supporting hydrology and water quality data.
2. Carrying out experimental incubation tests, to estimate hatch and survival rates of salmonid eggs within the drawdown zone.

This report collates all the data collected to date (Years 1-5), summarizes analyses, and discusses the results as they pertain to the impact hypotheses and management questions.

Figure 1. Elevation of Upper Campbell Reservoir (recorded at Strathcona Dam), pre- and post-implementation of the Interim Flow Management Strategy. Grey lines represent elevations for individual years, blue lines represent mean elevations, red lines represent the 90th percentile elevations, and green lines represent the 10th percentile elevations. Timing of salmonid spawning and incubation periods are shown.

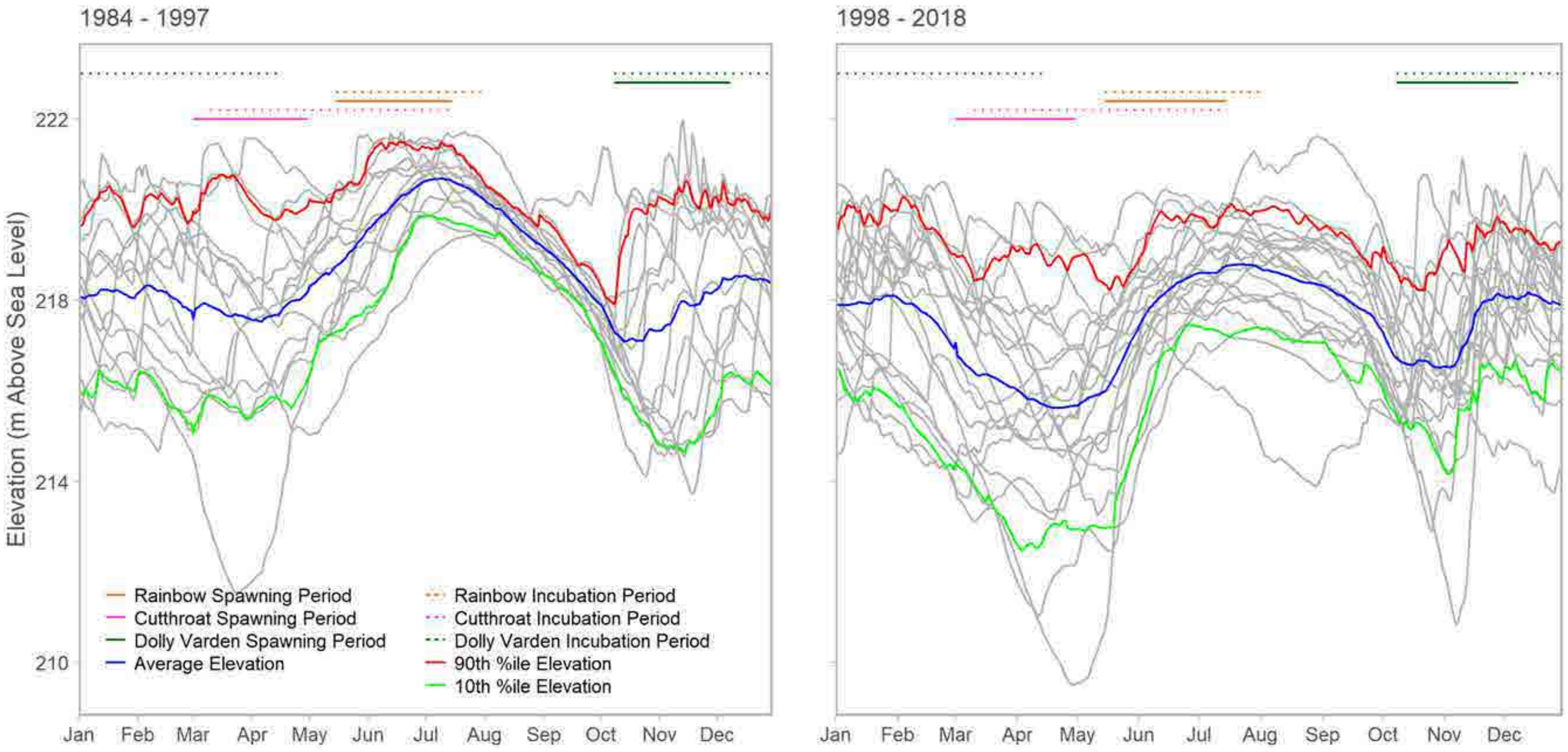
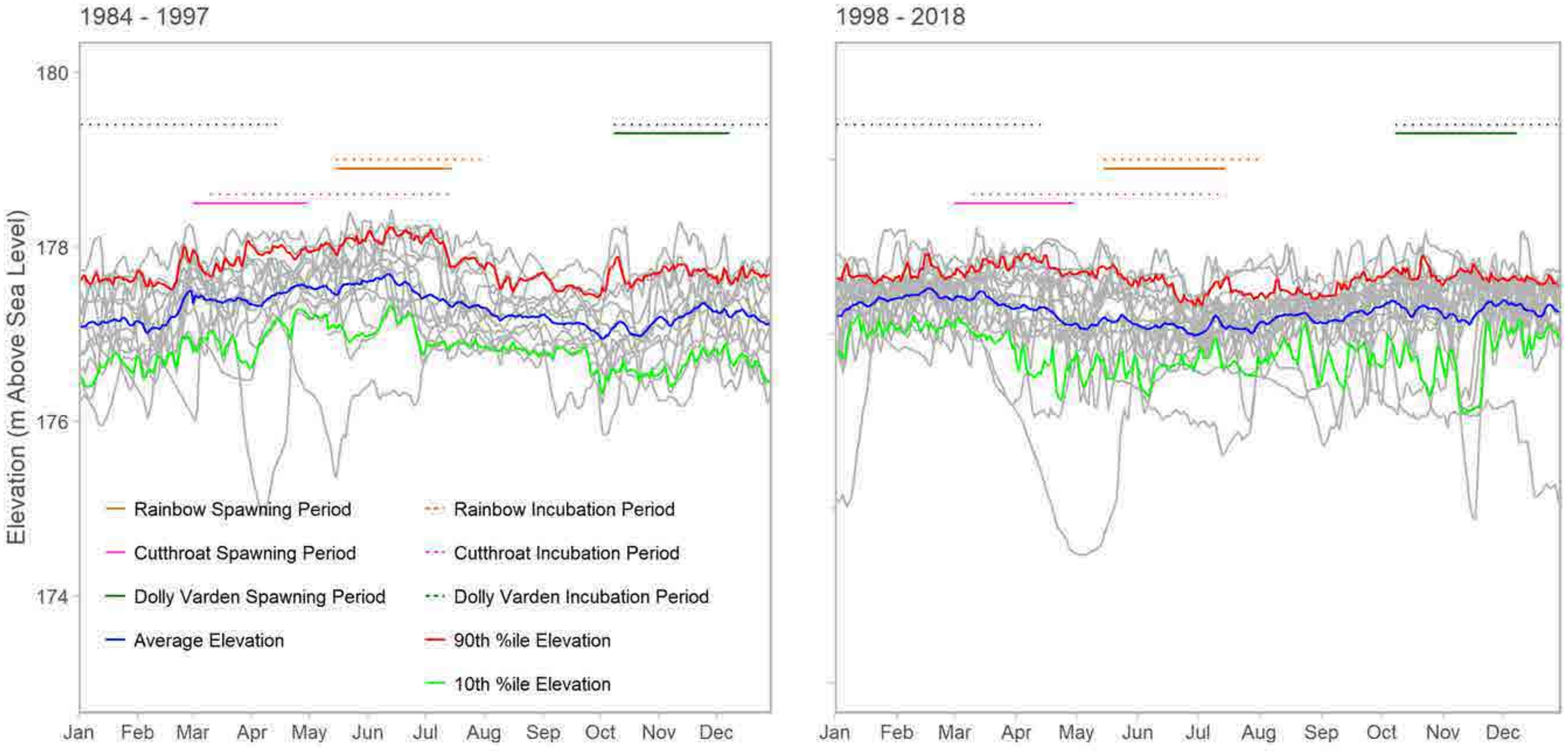


Figure 2. Elevation of Lower Campbell Reservoir (recorded at Ladore Dam), pre- and post-implementation of the Interim Flow Management Strategy. Grey lines represent elevations for individual years, blue lines represent mean elevations, red lines represent the 90th percentile elevations, and green lines represent the 10th percentile elevations. Timing of salmonid spawning and incubation periods are shown.



2. METHODS

2.1. Effective Spawning Habitat (ESH)

To quantify how reservoir elevations may affect the success of spawning in tributary sections of the drawdown zones, an "effective spawning habitat" performance measure was developed in the WUP (FTC 2003). The term "effective spawning habitat" is used to refer to habitat that maintains its quality sufficiently to allow successful spawning and incubation. This performance measure is used to evaluate mortality of eggs following inundation, caused by accumulation of by-products of metabolism and insufficient oxygen replenishment. BC Hydro developed an Effective Spawning Habitat (ESH) model to quantify effective spawning habitat and to track the amount of habitat available for spawning that also receives sufficient flow during incubation periods (Leake, pers. comm. 2014).

The amount of spawning habitat present for each day of spawning, and remaining as such thereafter during incubation, was determined from reservoir-specific relationships between reservoir level and available spawning habitat (Figure 3). Mean daily reservoir elevations for Strathcona Dam (Upper Campbell Reservoir) and Ladore Dam (Lower Campbell Reservoir) used in ESH modelling were provided by BC Hydro (Leake, pers. comm. 2014).

The incubation period was defined separately for the three species of interest, given their different life histories (Table 2); each species differs in the date of start and duration of incubation. Life history parameters were assumed to be constant across years. Incubation begins on the day of spawning and is assumed to last until a species-specific threshold in accumulated thermal units (ATU; i.e., daily accumulation of water temperature) is reached: 550 ATU for Cutthroat Trout, 600 ATU for Rainbow Trout, and 700 ATU for Dolly Varden (Table 2). Once this threshold is reached, eggs hatch. The metric Accumulated Thermal Units (ATU) was defined as the cumulative sum of daily average water temperature (Figure 4). The ATU was tracked for each species during the corresponding incubation period and when the threshold ATU was reached (or on the incubation date end, whichever comes first), incubation was assumed to cease.

For each day of the incubation period, an "effective spawning elevation" was derived from the reservoir elevation. If this elevation exceeded the reservoir elevation on the day of spawning by 25 cm for two consecutive days, then a portion of habitat was assumed to be lost. Effective spawning habitat area was determined from the effective spawning elevation and reservoir-specific relationships (Figure 3).

To obtain overall effective spawning habitat, the daily effective spawning habitat area was weighted by species-specific spawning intensities (Figure 5), to account for seasonality in the use of spawning habitat. Spawning intensities were assumed to be constant across years, and follow a normal distribution with species-specific mean and standard deviations provided in Table 2. Standard deviation in mean spawning date was assumed to be equal to spawning duration divided by six.

Effective spawning habitat and loss of effective habitat were summed over each day of spawning to determine the total effective spawning habitat and total effective spawning habitat loss for the duration of the spawning period.

The model is presented below as pseudo code. For each species, year, and day within the spawning period, the following steps were completed:

1. The reservoir elevation ("spawning elevation") was determined;
2. The "effective spawning elevation" was set to the spawning elevation, the total ATU was set to the water temperature for the spawning day;
3. For each day of the incubation period.
    a. The reservoir elevation was compared to the effective spawning elevation;
    b. If the reservoir elevation exceeds effective spawning elevation by 25 cm for two consecutive days, then the effective spawning elevation was set to the reservoir elevation minus 25 cm.
    c. The ATU for the incubation day was added to the total ATU.
4. At the end of incubation (when the total ATU meets the values in Table 2, or on the incubation end date in Table 2; whichever comes first) the effective spawning habitat area was determined from the effective spawning elevation (Figure 3);
5. Effective spawning habitat (area days, expressed as m^2d) was calculated by multiplying the effective spawning habitat area by the spawning intensity, which was provided as a function of calendar date (Figure 5);
6. The initial spawning habitat was calculated by determining the habitat area for the spawning elevation and multiplying by the spawning intensity; and
7. Loss of habitat was calculated by subtracting the effective spawning habitat from the initial spawning habitat.

The above calculations were computed for each day of the spawning period and summed over each year to obtain total effective spawning habitat and habitat loss.

Information pertaining to reservoir-specific relationship between reservoir elevation and available habitat (Figure 3), water temperature in the Upper and Lower Campbell Reservoirs (Figure 4), species-specific life histories (Figure 5 and Table 2), as well as mean daily reservoir elevations for Strathcona Dam (Upper Campbell Reservoir) and Ladore Dam (Lower Campbell Reservoir) used in ESH modelling were provided by BC Hydro.

Table 1. **Spawning and incubation timing information used in the ESH model for Cutthroat Trout, Rainbow Trout, and Dolly Varden (Leake, pers. comm. 2014).**

Species	Period	Start	End	Peak	µ (days)	σ (days)	Duration (days)	Total ATUs for Fish
Cutthroat Trout	Spawning	01-Mar	30-Apr	22-Mar	22	10.2	61	550
	Incubation	01-Mar	15-Jul					
Rainbow Trout	Spawning	15-May	31-Jul	08-Jun	25	13	78	600
	Incubation	15-May	15-Aug					
Dolly Varden	Spawning	08-Oct	08-Dec	01-Nov	25	10.3	62	700
	Incubation	08-Oct	15-Apr					

Spawning Intensity$=e^{(-(((\text{Day-Start Day}+1)-\mu)^2)/(2\sigma^2))}/(\sigma\sqrt{(2\pi)})$

Figure 3. **Relationships between spawning habitat within the drawdown zone and reservoir elevation for Upper Campbell Reservoir at Strathcona Dam (SCA) and Lower Campbell Reservoir at Ladore Dam (LDR). Additional spawning habitat above the drawdown zone is not accounted for in the model.**

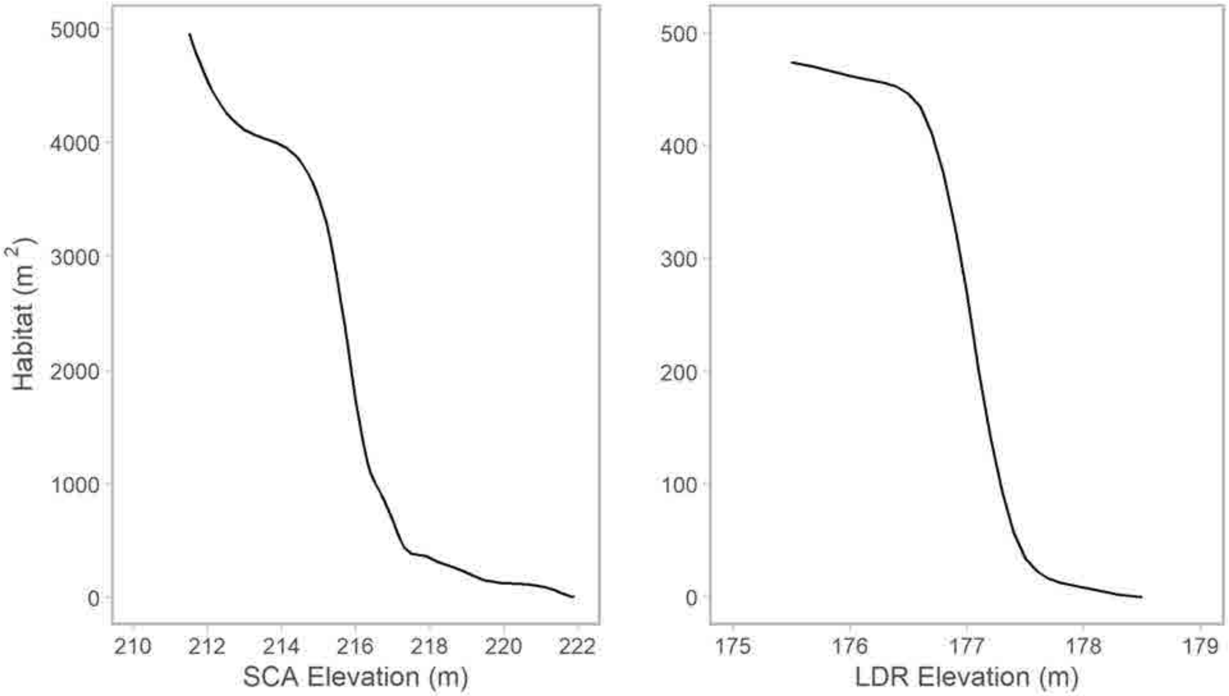


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Figure 4. **Water temperature trends used for ESH model for Upper Campbell Reservoir at Strathcona Dam (SCA) and Lower Campbell Reservoir at Ladore Dam (LDR).**

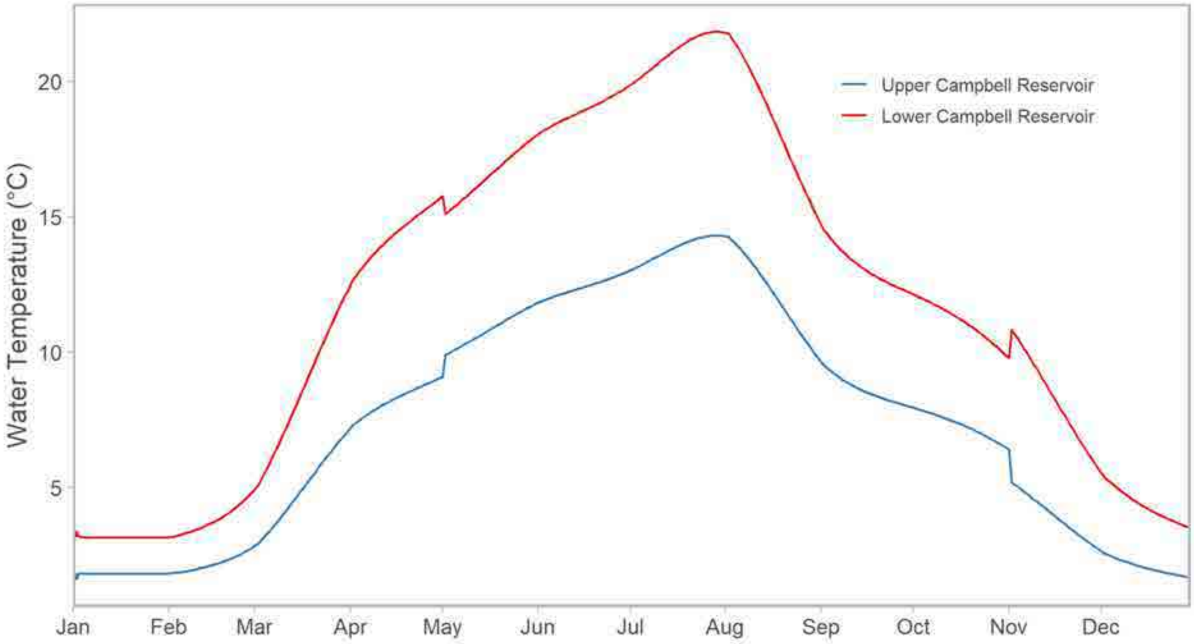
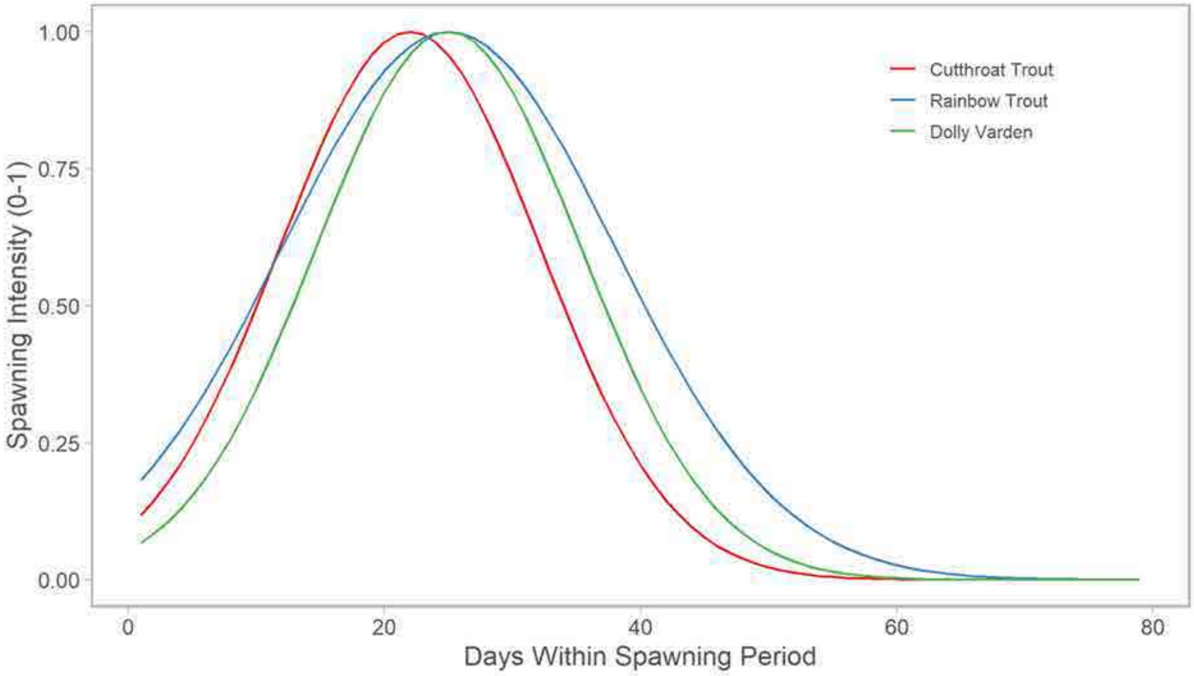


Figure 5. **Timing of spawning intensity for Cutthroat Trout, Rainbow Trout, and Dolly Varden used in the ESH model (Leake, pers. comm. 2014).**



2.2. Population Index for Upper Campbell Reservoir

2.2.1. Field and Laboratory Work

2.2.1.1. Gill Netting

The study areas for JHTMON-3 are the Upper Campbell (including Buttle Lake) and Lower Campbell reservoirs and tributaries. Sample sites within the study areas were selected based on location within the drawdown zone and are presented in Map 2. Bathymetric maps were reviewed to identify sampling sites with suitable depth profiles. Site locations were selected in 2014 and the same locations were resampled in 2015, 2016, 2017, and 2018.

The Year 5 gill netting surveys of Upper Campbell Reservoir were conducted using the same methods as Year 2 (2015), Year 3 (2016), and Year 4 (2017) studies. The gill netting sampling objective was to produce a fish abundance index by species and age. Gill netting targeted rearing areas for younger fish. To maintain consistency, the same six sites as in previous years were sampled, and during similar dates, i.e., late summer (between August 20 and August 22, 2018) (Table 2). Both floating and sinking gill nets were used to target specific strata within the water column.

At each site, one surface and one bottom overnight gill net was set, for a total of 12 overnight RISC nets sets in Upper Campbell Reservoir. The catch and depth fished for each panel of each net was recorded. Nets were set perpendicular to shore with sinking nets set on the bed and floating nets set on the surface. RISC-standard gill nets were used (91.2 m long); the nets consist of six panels, each 15.2 m long and of different mesh sizes (25 mm, 76 mm, 51 mm, 89 mm, 38 mm, and 64 mm) strung together to form a 91.2 m long and 2.4 m deep net. Two Nordic nets were used in addition to the RISC nets at sites UCR-LKGN04 and UCR-LKGN07; these nets were 13.0 m long by 1.8 m wide, with varying mesh sizes (12.5 mm, 19 mm, 16 mm and 25 mm) sequenced to capture a range of size classes of fish.

When setting a net, the boat operator ensured the proper location and depth of the site using a GPS and depth sounder and positioned the net according to depth contours and wind conditions. The net was held in place with a net anchor at each end of the net. Nets were set overnight with soak times of 17 to 21 hours. Floating lights were attached to each net to mark their location overnight for boater safety. All fish captured from 80 mm to 150 mm for parr (with the exception of Miller Creek; 90 mm to 180 mm for parr), during gill netting were identified to species, weighed, and measured to the nearest mm (fork length) in the field. Scales and fin rays were taken from Rainbow Trout and Cutthroat Trout to allow for age classes to be assigned to both species. The aim of field protocols associated with this sampling was to ensure that all live fish were returned to the reservoir in good condition. Captured live fish were anaesthetized as necessary to reduce handling stress.

Table 2. Sampling dates, site locations, and site conditions for Year 5 gill netting surveys on Upper Campbell Reservoir, August 2018.

Waterbody	Site	Sampling Date	UTM Zone	UTM Easting	UTM Northing	Set #	Net Type	Net Position[1]	Net Length	Water Temp. (°C)	Turbidity[2]	Estimated Visibility (m)
Upper Campbell Reservoir	UCR-LKGN01	20-Aug-18	10U	314096	5539930	1	RISC	FL	91.2	20.2	C	8
		20-Aug-18	10U	314096	5539930	2	RISC	SK	91.2	20.2	C	8
	UCR-LKGN02	20-Aug-18	10U	314629	5537246	1	RISC	SK	91.2	20.9	C	8
		20-Aug-18	10U	314629	5537246	2	RISC	FL	91.2	20.9	C	8
	UCR-LKGN04	21-Aug-18	10U	308638	5533904	1	RISC	SK	91.2	21.6	C	8
		21-Aug-18	10U	308638	5533904	2	RISC	FL	91.2	21.6	C	8
		21-Aug-18	10U	308638	5533904	3	Nordic	SK	13	21.6	C	8
	UCR-LKGN06	21-Aug-18	10U	309419	5527967	1	RISC	SK	91.2	22	C	8
		21-Aug-18	10U	309419	5527967	2	RISC	FL	91.2	22	C	8
	UCR-LKGN07	22-Aug-18	10U	310848	5526008	1	RISC	SK	91.2	21.6	C	8
		22-Aug-18	10U	310848	5526008	2	RISC	FL	91.2	21.6	C	8
		22-Aug-18	10U	310848	5526008	3	Nordic	SK	13	21.6	C	8
	UCR-LKGN08	22-Aug-18	10U	305645	5529532	1	RISC	SK	91.2	21.4	C	8
		22-Aug-18	10U	305645	5529532	2	RISC	FL	91.2	21.4	C	8

[1] SK - Sinking, FL - Floating

[2] C - Clear, L - Lightly turbid, M - Moderately turbid, T - Turbid

2.2.2. Data Analysis

2.2.2.1. Population Index

Catch Per Unit Effort

Catch per unit effort (CPUE) from gill netting, measured as fish caught per set-hour, was used as the metric of relative abundance in Upper Campbell Reservoir. CPUE was computed by individual net panel to estimate species relative abundance by 5 m depth intervals.

Individual Fish Analysis

Biological statistics computed for each species in the gill net catch include mean and standard deviation of length and weight, length-frequency and age distributions, weight-length regressions, and Fulton's condition factor (Ricker 1975). Age distributions were calculated for Rainbow and Cutthroat Trout only. Partially consumed individuals were excluded from analyses to ensure accuracy of fork length and/or weight measurements.

Stomach Content Analysis

Diets of Cutthroat Trout and Rainbow Trout were assessed in 2015, 2017, and 2018, through the analysis of stomach contents of a subset of fish. Stomach contents were examined under a dissecting microscope, and classified in one of the following five categories: Fish, Plankton, Benthic, Terrestrial, and Other. The percent volume each category represented in the stomach contents was recorded.

Aging Comparisons

Aging of fish by examination of the scales, fin rays, and otoliths was undertaken by experienced Ecofish fisheries biologists, with the assistance of A-Tlegay staff. A subset of the samples was measured while the remainder of samples were stored in case additional samples are required. Aging protocols are provided in Appendix A.

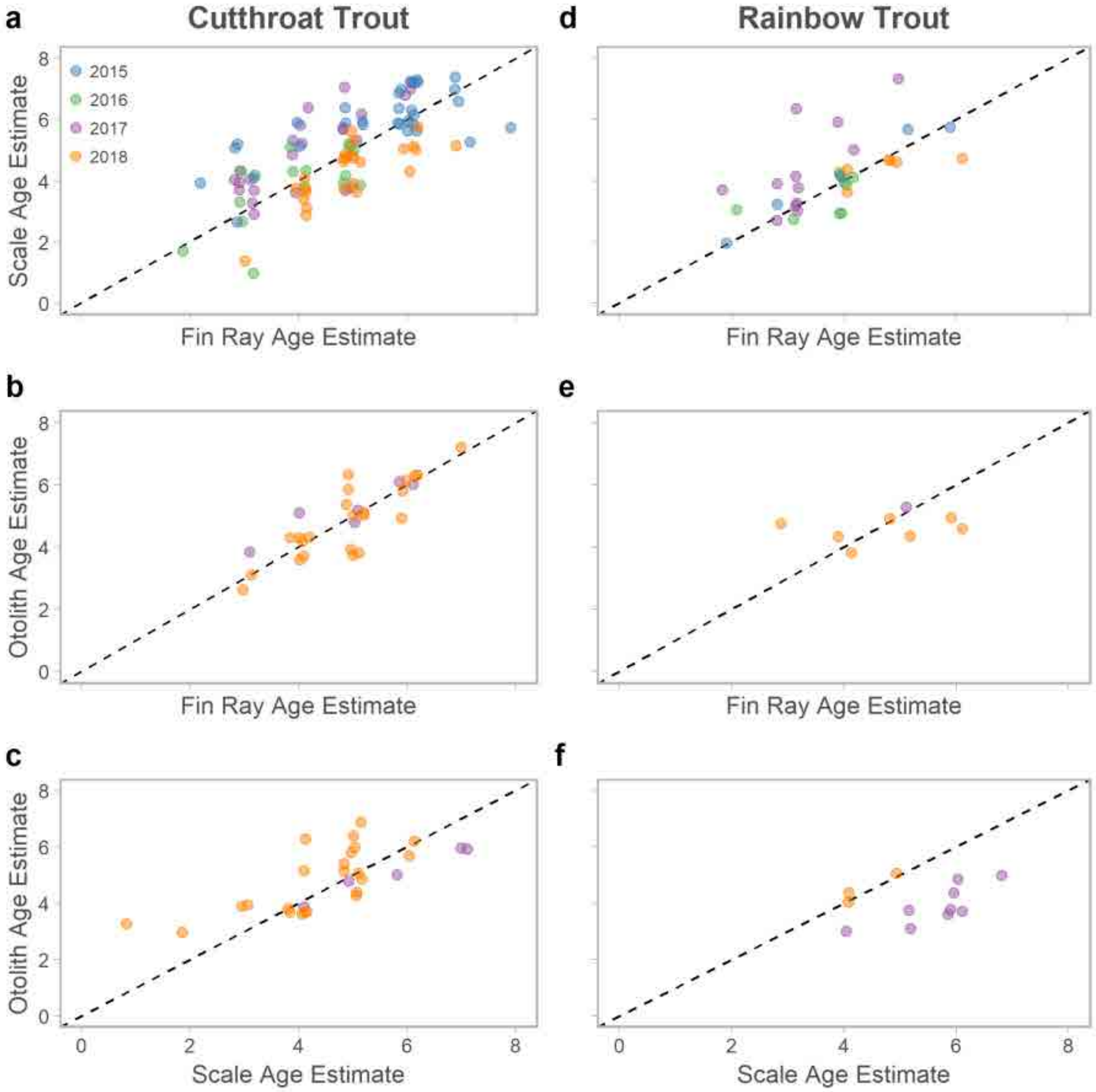
A preliminary assessment of the relative accuracy and feasibility of assigning age classes from the measured fork length was carried out during Year 4 of the monitoring program (Bayly *et al.* 2018). Age breaks can be confidently assigned based on scale ages for younger age classes. However, it is challenging for older age classes given that growth plateaus and therefore the separation between age classes in an age-length plot becomes more diffuse (Bayly *et al.* 2018).

Selection of the appropriate anatomical structure (scales, fin rays, or otoliths) to determine age of fish requires balancing precision and accuracy of the method with sample size limitations. Reading scales is easier, faster and cheaper, but less accurate than the other methods. Otoliths are more laborious and expensive to read; whereas fin rays are in between in terms of both, accuracy and cost (e.g., Williamson and Macdonald 1997, Zymonas and McMahon 2009).

With the aim of improving our ability to delineate age breaks for older age classes, effort in the reading of otoliths was increased in Year 5, particularly for Cutthroat Trout. The decision to increase reading of otoliths of Cutthroat Trout was based on maximising the gain in information obtained, given budgetary constraints. Given that a component of the present report is the integration of multiple sources of information in a statistical catch-at-age model to formally test the hypothesis that reservoir operations do not impact Cutthroat Trout recruitment, we decided to age all Cutthroat Trout caught in Year 5 to support the development of the model.

Figure 6 shows a comparison of ages read in the three structures; each data point represents the age assigned by two different methods for the same fish. Overall, the ages assigned by the three methods are consistently similar (i.e., the points are distributed around the 1:1 lines). The only deviation of note is that ages estimated by reading scales in 2017 seem to consistently be older than ages estimated by reading otoliths and fin rays for both Cutthroat and Rainbow Trout. In particular for Cutthroat Trout, there is very good coincidence between ages estimated by reading fin rays and otoliths, and both seem to result in slightly older ages than when estimated by reading scales.

Figure 6. Comparison between otolith, scale and fin ray age estimates from Cutthroat Trout (panels a to c) and Rainbow Trout (panels d to f) from 2015 to 2018. Each data point represents the age assigned by two different methods for the same fish. The dashed line provides a reference line of equivalent ages from each technique. Data points have been jittered to reduce overlap.



Age Cohort Analysis

Age information obtained from the subsample of fish that were aged during the five years of the monitoring project was used to assign ages to all Cutthroat Trout and Rainbow Trout caught. We fit species-specific length-at-age curves (Beverton, 1954; Beverton and Holt, 1957):

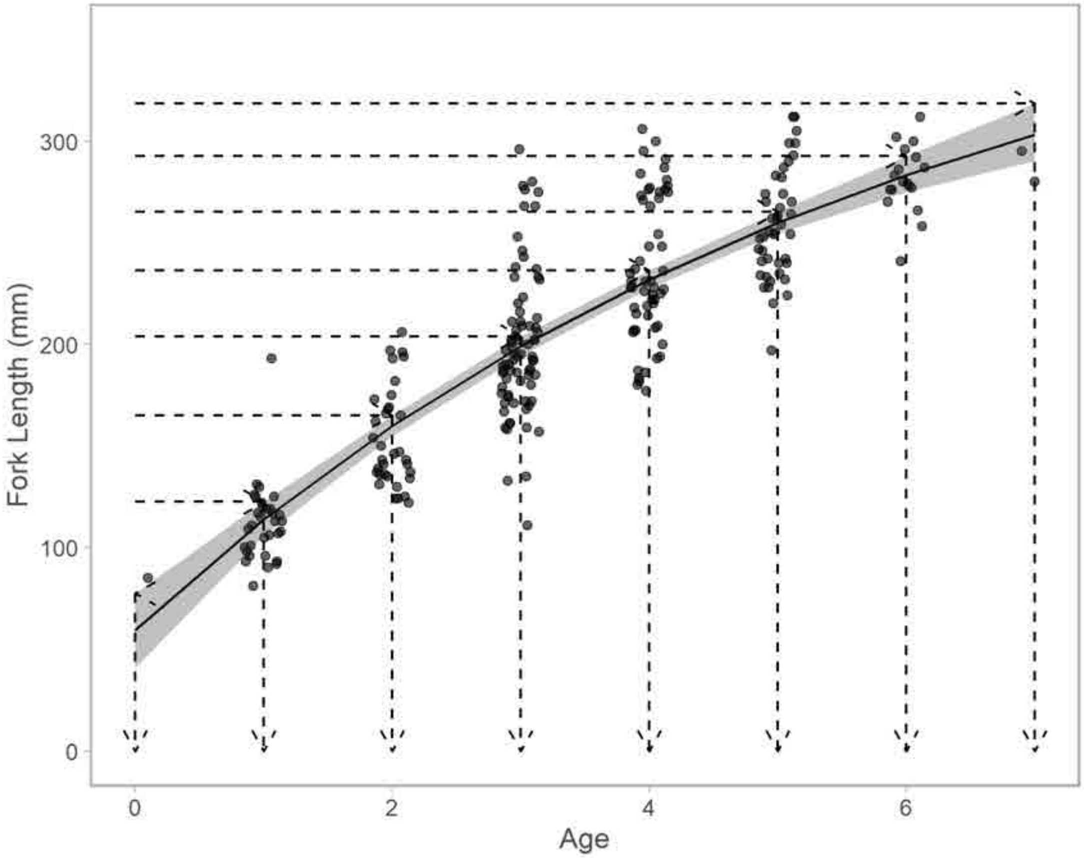
$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

where:

- L_t is the expected or average length at age t;
- L_∞ is the asymptotic average length;
- K is the body growth rate coefficient (units are yr^{-1}); and
- t_0 is a modeling artifact that is said to represent the time or age when the average length was zero.

We computed non-parametric bootstrap estimates (n_{boot} = 50,000 iterations) 95% confidence intervals of the average length at age. We then carried out a form of inverse inference, where we estimate the age of unaged fish, given their length and the expected length at age. The lengths of fish age t are bounded by the upper confidence interval of the lengths of fish age t-1 and the upper confidence interval of fish of age length t (see an illustration in Figure 7).

Figure 7. Illustration of the methods for assigning ages to unaged fish. A length at age curve (solid line) is fit to the age-length data, and the 95% Confidence Interval of the expected length-at-age is estimated through non-parametric bootstrap (shaded region). These curves are used to find the range of length that correspond to a given age *t* (arrows going from y-axis to upper confidence interval and then down to age).



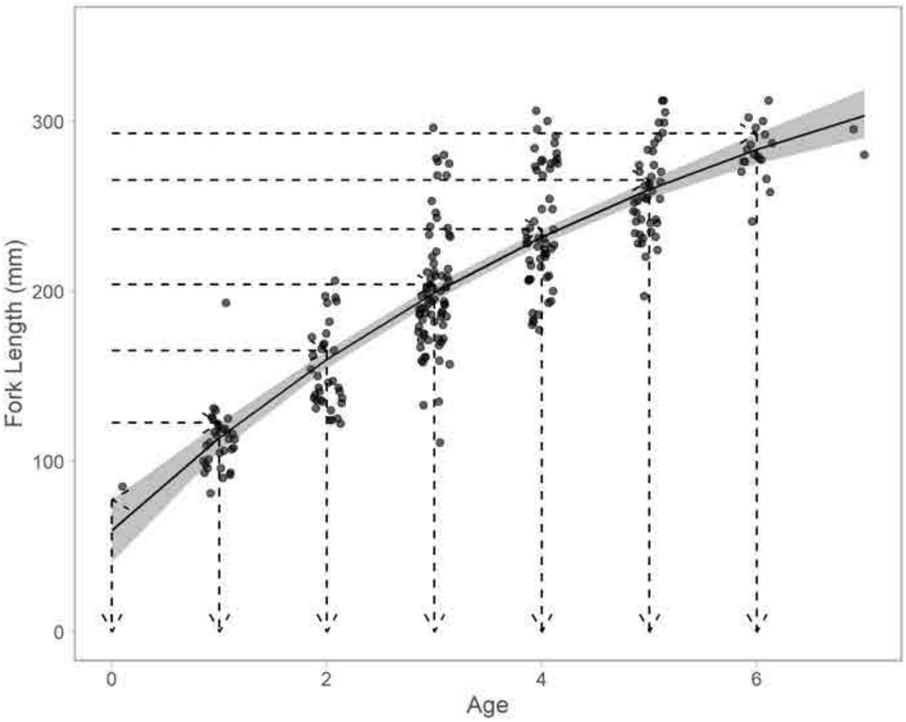
Rainbow Trout

A total of 264 scales, 37 fin rays, and 17 Rainbow Trout otoliths were read during Years 1 to 5 of the monitoring program (Table 3). This excludes fish that suffered total or partial damage due to e.g., being partially consumed by crayfish, and therefore an accurate fork length could not be measured. Most aged fish were between the ages of 1+ and 6+, with only 3 fish aged as 0+ and 3 as 7+. Therefore, we grouped fish aged 6 and older into a cumulative age class ≥6+. Given the differences in sample sizes among hard structures (Table 3), we based the length at age curve for Rainbow Trout on ages read from scales (Figure 8).

Table 3. **Sample size of aged Rainbow Trout structures, by age, during Years 1 to 5 of the monitoring program.**

Species	Structure	Age	n
Rainbow Trout	Scales	0+	3
		1+	32
		2+	34
		3+	76
		4+	55
		5+	43
		6+	18
		7+	3
	Fin Rays	0+	-
		1+	-
		2+	3
		3+	11
		4+	12
		5+	8
		6+	3
		7+	-
		0+	-
	Otoliths	1+	-
		2+	-
		3+	2
		4+	9
		5+	6
		6+	-
		7+	-

Figure 8. **Rainbow Trout length at age curve used for assigning age classes to fish of unknown age, based on their fork length.**



Cutthroat Trout

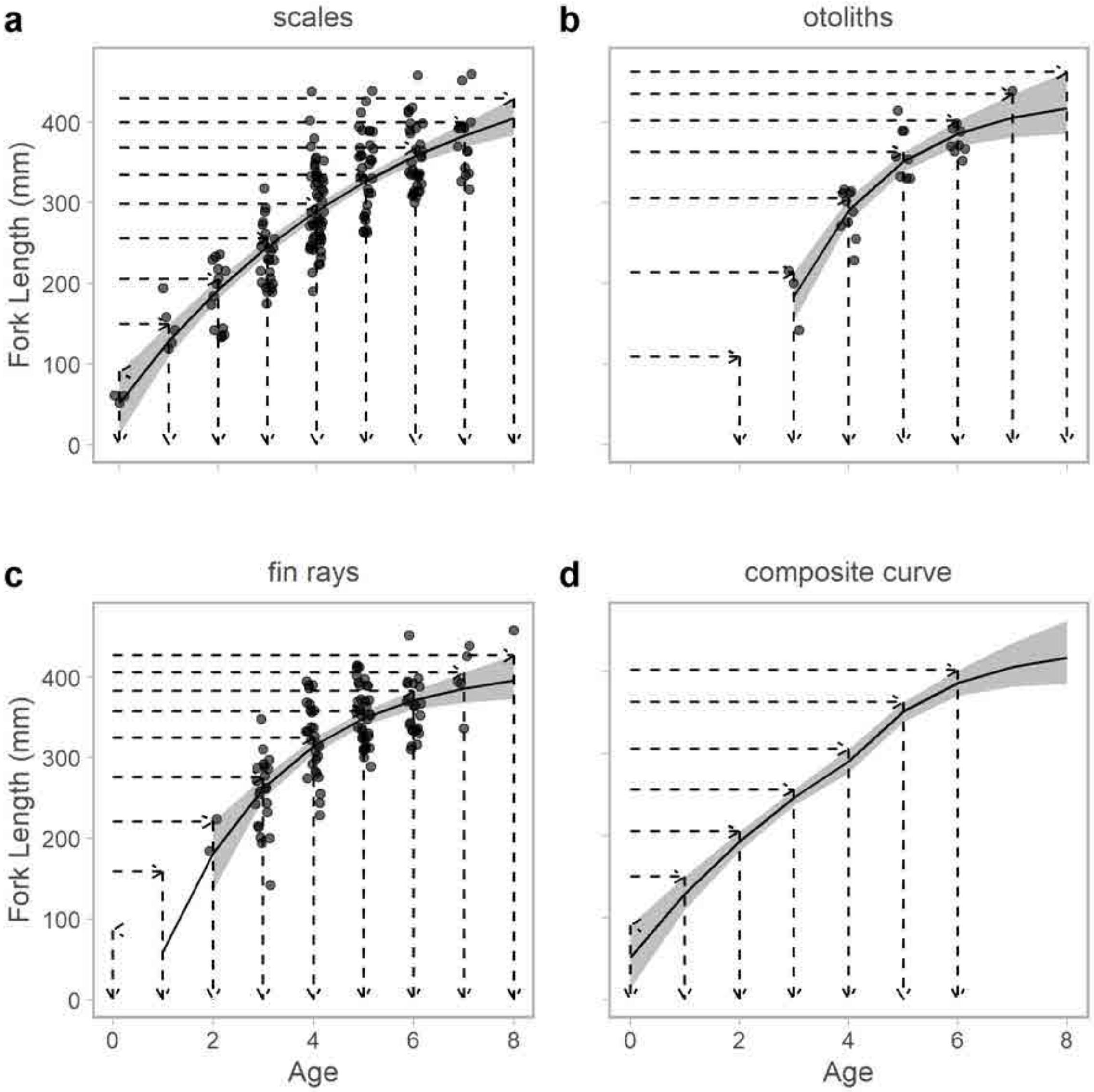
A total of 179 scales, 118 fin rays, and 30 Cutthroat Trout otoliths were read during Years 1 to 5 of the monitoring program (Table 3). This excludes fish that suffered total or partial damage due to e.g., being consumed by crayfish, and therefore an accurate fork length could not be measured. Most aged fish were between the ages of 1+ and 6+, with only 3 fish aged as 0+, 21 as 7+, and 1 as 8+. Therefore, we grouped fish aged 6 and older into a cumulative age class ≥6+.

The most accurate age readings are those based on otoliths. Thus, despite the relative smaller sample size we fit separate age at length curves by structure (Figure 9). All age readings carried out on otoliths were of relatively older fish (4+ and older). Hence, we created a composite curve, where the age breaks for young fish (3+ and younger) were obtained from scale data and age breaks for older fish (4+ and older) from otolith data (Figure 9d).

Table 4. **Sample size of aged Cutthroat Trout structures, by age, during Years 1 to 5 of the monitoring program.**

Species	Structure	Age	n
Cutthroat Trout	Scales	0+	3
		1+	5
		2+	14
		3+	25
		4+	51
		5+	33
		6+	32
		7+	16
		8+	-
	Fin Rays	0+	-
		1+	-
		2+	2
		3+	22
		4+	28
		5+	36
		6+	24
		7+	5
		8+	1
	Otoliths	0+	-
		1+	-
		2+	-
		3+	3
		4+	10
		5+	8
		6+	8
		7+	1
		8+	-

Figure 9. Cutthroat Trout length at age curves, a) curve based on ages from scales, b) curve based on ages from otoliths, c) curve based on ages from fin rays, d) composite curve based on ages read on otoliths and scales. The composite curve was used for assigning age classes to fish of unknown age, based on their fork length.



2.3. Snorkel Surveys of Spawners in Reservoir Tributaries

Snorkel surveys of spawners and redds were undertaken in the lower reaches of the tributaries of Buttle Lake, Upper Campbell Reservoir, and Lower Campbell Reservoir during the Cutthroat Trout and Rainbow Trout spawning periods. The tributaries were selected based on their reported spawning value for both trout species, and included seven survey reaches upstream of Buttle Lake and Upper

Campbell Reservoir that have been surveyed historically since the early 1990s and were included in all previous years of the monitoring program. Snorkel surveys were undertaken in the following six tributaries of Buttle Lake and Upper Campbell Reservoir: Elk River (upper and lower reaches): Ralph Creek, Thelwood Creek, Wolf River, Phillips Creek, and Henshaw Creek (Table 5). In addition, snorkel surveys were undertaken in the following three tributaries of Lower Campbell Reservoir: Miller Creek, Fry Creek, and Greenstone River. Spring snorkel surveys were completed in tributaries of the Lower Campbell Reservoir in March and April to assess Cutthroat Trout spawning activity, and snorkel surveys of Upper Campbell Reservoir tributaries were completed in the late spring/early summer (June) to assess Rainbow Trout spawning.

On each survey date, individual stream sections were surveyed once by two experienced technicians swimming in pairs. To allow for comparison between years, the 2018 surveys followed standardized survey methods within each reach, as conducted during the Year 1 to Year 4 (2014 to 2017) surveys, and historically by MFLNRO and BCCF (Pellett 2013). A number of variables were measured (Table 6) and photographs were taken of each site. Rainbow Trout was the target species for these historic surveys in Upper Campbell Reservoir tributaries and this focus was maintained for JHTMON-3 snorkel surveys to maximize comparability with historic records.

Similar to previous years, a fork length of 150 mm was designated as the boundary between juvenile and adult fish, based on the Provincial snorkel form template. The estimated fork lengths of juvenile fish ranged from 0 mm to 80 mm for fry, and from 80 mm to 150 mm for parr, during the 2018 surveys.

Surveys for the Cutthroat Trout spawning period were carried out in tributaries of the Lower Campbell Reservoir on March 9. An additional survey of the Greenstone River was carried out on April 16 due to the relatively cold conditions of this river compared to Miller and Fry creeks. Tributaries of Buttle Lake and Upper Campbell Reservoir were not sampled during the Cutthroat Trout spawning period, as described in Hatfield *et al.* (2016). Due to low Cutthroat Trout densities in the surveyed tributaries, redd counts were used to provide a reference for adult spawning effort.

Surveys for the Rainbow Trout spawning period were undertaken from June 4 to 7 in the tributaries of Buttle Lake and Upper Campbell Reservoir. Data recorded from the 2018 Rainbow Trout spawning surveys were compared to the Year 1 to Year 4 (2014 to 2017) dataset and available historical data for the Upper and Lower Campbell Reservoir. This historical record allows a quantitative comparison of abundance change over time, although it is noted that the data record is short, and sampling has not been undertaken during all years. Tributaries of Lower Campbell Reservoir were not sampled during the Rainbow Trout spawning period (Hatfield *et al.* 2016).

Discharge measured in the Elk River at Water Survey of Canada gauge 08HD018 has historically been used as a reference to assess suitability for the Rainbow Trout snorkel surveys; based on the criterion that suitable survey conditions correspond to a discharge of < 20 m^3/s (Pellett 2013). This was also used for spring surveys, to determine suitable flows for access and visibility. Mean daily discharge at the gauge during the spring and summer survey dates were below this < 20 m^3/s guidance value; suggesting that conditions were good for conducting snorkelling surveys.

Table 5. Snorkel survey reach details for Year 5 surveys.

Watershed	Stream	Survey Distance (km)	Survey Start Location	Survey End Location
Upper Campbell	Upper Elk River	6.0	Drum Creek 200 m US confluence	HWY 28 take out/ put in
	Lower Elk River	5.4	HWY 28 take out/put in	Upper Campbell Lake
Buttle	Ralph River	0.9	50 m u/s Shepard Creek	Buttle Lake
	Thelwood Creek	2.5	Falls at powerhouse	Bridge at Buttle Lake
	Wolf River	0.3	Falls Pool	Buttle Lake
	Phillips Creek	0.3	300 m u/s lake	Buttle Lake
	Henshaw Creek	0.5	Cascades	Buttle Lake
Lower Campbell	Miller Creek	0.4	Cascades	Fry Lake
	Fry Creek	1.2	Barrier DS logging road	Lower Campbell Lake
	Greenstone River	2.4	~1.0km u/s of Bridge	Lower Campbell Lake

Table 6. Variables measured during the Year 5 snorkel surveys in the selected tributaries of Upper Campbell Reservoir, Buttle Lake, and Lower Campbell Reservoir.

Variable	Unit/Classification
Weather	Conditions recorded
Water temperature	°C
Effective Visibility	Measured or estimated in meters
Fish size class	fry/parr/adults; 150-250mm, 251-350mm, 351-450mm, and >450mm
Fish species	Cutthroat Trout (CT)/Rainbow Trout (RB)/Dolly Varden (DV)
Fish condition	Bright/moderately coloured/mid-spawn/post-spawn/undetermined
Redd observations	Location/size/number/species

2.4. Spawning Habitat Availability

Extensive spawning habitat field surveys were carried out in 2017 (Year 4, Bayly *et al.* 2018). No additional field surveys were carried out in 2018 (Year 5). For completeness, spawning habitat field surveys from 2017 and updated analyses are presented in this report.

2.4.1. Delineation of Drawdown Zone

Previous studies indicate that salmonids spawn in tributaries to reservoirs, both within and above the drawdown zones (Bayly *et al.* 2018). To evaluate spawning habitat use and spawning habitat availability within and upstream of the drawdown zones, endpoint boundaries were defined for the upper and lower extent of the drawdown zones. This involved extracting upper and lower operational water levels of each reservoir from high resolution LiDAR elevation data. These data were available from LiDAR surveys completed by Terra Remote at low reservoir levels observed in 2017 with average point spacing in the drawdown zones of approximately 0.5 m. This dataset was compared to surveyed benchmarks within each drawdown zone to gauge its accuracy and reliability. LiDAR data were also compared to bathymetry data collected in 2010 by CRA Canada Surveys Inc. We considered the full drawdown zone to include the entire area of the alluvial fan between the high waterline and the low waterline, although habitat availability metrics were calculated within the defined channels (described below).

The upper extent of the drawdown zones was defined as the annual maximum operating levels for each reservoir as specified in the WUP (BC Hydro 2012). This upper elevation limit was 220.5 m for the Upper Campbell Reservoir (including Buttle Lake) and 178.3 m for the Lower Campbell Reservoir (BC Hydro 2012). LiDAR data were used to locate these end points in locations that were void of vegetation cover. These upper limits were not exceeded during the spawning period in either 2017 or 2018.

The lower endpoints of drawdown zones were more challenging to define. Minimum annual operational levels were not captured by LiDAR data. We therefore defined the lower extent of the drawdown zones at the locations where the main thalweg became unconfined within the alluvial fan at the lake confluence. These locations roughly corresponded with the elevation of the preferred minimum operational water level in summer months (June 21 – September 10) (Upper Campbell Reservoir: 217.0 m; Lower Campbell Reservoir: 176.5 m). The selection of these locations as drawdown zone endpoints was supported by an absence of any redd observations, the absence of a confined channel, and the absence of suitable spawning habitat at or beyond these endpoints. These lower limits also closely correspond to the lowest water levels during the spawning period in 2017 and 2018.

2.4.2. Habitat Surveys

Habitat surveys were conducted to assess quantity and quality of spawning habitat within and above the reservoir drawdown zones. Target waterbodies included:

1. Lower Campbell Reservoir: Fry Creek, Greenstone Creek and Miller Creek;
2. Upper Campbell Reservoir: Elk River mainstem (from Upper Campbell Reservoir to the Drum Creek confluence) and the following tributaries: Tlools Creek, Filberg Creek, Cervus Creek, Isardi Creek and Drum Creek (Crest Creek), and
3. Buttle Lake: Phillips Creek, Ralph River, and Wolf Creek.

Spawning habitat was summarized for each area using several metrics selected as indicators of spawning habitat availability. These metrics included linear stream distance, wetted area, bankfull channel width, bankfull channel area, inundated portions of the drawdown zones during the spawning period and an additional qualitative metric of spawning habitat potential used only upstream of the defined drawdown zone. These metrics were summarized in GIS for each area.

A combination of Unmanned Aerial Vehicle (UAV) surveys using a DJI Phantom 3 Pro (drone), and ground-based field inventory surveys were used to assess and quantify spawning habitat availability in each tributary. UAV surveys were used to efficiently survey large areas, capture high resolution aerial imagery, and delineate habitat with georeferenced data. Ground-based field surveys were undertaken to quantify spawning habitat in locations that were inaccessible to UAVs (i.e., overhanging vegetation obstructing view) and to survey redd distribution and abundance. Field surveys were also used to validate (ground truth) the spatial analysis. Stream segments that were heavily obstructed from overhanging vegetation that could not be surveyed from UAVs generally occurred in the furthest upstream sections of each tributary (usually in locations with steep banks and narrow channels; see Section 2.4.5).

The field survey within each tributary extended from the lower limit of the drawdown zone upstream to the first documented fish migration barrier. This allowed us to quantify the total spawning habitat available to adfluvial spawners. In cases where there were no clearly identifiable barriers, the upstream extent of spawning habitat was defined as the location prior to an extended length (>500 m) of unsuitable spawning habitat (e.g., a slab/boulder substrate lacking spawning gravel/cobble pockets) (Table 7). An exception was made for the mainstem of Elk River, where the upstream survey extent was limited to the confluence of Drum Creek (12.2 km upstream from the Upper Campbell reservoir). This decision reflected the large size of the Elk River and its status as a major spawning tributary.

All UAV field surveys were completed in July and October 2017. These time periods were selected to maximize the area of exposed habitat in aerial imagery and do not reflect spawning dates. Water levels at WSG Gauge 08HD031 ('Upper Campbell Reservoir') ranged from 219.41 m to 219.46 m across July survey dates and from 216.98 m to 216.82 m throughout October survey dates (Table 8). Upstream sections above the drawdown zones were surveyed in July to correspond with a period of low stream flow. The drawdown zone sections were re-surveyed in October, when water levels within the reservoirs are low (Table 8).

Table 7. Upstream survey endpoints for each waterbody.

Waterbody	Creek Name	UTM Zone	UTM Easting	UTM Northing
Lower Campbell	Fry Creek	10U	314741	5550140
	Greenstone Creek	10U	313140	5543307
	Miller Creek	10U	324268	5538932
Upper Campbell	Cervus Creek	10U	299868	5526078
	Drum Creek	10U	293501	5524999
	Elk River	10U	294344	5524853
	Filberg Creek	10U	301902	5527471
	Idsardi Creek	10U	296506	5526537
	Tlools Creek	10U	301761	5529376
Buttle Lake	Phillips Creek	10U	315129	5505249
	Ralph River	10U	318228	5500339
	Wolf Creek	10U	310809	5516642

Table 8. UAV field survey details for each waterbody.

Reservoir	Creek	Date	Start Time	End Time	Area (ha)	Altitude (m AGL[1])
Lower Campbell Reservoir	Fry Creek	8-Jul-2017	9:06	9:45	1.3	15
		8-Jul-2017	9:54	12:31	44.6	90
		8-Jul-2017	11:09	11:45	12.5	45
		8-Jul-2017	13:10	13:19	13.8	90
		8-Jul-2017	13:10	17:14	5.6	15
		8-Jul-2017	13:43	14:16	1.2	15
		8-Jul-2017	18:09	18:42	0.8	12
		10-Jul-2017	12:14	12:46	1.1	15
		10-Jul-2017	13:54	14:09	0.7	15
		10-Jul-2017	14:44	15:17	0.5	15
		10-Jul-2017	15:20	16:39	20.9	90
		10-Jul-2017	15:49	16:03	1.3	20
	Greenstone Creek	9-Jul-2017	9:12	9:42	1.1	15
		9-Jul-2017	9:42	9:54	8.5	90
		9-Jul-2017	10:02	10:05	0.1	7
	Miller Creek	9-Jul-2017	12:48	14:21	2.5	15
		9-Jul-2017	14:22	14:38	13.4	90
Upper Campbell Reservoir	Cervus Creek	10-Jul-2017	18:30	19:20	1.2	12
		11-Jul-2017	12:03	12:20	0.2	6
		14-Jul-2017	9:05	9:30	5.2	50
	Drum Creek	11-Jul-2017	13:20	14:46	2.2	14
		17-Jul-2017	7:57	8:28	12.2	90
	Elk Drawdown	27-Oct-2017	9:50	14:29	29.2	25
		27-Oct-2017	14:30	15:11	45.5	90
		11-Jul-2017	8:00	10:38	12.6	25
		13-Jul-2017	7:58	9:51	22	39
	Elk River	11-Jul-2017	10:39	10:44	5.1	50
		13-Jul-2017	9:51	10:05	14.1	55
		13-Jul-2017	10:56	13:34	46.2	55
		13-Jul-2017	14:50	18:16	53.4	55
		14-Jul-2017	9:48	13:19	50.3	55
		14-Jul-2017	14:05	16:44	24.6	55
		17-Jul-2017	8:30	13:22	48.7	53
		17-Jul-2017	15:58	16:09	10.6	50
	Idsardi Creek	11-Jul-2017	15:55	17:09	1.9	18
	Tlools Creek	17-Jul-2017	14:33	15:20	2.3	18
		17-Jul-2017	15:21	15:26	9.3	90
Buttle Lake	Philips Creek	12-Jul-2017	11:52	12:48	2.5	18
		12-Jul-2017	12:22	12:58	14.2	90
		28-Oct-2017	14:34	15:17	6.8	25
	Ralph Creek	27-Oct-2017	16:04	17:14	11.3	25
		27-Oct-2017	16:39	17:13	21.7	90
		12-Jul-2017	14:11	15:51	5.3	22
		12-Jul-2017	14:23	15:02	17.6	90
	Wolf Creek	12-Jul-2017	9:24	10:34	5.1	19
		12-Jul-2017	10:38	10:43	11	90
		12-Jul-2017	16:57	17:03	11.3	90
		28-Oct-2017	9:52	12:36	10.8	25
		28-Oct-2017	10:50	11:18	42	90

[1] UAV flight altitude Above Ground Level (AGL).

2.4.3. Spawning Habitat Delineation from UAV Imagery

High resolution aerial imagery was acquired with a DJI Phantom 3 Pro UAV. Overlapping images collected with the UAV were assembled into georeferenced orthomosaics using photogrammetric structure from motion techniques (Peterson *et al.* 2015). Resolution of the final orthomosaics is subject to the local on flight altitudes and corresponding camera resolution. For this study, flight altitudes ranged from 12 m – 28 m above ground level (AGL) for flights in each of the smaller tributaries, and up to 50 m (AGL) for flights over the Elk River (Table 8). Pix4D Mapper Pro V3.3 (https://www.pix4d.com/product/pix4dmapper-pro) was used for all image processing and analysis. The final pixel resolution of the georeferenced orthomosaic layers ranged from 0.6 – 2.5 cm/pixel across the surveyed waterbodies.

Several unique spatial habitat metrics were calculated manually from the UAV orthomosaic. These metrics were used as indicators of spawning habitat availability (e.g., Figure 10). By evaluating multiple metrics, we were able to take advantage of the different strengths and limitations of each indicator and effectively reduce the overall subjectivity inherent in quantifying spawning habitat availability. Comparisons for each waterbody were made within the drawdown zone and upstream of the drawdown zone. All measurements and delineations were completed in QGIS (v. 2.18.14) (QGIS Development Team 2018) and ArcMap (v. 10.5) (ESRI 2016).

Linear Distance: Linear distance was calculated as the length of the surveyed mainstem of each stream. Drawdown zones and upstream areas were represented as lines extending the length of each area. Stream centrelines were initially extracted from the BC Freshwater Atlas. Streamlines were then evaluated and adjusted manually using underlying UAV imagery and tracing the thalweg centreline of each stream. Major side channels and secondary channels that were over 50 m wide were represented as separate lines. Streamlines were then clipped with drawdown zone boundaries for each tributary and summarized as the total length (m) within and above the drawdown zones.

Wetted Area: Wetted area was delineated manually from the UAV orthomosaics by drawing polygons over the water surface in GIS. The resolution of all imagery was sufficient to clearly identify the waterline along the lateral edge of each stream. All wetted area delineations were made using imagery collected at low water for each area (Table 8). UAV aerial surveys targeted time periods where the water levels were low (both upstream and within the drawdown zone). Consequently, these measurements do not reflect seasonally wetted areas, but instead represent approximate wetted area at low water periods. Bankfull channel width measurements (described below) were included as an indicator of wetted area at high water.

Wetted area measurements in the drawdown zones were manually adjusted to follow the base of the thalweg sidewalls for each tributary, rather than covering the entire alluvial fan at the lake confluence. This resulted in a delineation of wetted channels within the drawdown zones if the reservoir was at its lowest level. These wetted area adjustments in the drawdown zones were necessary in order to make wetted area summaries comparable across tributary surveyed on different dates at different water levels. These adjustments also excluded portions of the alluvial fan that were void of any suitable spawning habitat (substrate composition: fines and/or vegetation).

Bankfull Channel Width: Bankfull channel width measurements were taken along the length of each stream at fixed distance intervals. Initial attempts were made to delineate the bankfull channel width with polygons; however, dense vegetation along streambanks only allowed for accurate measurements of bankfull channel width intermittently from aerial imagery. Bankfull channel width measurements were summarized by calculating the median values for each waterbody within the drawdown zone and upstream of the drawdown zone separately. Distance intervals were set at 50 m, but adjusted to 200 m for the Elk River.

Bankfull channel width measurements in the drawdown zones were highly approximate. These measurements were manually adjusted and set at the crest of the upper thalweg sidewalls for each channel split. These bankfull channel width adjustments in the drawdown zones were necessary due to the large unconfined extent of the alluvial fans at the tributary lake confluence zones, and they also made measurements comparable across tributaries and excluded portions of the alluvial fan that were void of any suitable spawning habitat (substrate composition: fines and/or vegetation).

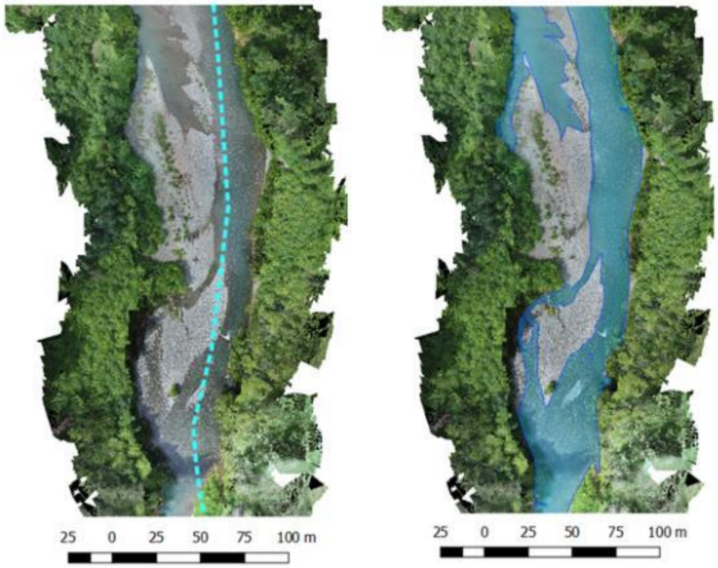
Bankfull Area: Bankfull area measurements were calculated as the median bankfull channel width (m) for each section multiplied by the linear distance (m). This metric was included to better represent the overall area at high water potentially available as spawning habitat. Bankfull channel area measurements were also useful for comparisons with wetted area measurements to evaluate potential discrepancies.

Spawning Potential: Spawning potential was evaluated qualitatively by identifying individual stream reach segments (based on meso-habitat characteristics) and then classifying each of these stream reach segments as having either 'Low', 'Medium', or 'High' potential as spawning habitat. This metric was included to capture additional habitat attributes that are readily apparent in imagery but not easily quantifiable. Stream reaches dominated by fines, large boulders or bedrock substrates were classified as having 'Low' spawning potential. Stream reaches with a large portion of spawning gravel substrates ranging in diameter from 10 mm to 75 mm were classified as having 'High' spawning potential. Stream reaches were classified as 'Medium' if spawning gravel was limited. Delineated stream reaches were summarized for each tributary linearly to determine the total length classified as 'Low', 'Medium', or 'High'. Although useful, this metric is subjective since it is dependent on the opinion of the fisheries biologist completing the assessment. A single experienced fisheries biologist was assigned the task of delineating reaches and assessing spawning potential for all tributaries, so that relative comparisons would not be affected by observer bias. To assess overall generalizability and repeatability, a second fisheries biologist then repeated reach delineations and spawning potential classifications (high, medium, or low) for an upper and lower sub-section of the Elk River, Fry Creek, and Ralph River. Repeatability was assessed by randomly sampling 100 m long sections (n=38) of stream and comparing the relative portion in each spawning potential category. Redd survey data (represented as points) were also overlaid onto the aerial imagery to help inform spawning habitat designations.

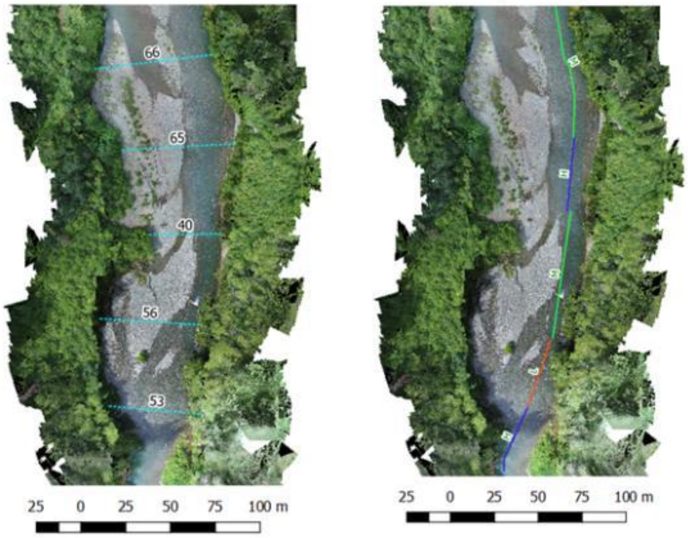
We expect the spawning potential metric to have limited utility in the drawdown zone reaches. The reservoir water level during the habitat survey period did not match the reservoir water level during the spawning period. We therefore include this metric for comparative purposes, but do not base our conclusions on it.

Figure 10. **Sample of spawning habitat availability indicator metrics calculated from UAV orthomosaic imagery.**

A) LINEAR DISTANCE (m) B) WETTED AREA (m^2)



C) BANKFULL CHANNEL WIDTH (m) D) QUALITATIVE SPAWNING POTENTIAL (H/M/L)



2.4.4. Ground-based Spawning Gravel Surveys

A spawning gravel inventory/assessment was undertaken in the upstream most sections where UAV access was restricted due to stream vegetation or other visual obstructions. Total spawning habitat was estimated and classified according to FHAP methods (Johnston and Slaney 1996) with minor modifications described below. Individual patches of gravel (10 mm to 75 mm diameter) suitable for resident trout were measured and georeferenced. Spawning gravel patches suitable for resident trout were recorded; none of the study streams are accessible to anadromous fish. Only gravel patches greater than 1.0 m^2 were recorded. Patches were also classified as functional or non-functional based on location from wetted edge and extent of compaction and embeddedness.

For each spawning gravel patch, measurements included average length and width of the patch, average water depth, and depth range. Multiple small gravel patches located in close proximity, or those separated by only a few large cobbles or boulders, were recorded as a single composite patch. Johnston and Slaney (1996) describe functional spawning habitat as having water depths greater than 15 cm and water velocities between 0.3 m/s to 1.0 m/s during the spawning season. During time of assessment, flows were relatively low; therefore, to avoid underestimating functional spawning gravel area, only areas assumed (by field crews) to be dry during spawning and incubation periods were classified as non-functional based on their proximity to the water's edge.

Compaction was subjectively classified as low (L), moderate (M), or high (H) using a 'Boot Test', which is a relative measure of gravel compaction. The boot test involves kicking the substrate and evaluating the degree of penetration. Compaction was classified as "low" if the boot easily and deeply penetrates the gravel substrate (>4 cm), "moderate" if a portion of the boot penetrates the gravel (approximately 2 cm to 4 cm), and "high" if the boot only slightly enters or does not enter the substrate completely (<2 cm).

The embeddedness of the gravel was measured as the amount of fines (<2 mm) that were present in the substrate at each spawning gravel patch. Embeddedness was subjectively classified, based on visual inspection as: trace (T, <5%), low (L, 5% to 25%), medium (M, 25% to 50%), high (H, 50% to 75%), or very high (VH, >75%).

2.4.5. Quantifying Metrics Upstream of UAV Survey Extent

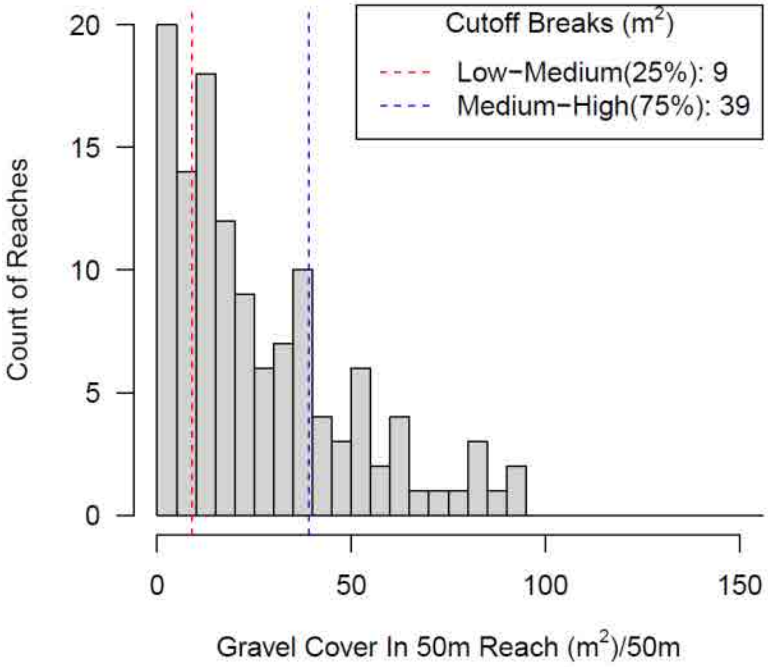
For some tributaries, it was not possible to collect UAV imagery in furthest upstream sections due to dense overhanging vegetation cover. This lack of complete coverage was problematic because it meant that the full upstream extent of available spawning habitat could not be quantified from the UAV imagery alone. To overcome this issue, we relied on information collected from the ground-based spawning gravel surveys to quantify spawning habitat availability in areas that could not be effectively surveyed by the UAV. The same five spawning habitat availability metrics (described above, Figure 10) were extended beyond the endpoint of the UAV survey extent using field survey data. These values were then combined with estimates of each spawning indicator from UAV imagery for a final comparison of available spawning habitat within and upstream of the drawdown zones.

In areas upstream beyond the extent of UAV imagery coverage, linear stream distances were extracted from the BC Freshwater Atlas streamlines. Estimates of wetted area and bankfull channel width were made from representative location downstream from the upper limit of UAV imagery. To estimate the total wetted area, we multiplied linear stream distances by the wetted width.

Spawning potential in sections upstream of the extent of UAV imagery was estimated by analyzing the field gravel survey data and making estimates of spawning potential based on the quantity of spawning gravel. To do this, we summed gravel patch areas to calculate the total spawning gravel area for every 50 m stream segment upstream of the boundary of the UAV imagery. We then evaluated the frequency distribution of these data across all waterbodies to identify thresholds for 'Low', 'Medium', and 'High' spawning potential. We chose the 25th and 75th percentiles from this distribution of gravel area as thresholds to define spawning potential breakpoints for each 50 m stream segment. The 25th and 75th percentiles were chosen to approximately match the final distribution of 'High', 'Medium', and 'Low' classes in upstream areas with coverage from the UAV imagery (See Section 3.4, 24.5% 'Low', 43.3% 'Medium', and 31% 'High'). The resulting categories to define spawning potential from gravel coverage were: Low (0 – 9 $m^2/50$ m); Medium (9 – 39 $m^2/50$ m); and High (>39 $m^2/50$ m) (Figure 11). Although these breakpoints may be an oversimplification, we expect this methodology to underestimate suitable spawning habitat in these upstream areas (further scrutinizing $H_0$3).

Final analysis of spawning habitat metrics was completed with data combined from areas with UAV aerial imagery and areas without UAV aerial imagery. Separating final summary statistics based on these two different methodologies allowed us to determine how sensitive our overall results were to including estimates from the upstream sections with no UAV coverage.

Figure 11. **Distribution of spawning habitat gravel (m²) for every 50m of stream identified from ground-based field surveys upstream of UAV survey extent. Vertical dashed lines correspond to the Low-Medium and Medium-High breakpoints chosen to classify these reaches as Low, Medium or High spawning potential.**



2.4.6. Habitat Availability in the Drawdown Zones During the Spawning Period

Reservoir levels observed during the 2017 and 2018 spawning period were used as example years to evaluate how reservoir backwatering can affect spawning habitat availability and spawning habitat use. Higher reservoir levels during the spawning period are expected to reduce availability of optimal spawning habitat for salmonids by backwatering stream sections in the drawdown zones. We defined the total available spawning habitat in the drawdown zones as the total channel area delineated from the 'wetted area' metric (above). This layer was then clipped with the underlying LiDAR elevation data and the corresponding reservoir elevation during the spawning period. The end result of this process was an estimate of the total spawning habitat remaining in the drawdown zone for a given reservoir elevation.

Spawning habitat periodicity was obtained from the BC Hydro Water Use Plan (BC Hydro 2012). This period extended from February 1 to March 24 for the Lower Campbell reservoir and from May 25 to July 31 for the Upper Campbell Reservoir. Median daily reservoir elevations were summarized for these periods from BC Hydro and Water Survey Canada Gauge data.

2.5. Spawning Habitat Use

2.5.1. Redd Surveys Within and Upstream of Drawdown Zones

Redd surveys were completed in 2017 and 2018 in each study stream to evaluate spawning habitat use within and upstream of the drawdown zones. The timing of these surveys targeted periods shortly after peak spawning for resident trout. Peak spawning periods were determined from snorkel surveys completed throughout March, April, and June. In the Lower Campbell Reservoir, redd surveys targeted the post spawning period for Cutthroat Trout. In the Upper Campbell Reservoir and Buttle Lake, redd surveys targeted the post spawning period for Rainbow Trout.

Redds were enumerated visually and mapped for each tributary by a crew of two experienced field technicians. Field technicians walked and snorkeled the length of each tributary accessible to adfluvial spawners. The same field technicians were used for all within-stream comparisons to minimize observer error. A subset of redds in the drawdown zone (at least one redd in each target stream) was inspected to confirm that visually identified redds were active, and to determine the stage of egg development as un-eyed, eyed, or alevin. At each redd (or group of redds) the following attributes were recorded: number of redds per waypoint, location in stream channel, redd(s) depth or depth range, estimated velocity (Low 0-0.10 m/s, Medium 0.1 – 0.5 m/s, High >0.5 m/s), habitat unit, dominant and sub-dominant substrate, cover, and whether the redd appeared to be new or old (i.e., created prior to the spawning period that was being assessed). Redd surveys within and above the drawdown zone were often conducted on different days. Effort depended on redd densities, stream accessibility, and total survey length.

Redd locations were summarized according to their elevation (for redds located within the drawdown zones) or distance upstream of the drawdown zone (for redds located above the drawdown zones). Each redd (or group of redds) was georeferenced using either a Total Station Theodolite (TST) (in the drawdown zone) or a high accuracy GPS (above the drawdown zone). It was necessary to use a TST in the drawdown zones to achieve a high vertical accuracy (< 0.01 m) and calculate inundation periods for redds from reservoirs levels (described below). However, for all other locations upstream from the drawdown zones approximate location was sufficient for this analysis. A Juniper Systems Geode high accuracy GPS receiver was used to map redd locations. Horizontal accuracies of this receiver are expected to be within 30 cm under ideal conditions; however, these conditions were rarely met due to overstory vegetation, canyon walls and other obstructions.

Critical reservoir water levels at which redds become inundated or exposed were determined by surveying the elevation of redds in the drawdown zone and comparing these values to known reservoir levels. The vertical distribution of redds within the drawdown zones was summarized for each drawdown zone. Since a small change in reservoir levels can result in a large change in the inundated area, it was necessary to use survey methods with sub-centimeter accuracy and precision for this survey to be effective. Ecofish hired Chicalo-Burridge Land Surveying and Geomatics Ltd. to install benchmarks in the drawdown zone area of each tributary drawdown zone. A Leica FlexLine TS06 plus model total station was used to collect a georeferenced waypoint at each redd(s) in the drawdown zone area. Vertical and horizontal accuracy using this equipment was +/- 1.5 mm.

Additional sources of error in redd elevation measurements likely originated from field error associated with difficulties in holding the survey rod steady in deep water (field technicians holding the survey rod often had to float/swim to hold the survey rod in place). Another potential source of error is a difference between reservoir elevation measured by BC Hydro at the dam reservoir levels and the water surface elevation at each stream mouth caused by spatial variations in reservoir elevation potentially due to internal waves and wind. These potential sources of error were not accounted for in our analysis.

2.6. Incubation Experiments

To assess the utility of the ESH performance measure, we conducted a study of salmonid incubation conditions in the drawdown zone of two tributaries to Upper Campbell reservoir. The aim of this work was to assess the link between egg incubation success and reservoir elevation, by testing impact hypothesis 4 from the JHTMON-3 terms of reference:

The objective of the incubation tests was to compare embryo survival and hatch success in inundated and non-inundated sites. It is hypothesized that inundation is lethal to eggs because of oxygen depletion at depth. Substrate composition, and groundwater (seepage) and water quality measurements were collected at each incubation test site to assess incubation habitat conditions. Both tests were conducted in spring 2018.

2.6.1. Sample sites

Incubation tests were carried out in Ralph River and Elk River. In each tributary, three sample sites were established across a gradient of inundation to test three treatment conditions:

- At an elevation above reservoir water level at time of outplanting;
- At an elevation of approximately 1 m depth below reservoir water level at time of outplanting; and
- At an elevation of approximately 3 m depth below reservoir water level at time of outplanting.

Incubation tests were established at each of the test sites, alongside discrete seepage measurements and supporting hydrology and water quality data. At each treatment location, a fisheries biologist/technician chose the most suitable spawning habitat available.

2.6.2. Incubation Tests

2.6.2.1. Study Design and Phases

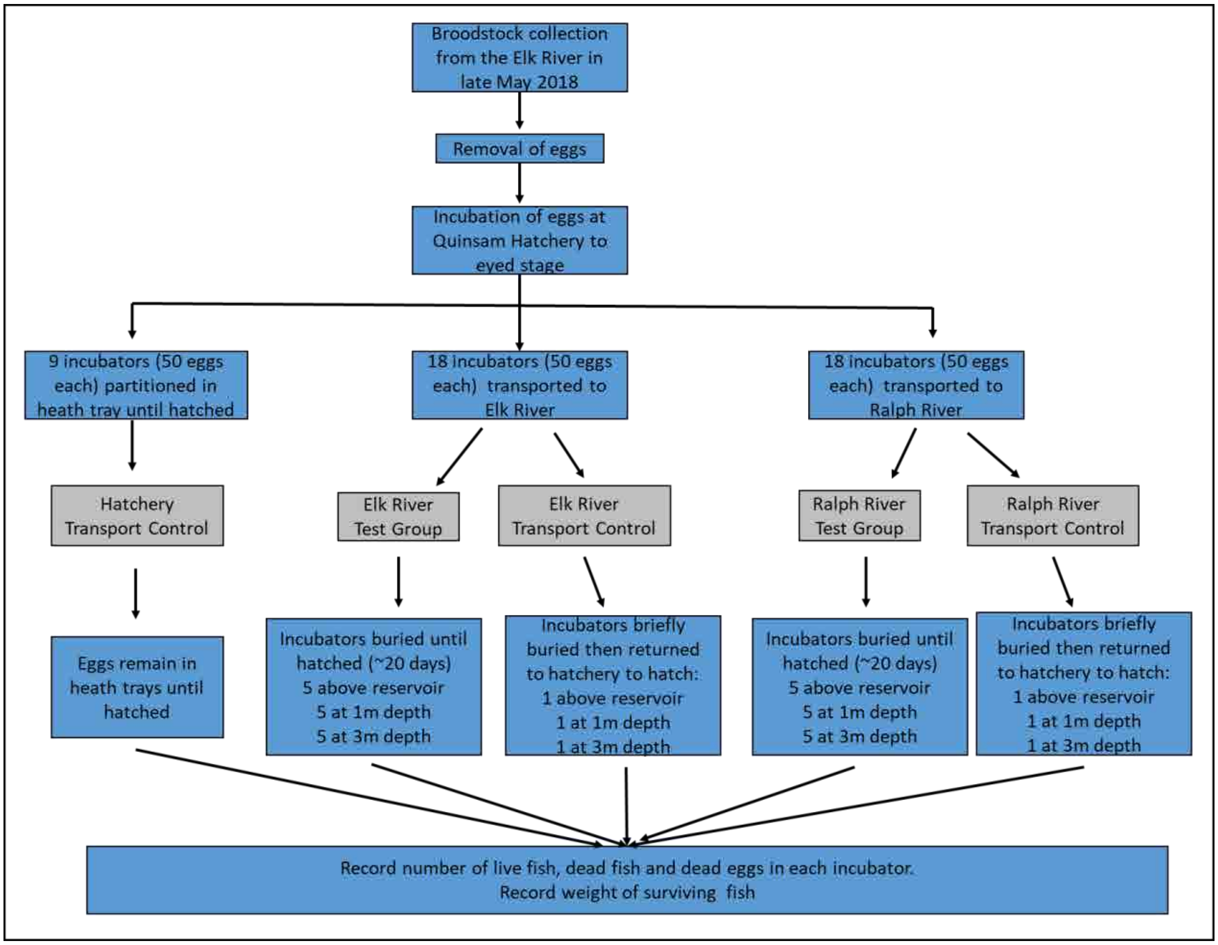
Incubation tests were conducted in a single Rainbow Trout incubation season in June and July 2018. The incubation tests were carried out with Rainbow Trout eggs, and it was assumed that results can be extrapolated to success of Cutthroat Trout and Dolly Varden eggs. We chose to conduct the tests using Rainbow Trout due to logistical reasons; specifically, broodstock could be collected efficiently due to the high abundance of this species and well-established locations of spawning sites.

The effect of inundation on the hatchability of Rainbow Trout eggs was investigated by comparing survival across sample sites at each of the two tributaries, as well as two controls that allowed identification of potential effects due to methodology. Each sample site represented a different treatment group based on incubation field conditions.

The treatment groups (eggs at the eyed stage placed at the study sites within and above the drawdown zone of the reservoir water level on the selected study tributaries for incubation) were matched with two controls groups, a hatchery control and a transport control. The hatchery control group were incubated at the Quinsam Hatchery for the entire study period and were not subjected to any experimental treatments or moved. The transport control group was used to identify potential effects of egg transport and burial; eggs from this group were incubated in the hatchery but were transported to the study area, placed in the river (buried) alongside the treatment group, and immediately returned to the hatchery for the remainder of the incubation period.

The test had two phases: 1) collection of broodstock, removal of the eggs, and incubation of eggs at the Quinsam Hatchery to the eyed stage; and 2) egg incubation test, which involved incubation at the study sites for the treatment groups and at the hatchery for the two control groups. A flow chart of the incubation test study design and phases is depicted in Figure 12.

Figure 12. **Summary of incubation test methods for the hatchery control, test groups, and transport controls.**



2.6.2.2. Field Methods and Data Collection

Collection of Broodstock and Incubation of Eggs to the Eyed Stage

Broodstock were collected with seine nets in Cervus Creek (Elk River) on May 30, 2018. A total of 25 ripe females and 24 ripe males were captured. Fish were transported to holding tanks and held until ripe at which point eggs were removed and fertilized by Quinsam hatchery staff. Eggs were incubated to the eyed stage at the Quinsam hatchery. Eggs were incubated on an isolated water supply from Cold Creek and water temperatures ranged between 9 and 10°C.

Egg Incubation Test

Field tests of incubation were conducted using eyed eggs to ensure that all replicates began with 100% viability. Embryos at earlier developmental stages are much more sensitive to handling.

Hatchery Control Group

The hatchery controls were incubated entirely under hatchery conditions, which are the same conditions as those used to incubated eggs to the eyed stage. Nine incubation controls were established at the hatchery. Each of the nine controls consisted of 50 eggs that were incubated in partitioned heath trays at the hatchery until the incubation test was completed. At that time live and dead eggs and alevins were enumerated.

Transport Control Group

The transport controls were transported to the field, buried, then recovered immediately and returned to the hatchery on the same day. They remained in the Quinsam hatchery throughout the incubation period and incubation methods were identical to those of the hatchery control group. There were six transport controls, one for each of the three treatment groups within each of the two tributaries. Each transport control was buried at the same location as a treatment group (e.g., above full pool, 1 m inundation, 3 m inundation). Each control consisted of one incubator containing 50 eggs. The transport methods and incubators used to transport the eggs were the same as those used for the treatment group.

Treatment Group

There were five treatment replicates per sample site at each of the two tributaries (15 in total per tributary). Eggs were transported to the field in the eyed stage and incubated using incubator devices. Each replicate consisted of one incubator device containing 50 eggs. Incubators were installed on June 19 (Elk River) and June 20 (Ralph River), and retrieved on July 6 (Elk River) and July 9 (Ralph River).

Incubator Devices

Eggs were incubated in incubator devices (cassettes), 10 cm long and 6.25 cm in diameter, and enclosed by 2 red caps. Each cassette had a total of 50 eyed eggs and was filled with glass marble substrate (1.6 cm in diameter). Plastic mesh size was 0.394 cm by 0.254 cm. Inside the plastic mesh tube a "fly screen" liner was installed with a mesh size of 1,600 microns.

Mesh size was determined through tests carried out at the Duncan Hatchery. It is desirable to use the largest screen size possible to minimize fouling on the incubator screens and maintain sufficient water flow through the incubator, while preventing alevins and fry from escaping.

Incubator Transportation and Installation

Incubator cassettes were transported in insulated coolers, and air temperatures were maintained between 8 and 12 °C, to match the temperature of the host river.

Incubators were installed in the tributaries, and covered with a minimum of 15 cm and a maximum of 30 cm of substrate. Each incubation site was marked with a pre-fabricated site marker. All incubators at a sample site were attached to the marker with a buried 0.5 m long stainless steel 1/8" cable.

Representative photographs of the different stages of the incubation tests are presented in Appendix B

2.6.2.3. Hatch and Survival Rates

Following retrieval of the incubator cassettes, the number of live fish, dead fish and dead eggs were tallied, and bulk weight of live fish was recorded.

Hatch rate was defined as:

$$HatchRate = \frac{\#LiveFish + \#DeadFish}{\#LiveFish + \#DeadFish + \#DeadEggs}$$

Survival rate was defined as:

$$SurvivalRate = \frac{\#LiveFish}{\#LiveFish + \#DeadFish + \#DeadEggs}$$

Mean fish weight was defined as:

$$MeanWeightFish(g) = \frac{TotalFishWeight(g)}{\#LiveFish}$$

where *Total Fish Weight* is the combined weight of all fish in the incubator device.

We analysed mean weight of fish that survived the incubation experiments (i.e., we excluded fish that did not survive), as this metric reflects sublethal effects of rearing conditions.

2.6.3. Water Temperature

Water temperature was measured from spring to summer 2018 in the mainstem of each of the incubation test study streams, in five other lake tributaries, and in the adjacent drawdown zone areas of all seven streams. Duplicate water temperature sensors/loggers (Onset TidbiT v2, -20°C to +70°C range, ±0.2°C accuracy or Onset Hobo Water Temp Pro v2, -40°C to 70°C range, ±0.21°C accuracy) were installed with recording intervals of 15 minutes. Incubation periods were calculated for each stream based on the number of degree days, with the intent of using similarities amongst streams to support extrapolating incubation test results across the reservoir tributaries. Detailed methods are described in Appendix C.

Remote time-lapse cameras were installed at the outlet of each study stream to collect two daily photos of the drawdown zone. This data was used to interpret the backwatering effects over redds during the seepage and egg incubation studies. Photographs of the drawdown zone are presented in Appendix D.

2.6.4. Incubation Habitat and Seepage Conditions

Included here is a summary of key methods used to measure the habitat variables at each site including substrate composition, *in situ* water quality, and seepage (groundwater) flow hypothesized to influence salmonid incubation success. A detailed description of the methods used to assess habitat variables and seepage conditions is provided in Appendix E.

Four key variables were measured to assess incubation habitat conditions: substrate composition (Section 2.6.4.2), seepage (groundwater) conditions (which included temperature variations and groundwater levels - see below for details of instrument installation), and dissolved oxygen (DO) and other water quality parameters (Section 2.6.4.4). Seepage conditions were in turn used to estimate seepage rates using the temperature tracer method and Darcy's equation. In addition, Upper Campbell Reservoir levels and stream flow were plotted with seepage rates to examine trends in groundwater movement in areas of the drawdown zone (Section 2.6.4.5). The selected study sites occur across a gradient of reservoir inundation (Table 9, Map 4 and Map 5).

2.6.4.1. Temperature Array Installation

To obtain continuous measurements of stream bed[2] temperature, four Onset Tidbit V2 temperature data loggers were installed in a vertical array at approximate depths of 0 cm (on the stream bed), 10 cm, 30 cm, and 50 cm. The stream bed sensor was fitted with a radiation shield with drilled holes to allow water to flow through, which ensured the temperature logger itself did not heat up in the sun. Temperature was continuously recorded at 2-minute intervals.

Temperature arrays were originally installed in February 2018 to obtain data prior to the incubation period (June-July 2018). Some sites needed to be relocated due to dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Additionally, sensors at a given depth for a site may also have been damaged or were found to be malfunctioning. In such cases, the sensor depths utilized (i.e., with viable data) are noted.

Piezometer Installation

Piezometers were installed at each study site to measure groundwater water levels (and in turn calculate seepage direction/vertical hydraulic gradient), conduct hydraulic response tests (to calculate hydraulic conductivity and determine seepage rates), and collect *in situ* water quality measurements (DO, specific conductivity, pH, and water temperature). Piezometer installation methods are provided in Appendix E.

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[2] Note that the terms 'stream' and 'stream bed' have been used throughout for ease; however, the statements also apply to 'lake' and 'lake bed'.

Table 9. Study site locations and instrument (temperature array and piezometer) installation/measurement dates during incubator installation (June 2018) and removal (July 2018).

Watercourse	Site[1]	Description	Temperature Array Installation Date	In situ Sampling Dates
Elk River	ELK-WT04	above reservoir water level	15-Feb-2018	-
	ELK-WT04B		19-Jun-2018	19-Jun-2018 6-Jul-2018
	ELK-WT03B	1 m below reservoir water level	19-Jun-2018	19-Jun-2018 6-Jul-2018
	ELK-WT02B	3 m below reservoir water level	19-Jun-2018	-
Ralph River	RAL-WT04	above reservoir water level	15-Feb-2018	20-Jun-2018 9-Jul-2018
	RAL-WT03		14-Feb-2018	-
	RAL-WT03B	1 m below reservoir water level	15-Feb-2018	20-Jun-2018 9-Jul-2018
	RAL-WT02B	3 m below reservoir water level	20-Jun-2018	-

[1] Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018); however, some sites needed to be relocated slightly due to site dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Only sites for which viable data were obtained have been included.

2.6.4.2. Substrate Composition

Porosity, the portion of substrate volume occupied by pore spaces, was measured in the laboratory from sediment samples collected on June 19 and 20, 2018 (during piezometer installation) at each study site (Table 9, Map 4 and Map 5). Sediments were collected with a bucket and spade to a minimum depth of approximately 35 cm. A particle size analysis was conducted (Danielson and Sutherland 1986) and the average percent of fines (defined as particles < 2 mm) was reported. Porosity was used to compute the soil bulk density, the ratio of the mass of dry solids to the bulk volume of the substrate, assuming a sediment density of 2.65 g/cm^3 (Thien and Graveel 2002). Sediment thermal properties (i.e., thermal conductivity and sediment heat capacity) were calculated using dry bulk density values for use in the temperature tracer method (Lapham 1989). Dispersion was assumed uniform for the entire project using typical values found in the literature (Bianchin *et al.* 2010, Birkel *et al.* 2016).

2.6.4.3. Seepage

Approximate seepage rates/specific discharge (q) were calculated using the temperature tracer method (Voytek *et al.* 2014, Koch *et al.* 2015) and Darcy's equation (Darcy 1856). Included here is a summary of key methods used to calculate seepage that proved to be most relevant to the incubation test results.

The temperature tracer method is described within this report (see below) as installation of the temperature arrays could be completed at all three inundation sites where incubation test sites were located (Table 9, Map 4 and Map 5).

Piezometers were only installed at the above reservoir water level and 1 m depth below reservoir water level sites; the third inundation sites (3 m below reservoir water level) were too deep for piezometers. A detailed description of the methods used to calculate vertical hydraulic gradient, hydraulic conductivity and seepage rates based on Darcy's Equation are provided in Appendix E.

Temperature Tracer Method

Seepage rates were estimated at the study sites where temperature arrays were installed using temperature as a tracer method (Table 9, Map 4 and Map 5). The propagation of diurnal heat fluxes from a stream bed into a stream can be used to estimate groundwater recharge and discharge from the stream to the stream bed. Groundwater exchange rates were modelled using water temperature profiles and one-dimensional flow and heat-transport equations using 1DTempPro (Voytek *et al.* 2014, Koch *et al.* 2015). The 1DTempPro model has a function to estimate groundwater exchange rate using at least three thermistors, with one on the stream bed, and two at different depths in the stream bed. Four sensors were used where feasible (i.e., sensor function was maintained) to improve the accuracy of the estimates. The generalized premise of the model is that the phase lag and amplitude ratio between the sensors indicates the direction (amplitude ratio) and strength (amplitude ratio and phase lag) of groundwater exchange (Briggs *et al.* 2014).

Seepage rate was estimated at each site using subsets of the data collected from February 13, 2018 to July 9, 2018. 1DTempPro has an optimizer function that allows estimation of average seepage rate for a given period; additional details of the optimization used for this study are found in Appendix E. The only field data required are the temperature array time series and porosity. Periods were selected to estimate seepage rates given varying reservoir levels, stream flow rates, and seasons. The incubation period included three periods to account for substantial variations in stream flow and modest variations in reservoir level (Period 4, June 20 – June 23, 2018; Period 5, June 24 –June 28, 2018; and Period 6, June 29 – July 6, 2018). Seepage rates over the entire incubation period were also averaged. Details with respect to the pre-incubation period are included in Appendix E.

2.6.4.4. *In situ* Water Quality

DO, water temperature, pH and electrical conductivity were measured *in situ* at approximately 0 cm (substrate surface), 30 cm, and 50 cm substrate depths at the 1 m below reservoir water level and above reservoir level sites in Elk River (Table 9 and Map 4) and Ralph River (Table 9 and Map 5).

Included here is a summary of key methods used to measure *in situ* water quality parameters that proved to be most relevant to the incubation test results (i.e., DO and water temperature). Data collection methods for all *in situ* water quality parameters (including pH and conductivity) are provided in Appendix E.

Data were compared to the British Columbia Water Quality Guidelines (BC WQG; MOE 2018) for DO (Table 10). The instantaneous minimum BC WQG for the protection of buried embryo/alevin life stages for DO is 6 mg/L. Water temperature data were also compared to the provincial optimum water temperature ranges for Cutthroat Trout incubation (9.9-12.0 °C; Oliver and Fidler 2001, MOE 2018), Rainbow Trout incubation (10.0-12.0 °C; Oliver and Fidler 2001), and Dolly Varden (equivalent temperature requirements as Bull Trout, 2.0-6.0 °C; MOE 2001).

Table 10. BC Water Quality Guidelines for the Protection of Aquatic Life for dissolved oxygen (mg/L).

	BC Guidelines for the Protection of Aquatic Life[1]		
	Life Stages Other Than Buried	**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).

2.6.4.5. Surface Hydrology

Upper Campbell Reservoir levels and stream flow were plotted with seepage rate directions[3] (i.e., upwelling or downwelling) and precipitation data to examine trends in groundwater movement in areas of the drawdown zone. Upper Campbell Reservoir levels were obtained from BC Hydro. Daily precipitation data were obtained for the BC Hydro climate station Elk River above Campbell Lake[4]. Elk River water level and discharge data were obtained from the Water Survey Canada (WSC) hydrometric station 'Elk River above Campbell Lake' (08HD018), located approximately 6 km upstream of ELK-WT04 (Map 4). The data provided by WSC were provisional at the time of

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[3] Seepage rate directions were based on q values for sites above reservoir level and 1 m below reservoir level obtained using the Temperature Tracer Method.

[4] https://www.pacificclimate.org/data/bc-station-data

reporting. A hydrometric gauge was installed on Ralph River (RAL-LG01) on February 14, 2018, to collect continuous water level measurements (Map 5).

Additional surface hydrology measurements, such as water depths and velocity, are described in Appendix E.

2.7. Statistical Catch-at-age Models

To formally test the hypothesis that the availability of functional spawning habitat limits trout populations in the Upper Campbell Reservoir, we implemented a statistical catch-at-age model to describe the population dynamics of Cutthroat Trout. We assume that results for Rainbow Trout will be similar to those of Cutthroat Trout.

Statistical catch-at-age models integrate biological information with fishery statistics and provide formal methods for estimating the current abundance of extant cohorts (Hilborn and Walters 1992). This framework can flexibly incorporate multiple data sources and account for biological and environmental processes. It is therefore an appropriate framework to incorporate information on catch at age, gill netting effort, and effective spawning habitat for Cutthroat Trout in the Upper Campbell Reservoir.

In this framework (Haddon 2011), the fishing mortality for each age, *a*, in each year *y* ($F_{a,y}$) are treated as model parameters. The inclusion of fishing mortality terms is intended to capture the dynamics of the stock, not with the aim of assessing harvest. Fishing mortality for each age, *a*, in each year *y,* are defined as:

$$F_{a,y} = s_a \hat{F}_y \qquad \text{Eq. 1}$$

where $\hat{F}_y$ is the fitted fishing mortality in year *y* and s_a is the selectivity of age *a*. The fishing mortalities are combined with the natural mortality, *M*, to generate the age- and year-specific survivorships, which are used to complete the matrix of numbers-at-age:

$$N_{a+1,y+1} = N_{a,y} e^{-(M+s_a \hat{F}_y)} \qquad \text{Eq. 2}$$

A logistic equation was used to describe age-specific selectivities (s_a). These are defined as:

$$s_a = \frac{1}{1+e^{-Ln(19)\frac{(a-a_{50})}{(a_{95}-a_{50})}}} \qquad \text{Eq. 3}$$

where a is age, a_{50} is the age at which selectivity is 50%, and a_{95} is the age at which selectivity is 95%.

Once the predicted numbers-at-age are calculated, the predicted catch-at-age can b estimated as:

$$\hat{C}_{a,y} = \frac{F_{a,y}}{M+F_{a,y}} N_{a,y}\left(1-e^{-(M+F_{a,y})}\right) \qquad \text{Eq. 4}$$

The predicted catch-at-age numbers ($\hat{C}_{a,y}$) are estimated by contrasting them with the observed catch-at-age numbers ($C_{a,y}$), and assuming lognormal residual errors. This yields the following log-likelihood function:

$$LLH_C = -\frac{n_C}{2}\left[\ln(2\pi) + 2Ln(\hat{\sigma}) + 1\right] - \sum_a \sum_y Ln(C_{a,y}) \qquad \text{Eq. 5}$$

where:

$$\hat{\sigma}^2 = \sum_a \sum_y \frac{\left(Ln(C_{a,y}) - Ln(\hat{C}_{a,y})\right)^2}{n_C} \qquad \text{Eq. 6}$$

We incorporated the observed gill netting effort (E_y) by modelling the fishing mortality (F_y) as:

$$F_y = \hat{q} E_y \qquad \text{Eq. 7}$$

where $\hat{q}$ is the estimated catchability coefficient. We assume lognormal residual errors, yielding the following log-likelihood function:

$$LLH_E = -\frac{n_E}{2}\left[\ln(2\pi) + 2Ln(\hat{\sigma}) + 1\right] - \sum_y Ln(\hat{q} E_y) \qquad \text{Eq. 8}$$

where:

$$\hat{\sigma}^2 = \sum_y \frac{\left(Ln(\hat{F}_y) - Ln(\hat{q} E_y)\right)^2}{n_E} \qquad \text{Eq. 9}$$

Therefore, we fitted the model by maximising the total log-likelihood function (LL_{Tot}),

where:

$$LLH_{Tot} = LLH_C + LLH_E \qquad \text{Eq. 10}$$

Natural mortality (*M*) is a constant in this model (i.e., it is not estimated during the fitting process). Therefore, we estimated a natural mortality rate based on life history parameters, as suggested by Then *et al.* (2015), as follows:

$$M = 4.118 K^{0.73} L_{\infty}^{-0.33} \qquad \text{Eq. 11}$$

where *K* and L_{∞} are parameters from a von Bertalanffy age-length growth function (see

Age Cohort Analysis). We used all intact Cutthroat Trout caught as part of this monitoring program to fit the von Bertalanffy growth function. Using parameters found after fitting the von Bertalanffy growth function, we estimated $M = 0.105$, and therefore we implemented the model with a natural mortality of 10%.

Given that most of the Cutthroat Trout we aged were between the ages of 1+ and 6+, with only 3 fish aged as 0+, we modelled the stock as composed of fish age 1+ to age ≥6+. Therefore, in this context, recruitment means recruitment to age 1+.

Using this basis, and following Paul (2013), we developed three models to test the effects that effective spawning habitat has on the recruitment of Cutthroat Trout. The models were as follows:

1. Constant recruitment model: this model assumes that recruitment to age 1 is the same across years, i.e., this model estimates a constant average recruitment (R_{avg});
2. Time-dependent recruitment model: this model is more flexible as it allows variable cohort strength, i.e., it accommodates natural variability by estimating strong and weak year classes. Therefore, this model estimates a recruitment parameter for each year of the monitoring program (R_y, $y = 2014, \ldots, 2018$); and
3. ESH-dependent recruitment model: this model estimates yearly recruitments as a linear function of the effective spawning habitat available the previous year (to correct for the fact that we define recruitment as age 1+), i.e.,

$$R_y(ESH) = h_1 ESH_{y-1} + h_0; \; y = 2014, \ldots, 2018 \qquad \text{Eq. 12.}$$

The following parameters are estimated by all models: q, a_{50}, a_{95}, F_y ($y = 2014, \ldots, 2018$. This is a vector of 5 fishing mortalities), and $N_{a,2014}$ ($a = 2+, \ldots, \geq 6+$. This is a vector of abundances for ages 2+ to ≥6+ needed to initialise the model). The constant recruitment model estimates one extra parameter R_{avg}, the time-dependent recruitment model estimates five extra parameters five extra parameters R_y, and the ESH-dependent recruitment model estimates two extra parameters: h_0 and h_1.

To gauge the parsimony of the three models, and therefore the working hypotheses they represent, we calculated the Akaike Information Criterion (AIC_i) for each model. AIC ($AIC = 2p - 2LLH$) represents a balance between model fit (i.e., the model's log-likelihood (LLH)), and model complexity (i.e., the model's number of parameters (p)). The most parsimonious model is the model with smallest AIC_i, model parsimony is ranked according to the difference in Akaike Information Criterion ($\Delta AIC_i = AIC_i - \min(AIC_i)$) (Burnham and Anderson (2002). Models where Δ is in the 2–7 range have some empirical support, while Δ larger than 10 represent very low empirical support compared to the best model (Burnham *et al.* 2011).

3. RESULTS

3.1. Effective Spawning Habitat (ESH)

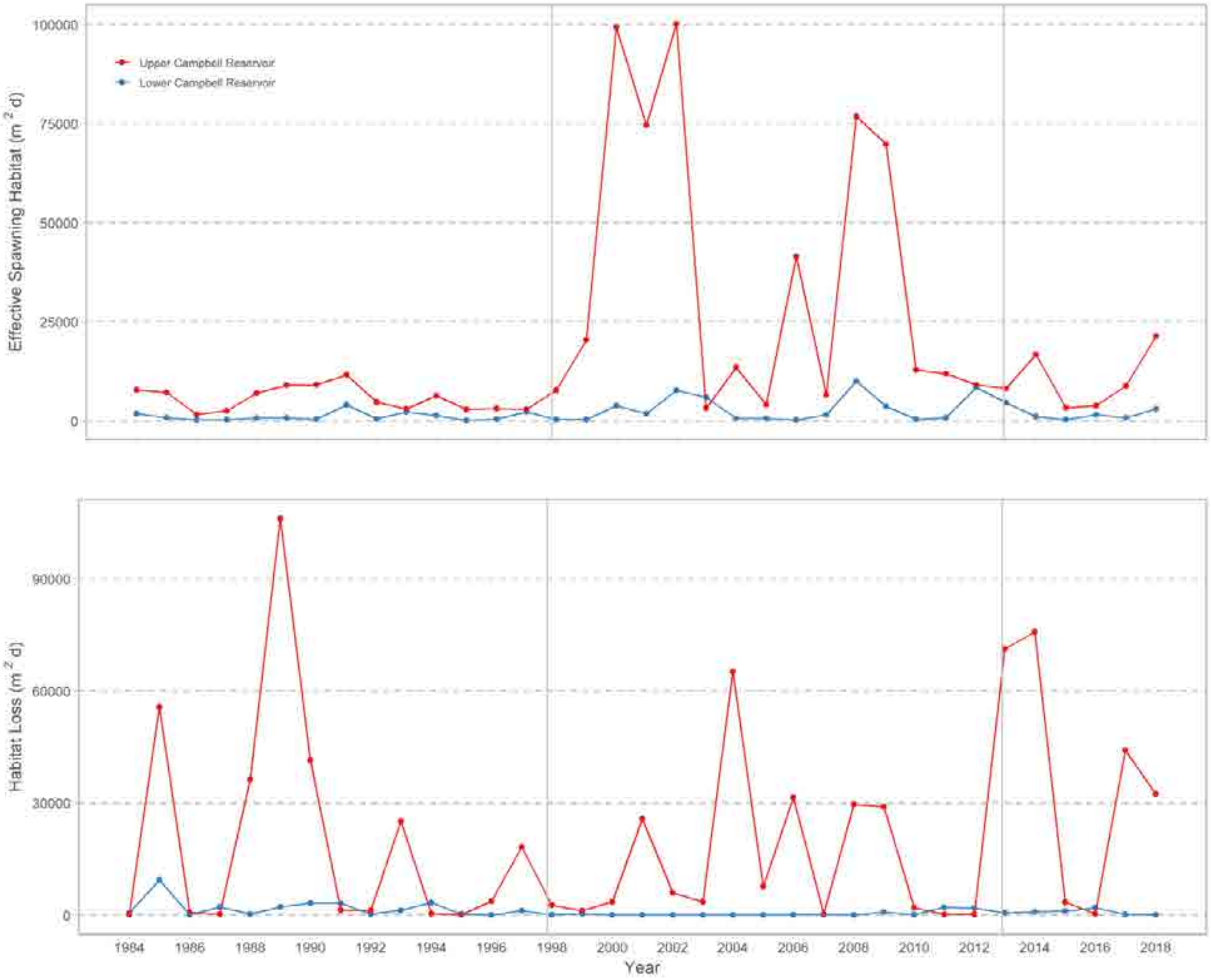
3.1.1. Cutthroat Trout

Effective spawning habitat values for both Lower and Upper Campbell reservoirs were variable among years, with much greater variability in the Upper Campbell Reservoir effective spawning habitat (range of 1,676 to 100,111 m^2d; mean = 19,807 m^2d) than the Lower Campbell Reservoir effective spawning habitat (range of 198 to 10,043 m^2d; mean = 2,132 m^2d) (Figure 13).

Following the implementation of the Interim Flow Management Strategy there were several years when ESH for Cutthroat Trout in the Upper Campbell Reservoir reached high levels (up to 100,000 m^2d). In 2018, the ESH for Cutthroat Trout in the Upper Campbell Reservoir was 21,447 m^2d, smaller than the peaks of the early 2000s and the mean ESH post-implementation of the IFMS of 29,244 m^2d, but four times larger than the mean ESH pre-implementation of the IMFS of 5,652 m^2d. During this monitoring program (2014-2018), effective spawning habitat in the Upper Campbell Reservoir was highest in 2018, followed by 2014, while values observed during 2015-2017 were an order of magnitude lower (Figure 13).

Effective spawning habitat loss was calculated as the difference between effective spawning habitat and initial spawning habitat during the spawning and incubation period. Oscillations in the water level of the Upper Campbell Reservoir are associated with effective spawning habitat losses ranging from 44 to 106,046 m^2d (mean = 20,737 m^2d). Water levels in the Lower Campbell Reservoir are less variable, resulting in relatively minimal loss of effective spawning habitat (range of 0 to 9,398 m^2d; mean = 1,057 m^2d; Figure 13). Effective spawning habitat loss habitat in the Upper Campbell Reservoir was variable and did not seem to have been affected by the implementation of the Interim Flow Management Strategy. During this monitoring program, the effective spawning habitat loss was minimal during 2015 (3,371 m^2d) and 2016 (m^2d), and higher in 2014 (75,823 m^2d), 2017 (44,131 m^2d) and 2018 (32,389 m^2d).

Figure 13. **Results of effective spawning habitat and loss of effective spawning habitat models for Cutthroat Trout from 1984 to 2018. Vertical lines denote dates of implementation of the Interim Flow Management Strategy (October 1997), and the Water Use Plan (November 2012).**

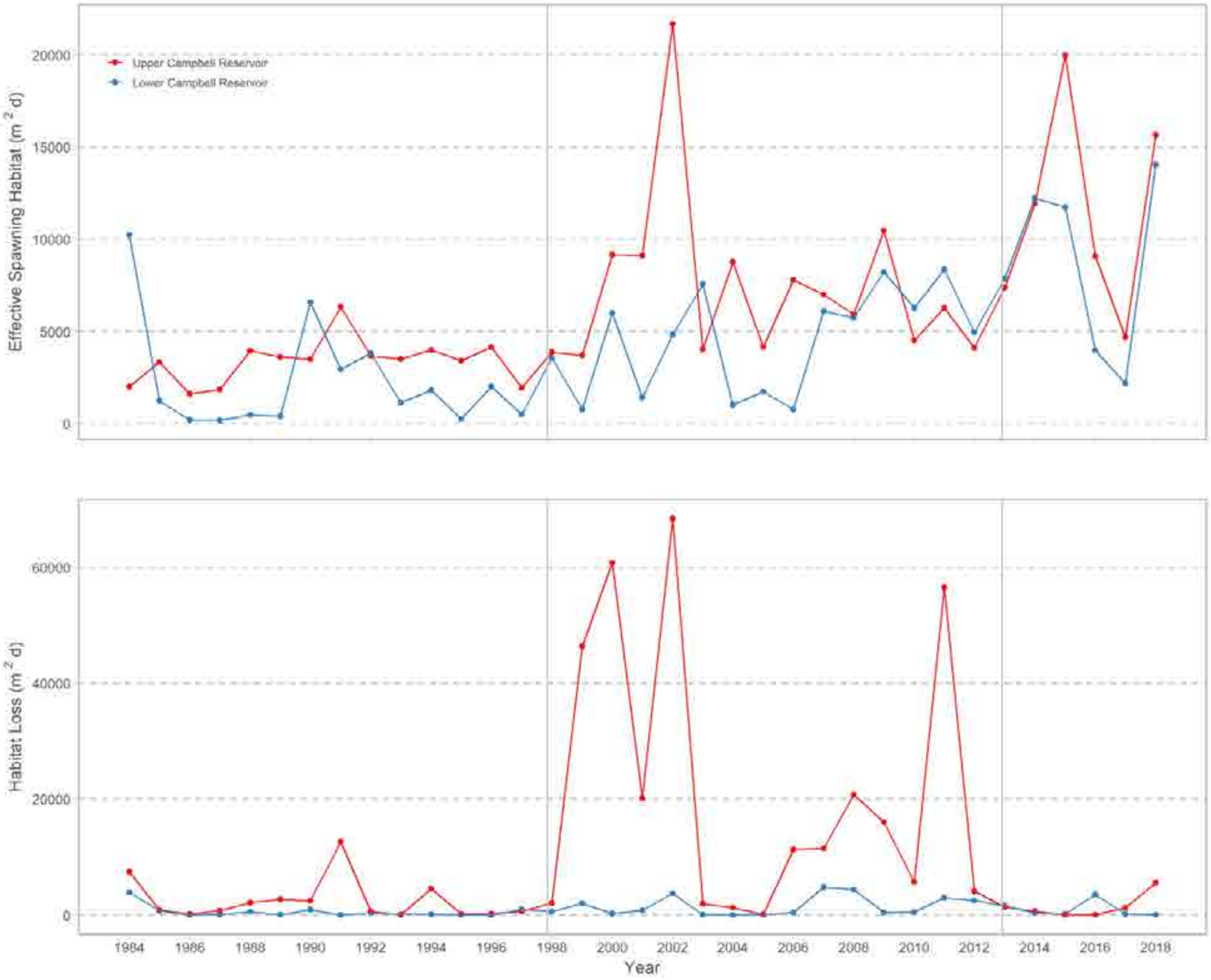


3.1.2. Rainbow Trout

Effective spawning habitat values for both Lower and Upper Campbell reservoirs were variable among years, with greater variability in the Upper Campbell Reservoir effective spawning habitat (range of 1,619 to 21,674 m²d; mean = 6,462 m²d) than the Lower Campbell Reservoir effective spawning habitat (range of 188 to 14,055 m²d; mean = 4,321 m²d). Following the implementation of the Interim Flow Management Strategy effective spawning habitat increased more than two-fold in both reservoirs (Upper Campbell Reservoir: mean$_{pre\text{-}IFMS}$: 3,350 m²d, mean$_{post\text{-}IFMS}$: 8,537 m²d; Lower Campbell Reservoir: mean$_{pre\text{-}IFMS}$: 2,271 m²d, mean$_{post\text{-}IFMS}$: 5,688 m²d). Effective spawning habitat in both reservoirs during this monitoring program was high, particularly during 2014, 2015, and 2018. During 2016 and 2017 it was smaller, although it was at average or above average values (Figure 14).

Oscillations in the water level of the Upper Campbell Reservoir are associated with effective Rainbow Trout spawning habitat losses ranging from 0 to 68,352 m^{2}d (mean = 10,600 m^{2}d). Water levels in the Lower Campbell Reservoir are less variable, resulting in relatively minimal loss of effective spawning habitat (range of 0 to 4,810 m^{2}d; mean = 1,062 m^{2}d) (Figure 14). It is noteworthy that Effective Spawning Habitat for Rainbow Trout in both reservoirs are completely in sync since at least 2007. Effective spawning habitat loss habitat in the Lower Campbell Reservoir is variable and does not seem to have been affected by the implementation of the Interim Flow Management Strategy. Effective spawning habitat loss in the Lower Campbell Reservoir was highest immediately following the implementation of the IFMS, and was until recently positively associated with the effective spawning habitat (i.e., there were large losses in years when ESH was high). During this monitoring program this pattern does not hold as ESH was high and habitat loss was very small (range: 0 - 5,539 m^{2}d) (Figure 14).

Figure 14. **Results of effective spawning habitat and loss of effective spawning habitat models for Rainbow Trout from 1984 to 2018. Vertical lines denote dates of implementation of the Interim Flow Management Strategy (October 1997), and the Water Use Plan (November 2012).**



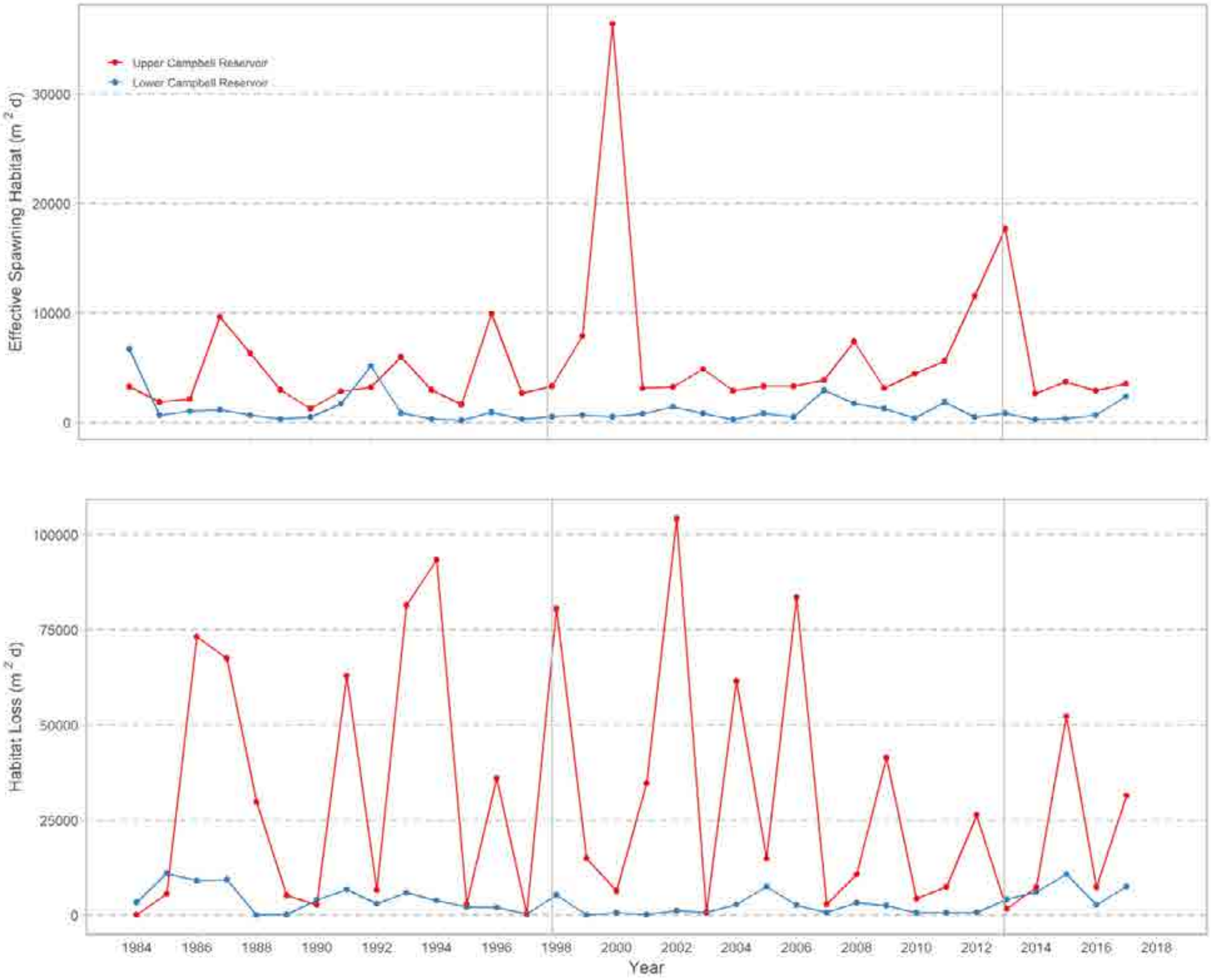
3.1.3. Dolly Varden

Given the timing of spawning and incubation of Dolly Varden (Figure 1), ESH metrics could only be calculated until 2017(Figure 15). Effective habitat values for both Lower and Upper Campbell reservoirs had much greater variability for the Upper Campbell Reservoir effective spawning habitat (range of 1,295 to 36,389 m^2d; mean = 5,648 m^2d) than the Lower Campbell Reservoir effective spawning habitat (range of 223 to 6,747 m^2d; mean = 1,196 m^2d) (Figure 15). The implementation of the Interim Flow Management Strategy does not seem to have affected the values of ESH for Dolly Varden, except for a couple of very high values in the Upper Campbell Reservoir in 2000 (36,389 m^2d) and 2013 (17,690 m^2d). Effective spawning habitat in the Upper Campbell Reservoir during this monitoring program (2014-2017) was consistently around 3,000 m^2d, while in the Lower Campbell

Reservoir was low during 2014-2016 (~400 m^2d), and increased during 2017 to ~2400 m^2d (Figure 15).

Fluctuations in the water level of the Upper Campbell Reservoir are associated with relatively regular oscillations in losses of effective Dolly Varden spawning habitat ranging from 73 to 104,159 m^2d (mean = 31,240 m^2d). In contrast, there has been comparatively little change in effective Dolly Varden spawning habitat loss among years in Lower Campbell Reservoir (range of 55 to 10,973 m^2d; mean = 3,586 m^2d) (Figure 15). Effective spawning habitat loss habitat in both reservoirs is variable and does not seem to have been affected by the implementation of the Interim Flow Management Strategy. During this monitoring program, the effective spawning habitat loss was variable, reaching a peak of 52,331 m^2d in 2015 in the upper Campbell Reservoir and a low of 2,707 m^2d in 2016 in the Lower Campbell Reservoir (Figure 15).

Figure 15. Results of effective spawning habitat and loss of effective spawning habitat models for Dolly Varden from 1984 to 2017. Vertical lines denote dates of implementation of the Interim Flow Management Strategy (October 1997), and the Water Use Plan (November 2012).



3.2. Population Index for Upper and Lower Campbell Reservoirs

3.2.1. Summary of Gillnet Sampling Results

Fish sampling from the six gill net monitoring sites recorded a total of 37 Cutthroat Trout, 127 Rainbow Trout, six Sculpin, seven Cutthroat Trout/Rainbow Trout hybrids (Table 11). No Dolly Varden or Threespine Stickleback were captured in 2018. Rainbow Trout had the greatest mean CPUE (0.47 fish/net hour), followed by Cutthroat Trout (0.14 fish/net hour). CPUE for Cutthroat Trout and Rainbow Trout varied among sites although site conditions were relatively similar (Table 11). At each site, CPUE for Rainbow Trout was greater than for Cutthroat Trout (Table 11). This difference was substantial given that CPUE for Cutthroat Trout was less or equal to 0.15 at all sites, whereas CPUE for Rainbow Trout was greater than 0.20 at all sites. Representative photographs and raw data collected during gillnet surveys are presented in Appendix F.

Table 11. Summary of gill net survey effort, catch statistics, and CPUE from the Upper Campbell Reservoir, August 2018.

Site	Sampling Date	# of Sets	Gill Netting Effort (hrs)	Gill Net Catch (# of Fish)					Gill Net CPUE (# of Fish / net hr)				
				CT	RB	DV	CC	CT/RB	CT	RB	DV	CC	CT/RB
UCR-LKGN01	20-Aug-18	2	40.9	3	13	0	0	1	0.07	0.32	0	0	0.02
UCR-LKGN02	20-Aug-18	2	40.5	3	19	0	2	0	0.07	0.47	0	0.05	0
UCR-LKGN04	21-Aug-18	3	59.2	4	14	0	0	2	0.07	0.24	0	0	0.03
UCR-LKGN06	21-Aug-18	2	38.8	6	19	0	0	3	0.15	0.49	0	0	0.08
UCR-LKGN07	22-Aug-18	3	57.2	7	38	0	3	0	0.12	0.66	0	0.05	0.00
UCR-LKGN08	22-Aug-18	2	38.1	14	24	0	1	1	0.37	0.63	0	0.03	0.03
	Total	**14**	**274.7**	**37**	**127**	**0**	**6**	**7**	**0.86**	**2.81**	**0**	**0.13**	**0.16**
	Average	**2.3**	**45.8**	**6.2**	**21.2**	**0**	**1**	**1.2**	**0.14**	**0.47**	**0**	**0.02**	**0.03**
	SD	**0.5**	**9.7**	**4.2**	**9.2**	**0**	**1.3**	**1.2**	**0.12**	**0.17**	**0**	**0.03**	**0.03**

3.2.2. Cutthroat Trout

3.2.2.1. CPUE

Cutthroat Trout were caught at every gill net sampling site; however, CPUE was variable across gill netting sites as well as gill net depth. The sampling site CPUE ranged from 0.07 to 0.37 fish/net hour at the gill netting sites, with an overall mean CPUE of 0.14 fish/net hour (Table 11). CPUE in floating nets was low (0.002 and 0.009 fish/hr), and Cutthroat were only captured in floating nets where bottom depths were less than 10m (Table 12). Cutthroat Trout were captured at all depths in sinking nets. CPUE was higher in sinking than than floating nets and there was no clear pattern of varying CPUE with depth in sinking nets (Table 12). This suggests that Cutthroat Trout have a benthic lifestyle and that they do not have a preferred depth within the range examined.

Table 12. CPUE (no. fish / hour) of a) all Cutthroat Trout and b) adult Cutthroat Trout (>150 mm) based on gill net type and bottom depth. Catches from Nordic gill nets were not included in this analysis.

a) All Cutthroat Trout

Net Type	Bottom Depth (m)			
	2.5	7.5	12.5	17.5
Floating	0.009	0.002	0	0
Sinking	0.019	0.013	0.022	0.016

Net depth for sinking nets is equal to bottom depth, and 2.5 m for floating nets

b) Adult Cutthroat Trout

Net Type	Bottom Depth (m)			
	2.5	7.5	12.5	17.5
Floating	0.011	0.002	0	0
Sinking	0.020	0.015	0.024	0.016

Net depth for sinking nets is equal to bottom depth, and 2.5 m for floating nets

3.2.2.2. Individual Fish Analysis

A total of 37 Cutthroat Trout were captured during gill netting surveys and size of captured fish ranged from 142 to 439 mm. Cutthroat Trout fork length had a mode around 350 mm, with a long left tail (Figure 16). The weight of Cutthroat trout caught in the Upper Campbell Reservoir followed an isometric growth curve (i.e., the exponent of the length-weight relationship is 3) (Figure 17).

Figure 16. Length-frequency histogram for Cutthroat Trout (CT) captured during the gill-netting surveys on Upper Campbell Reservoir, 2018.

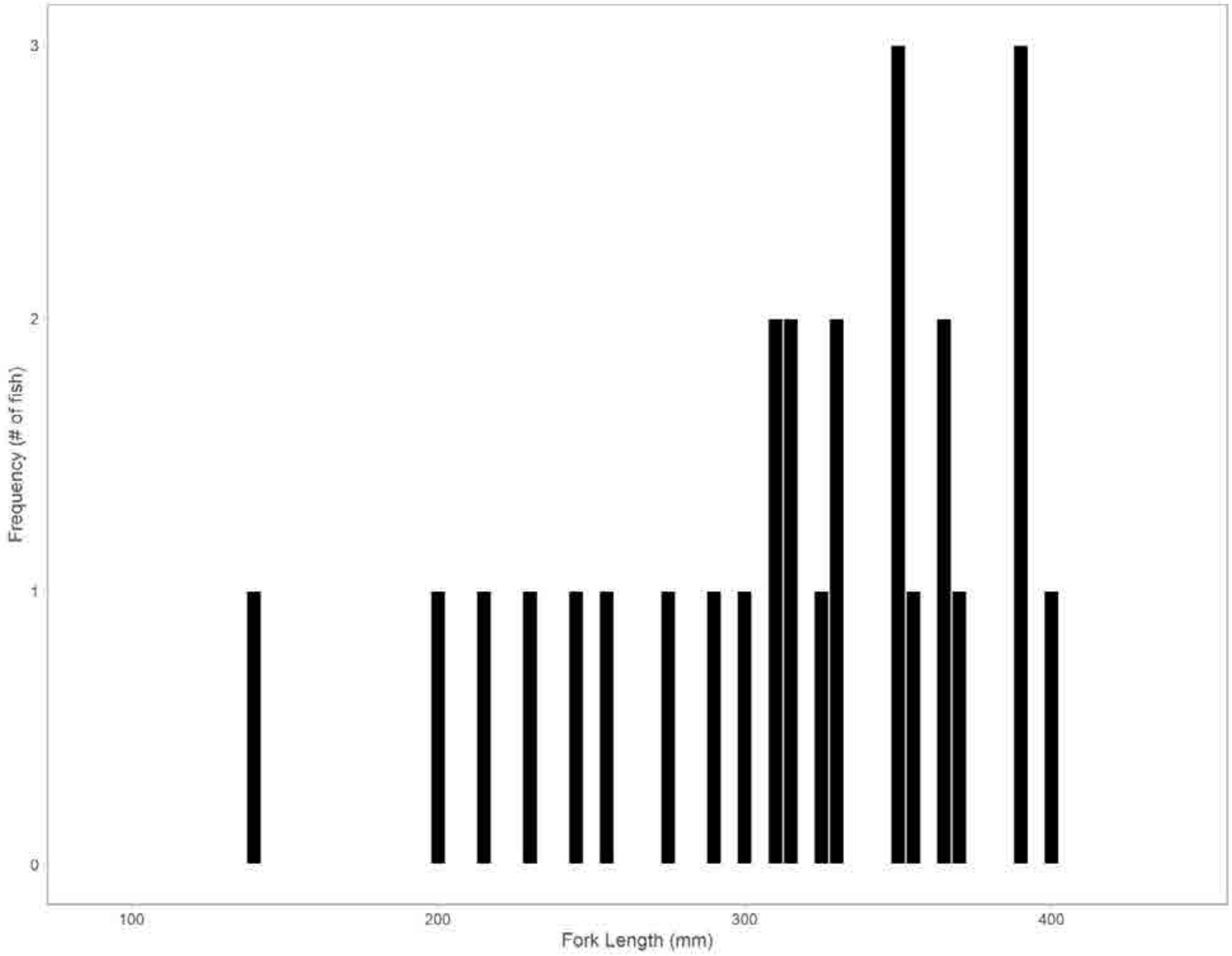
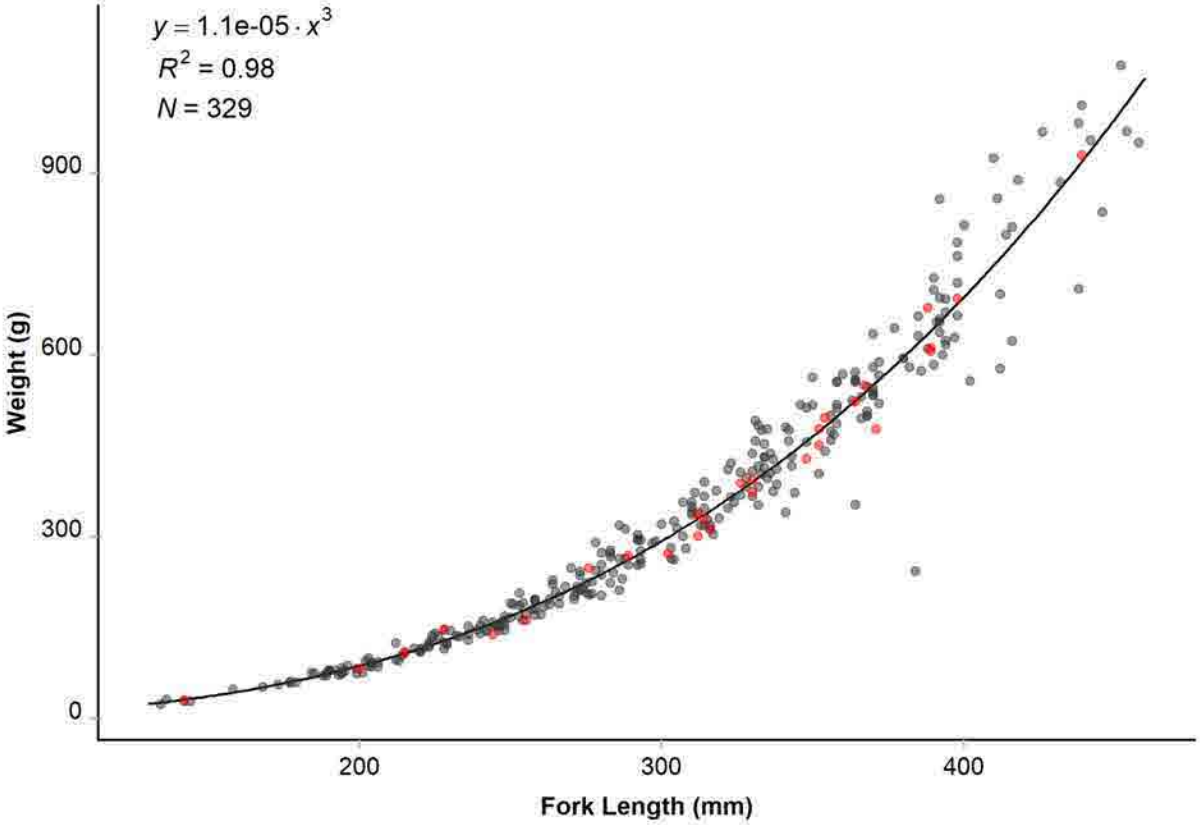


Figure 17. **Length-weight relationship for Cutthroat Trout captured during gill-net surveys in the Upper Campbell Reservoir, 2014-2018. Grey dots represent data collected during 2014-2017, and red dots (n = 28) represent data collected during 2018.**



3.2.2.3. Stomach Content Analysis

A total of 79 Cutthroat Trout stomach contents were analysed (Table 13). Cutthroat Trout in the Upper Campbell Reservoir fed largely on fish, with some contribution of benthic and terrestrial prey (Table 13). The contribution of the latter two groups increased in 2018 from 10% to 17% and from 10% to 35%, respectively (Table 13).

Table 13. **Diet analysis of Cutthroat Trout captured during gill net surveys in the Upper Campbell Reservoir, 2015, 2017, 2018. The data is presented as mean percent volume.**

Predator Species	Year	Sample Size	Plankton	Fish	Benthic	Terrestrial	Other
Cutthroat Trout	2015	18	-	77.8	5.6	11.1	5.6
	2017	33	-	78.8	10.6	10.6	-
	2018	28	3	44.8	17.1	35	-

3.2.2.4. Age Cohort Analysis

The age of Cutthroat Trout caught in gill nets in Year 5 ranged in age from 1+ to 6+ (Table 14). Most fish captured during Year 5 gill netting were ages 5+ and older, only a few younger fish were captured, and no fish age 0+ were captured (Table 14). Mean condition of Cutthroat Trout of all ages was good; the mean K was above 1 for all ages, and the minimum K was either above 1 or very close to 1 for all ages (Table 14)

The relative abundance of older fish was higher; the CPUE for fish Age 3+ to ≥6+ fish ranged from 0.015 to 0.047 fish/net hour, and was highest for age 5+ fish (0.047 fish/net hour) (Table 15). CPUE of younger fish was an order of magnitude lower (CPUE ages 1+ and 2+ = 0.004).

Table 14. **Summary of fork length, weight, and condition of Cutthroat Trout captured during gill netting surveys in Upper Campbell Reservoir, 2018, excluding partially consumed fish (n = 9).**

Age	Fork Length (mm)				Weight (g)				Condition (K)			
	n	Mean	Min	Max	n	Mean	Min	Max	n	Mean	Min	Max
0+	-	-	-	-	-	-	-	-	-	-	-	-
1+	1	142	142	142	1	30	30	30	1	1.05	1.05	1.05
2+	1	200	200	200	1	82	82	82	1	1.03	1.03	1.03
3+	4	236	215	255	4	139	110	162	4	1.07	0.95	1.24
4+	3	289	276	302	3	262	248	271	3	1.09	0.98	1.18
5+	11	331	312	354	11	390	301	496	11	1.06	0.99	1.12
≥6+	8	388	364	439	8	633	477	929	8	1.07	0.93	1.16

Table 15. **CPUE of Cutthroat Trout age cohorts captured during gill netting surveys in Upper Campbell Reservoir, 2018.**

Age	Number of Fish Caught	CPUE # of Fish/net hr)
0+	-	-
1+	1	0.004
2+	1	0.004
3+	4	0.015
4+	6	0.022
5+	13	0.047
≥6+	11	0.040

3.2.2.5. Comparison of Abundance Index to Effective Spawning Habitat

There is no clear relationship between age specific abundance indices of Cutthroat Trout and the effective spawning habitat in the Upper Campbell Reservoir (Table 16). There are substantial inter annual differences in CPUE; the largest values of CPUE were recorded for age 3+ fish in 2014 (0.08 fish/net hr), 4+ and 5+ fish and 6+ fish in 2015 (0.09 and 0.08 fish/net hr, respectively), and fish 5+ in 2016 (0.1 fish/net hr), with age-specific CPUE values in the last two years reduced substantially. This may indicate the presence of relatively strong age cohorts born in 2010-2012. In contrast, the values of Effective Spawning Habitat were high during 2008 and 2009 (~70,000 m^{2}d), dropping an order of magnitude in 2010 and remaining relatively stable until 2018 when they increased to around ~20,000 m^{2}d.

Table 16. **Effective Spawning Habitat values of the Upper Campbell Reservoir in relation to Cutthroat Trout abundance index for each age cohort.**

Spawning Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
ESH (m^{2}d)		76,846	69,836	12,880	11,874	9,103	8,191	16,760	3,338	3,904	8,900	21,447
Fish Abundance Index (# of Fish/net hr)	0+							-	-	-	-	-
	1+							0.01	0.00	0.00	-	0.00
	2+							0.05	0.01	0.04	0.02	0.00
	3+							0.08	0.05	0.03	0.03	0.01
	4+							0.07	0.09	0.03	0.02	0.02
	5+							0.06	0.09	0.10	0.03	0.05
	≥6+							0.06	0.08	0.04	0.06	0.04

3.2.3. Rainbow Trout

3.2.3.1. CPUE

Rainbow Trout were caught at every sampling site; however, CPUE was variable across gill netting sites and gill net depth. The sampling site CPUE ranged from 0.24 to 0.66 fish/net hour at the gill-netting sites, with an overall mean CPUE of 0.47 fish/net hour (Table 11).

Rainbow Trout (all (n = 121) and adult only (n = 101)) were captured at all depths, in both sinking and floating nets. CPUE was higher for floating nets than for sinking nets, at all bottom depths (Table 17). There is no clear pattern of CPUE with depth for sinking nets, but CPUE increases with bottom depth for floating nets (Table 17). These data suggest that Rainbow Trout have a pelagic lifestyle, and that abundance in the upper water column increases with depth.

Table 17. CPUE (no. fish / hour) of a) all Rainbow Trout and b) adult Rainbow Trout (>150 mm) based on gill net type and bottom depth. Catches from Nordic gill nets were not included in this analysis.

a) All Rainbow Trout

Net Type	**Bottom Depth (m)**			
	2.5	**7.5**	**12.5**	**17.5**
Floating	0.042	0.049	0.051	0.051
Sinking	0.033	0.039	0.029	0.033

Net depth for sinking nets is equal to bottom depth, and 2.5 m for floating nets

b) Adult Rainbow Trout

Net Type	**Bottom Depth (m)**			
	2.5	**7.5**	**12.5**	**17.5**
Floating	0.038	0.049	0.051	0.051
Sinking	0.032	0.037	0.027	0.033

Net depth for sinking nets is equal to bottom depth, and 2.5 m for floating nets

3.2.3.2. Individual Fish Analysis

A total of 127 Rainbow Trout were captured during gill netting surveys ranging from sizes of 60 to 336 mm (Figure 18). Older, mature fish (> 150 mm in length) were most frequently captured and were distributed throughout the Upper Campbell Reservoir. The weight of Rainbow trout caught in the Upper Campbell Reservoir during the length of the monitoring program (2014-2018) followed an allometric growth curve, with an exponent of 2.8 (Figure 19).

Figure 18. **Length-frequency histogram for Rainbow Trout captured during the gill-net surveys on Upper Campbell Reservoir, 2018.**

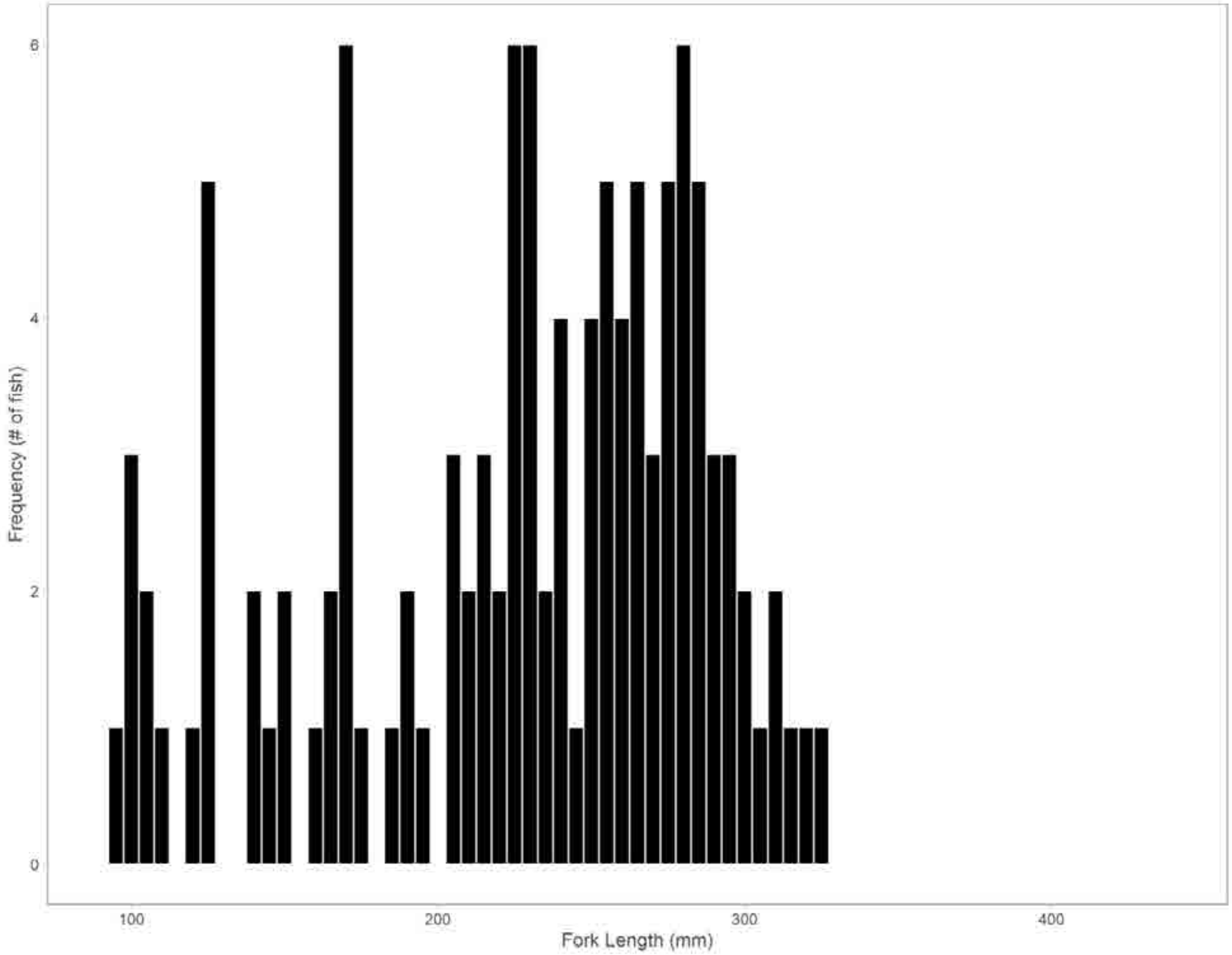
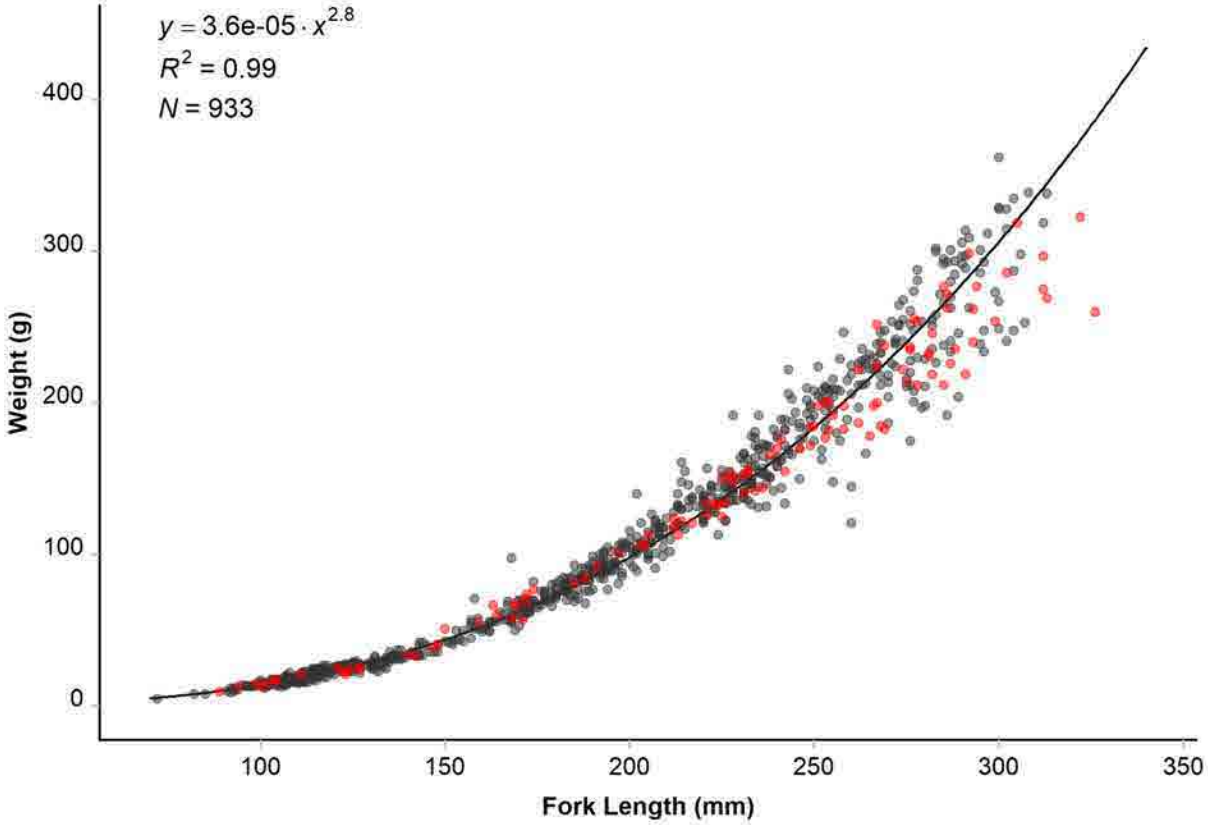


Figure 19. Length-weight relationship for Rainbow Trout captured during gill-net surveys in the Upper Campbell Reservoir, 2014-2018. Grey dots represent data collected during 2014-2017, and red dots (n = 113) represent data collected during 2018.



3.2.3.3. Stomach Content Analysis

A total of 169 Rainbow Trout were analysed for stomach contents; most of the effort was concentrated during 2017 and 2018 (59 and 102, respectively; Table 18). Rainbow Trout in the Upper Campbell Reservoir fed largely on terrestrial, and planktonic prey, with a small contribution of benthic prey. During 2015 there was a large contribution of benthic prey (75%), although this may be driven by the small number of stomachs analysed (8).

Table 18. **Diet analysis of Rainbow Trout captured during gill net surveys in the Upper Campbell Reservoir, 2015, 2017, 2018. The data is presented as mean percent volume.**

Year	Sample Size	Plankton	Fish	Benthic	Terrestrial	Other
2015	8	25	-	75	-	-
2017	59	31.4	-	1.7	66.9	-
2018	102	33.2	-	0.2	66.5	-

3.2.3.4. Age Cohort Analysis

The age of Rainbow Trout caught in gill nets in Year 5 ranged in age from 1+ to 6+ (Table 19). Most fish captured during Year 5 gill netting were ages 4+ and older, although a fair number of fish aged 2+ and 3+ were captured, and no fish age 0+ were captured (Table 19). Mean condition of Rainbow Trout of all ages was good; the mean K was above 1 for all ages, and the minimum K was either above 1 or very close to 1 for all ages, except for fish ages ≥6+ (Table 19).

The relative abundance of older fish was higher; CPUE of fish age ≥6+ was the highest (0.146 fish/net hr), followed by that of 4+ and 5+ fish (0.087 and 0.076 fish/net hr, respectively). The CPUE of fish ages 3+ and younger ranged from 0.036 and 0.055 fish/net hr.

Table 19. **Summary of fork length, weight, and condition of Rainbow Trout captured during gill netting surveys in Upper Campbell Reservoir, 2018, excluding partially consumed fish (n = 14).**

Age	Fork Length (mm)				Weight (g)				Condition (K)			
	n	Mean	Min	Max	n	Mean	Min	Max	n	Mean	Min	Max
0+	-	-	-	-	-	-	-	-	-	-	-	-
1+	9	103	89	121	9	16	9	25	9	1.46	1.28	1.60
2+	13	141	123	164	13	38	21	67	13	1.29	1.13	1.55
3+	12	180	168	203	12	78	57	106	12	1.32	1.14	1.46
4+	23	223	204	236	23	135	107	156	23	1.22	1.10	1.32
5+	19	252	238	265	19	184	155	222	19	1.16	0.96	1.26
≥6+	37	287	266	326	37	246	183	323	37	1.05	0.75	1.32

Table 20. CPUE (fish/net hour) of Rainbow Trout age cohorts captured during gill netting surveys in Upper Campbell Reservoir, 2018.

Age	Number of Fish Caught	CPUE (# of Fish/net hr)
0+	-	-
1+	10	0.036
2+	17	0.062
3+	15	0.055
4+	24	0.087
5+	21	0.076
≥6+	40	0.146

3.2.3.5. Comparison of Abundance Index to Effective Spawning Habitat

There was no clear relationship between age specific abundance indices of Rainbow Trout and the effective spawning habitat in the Upper Campbell Reservoir (Table 21). There were inter annual differences in CPUE; the largest values of CPUE were recorded for age 1+ fish in 2014 (0.36 fish/net hr), and age 1+ fish in 2016 (0.25 fish/net hr). The CPUE values for the other age classes in those same years were relatively high. This may indicate the presence of relatively strong age cohorts in 2012 and 2014, but it also may indicate that general conditions in the reservoir were better during 2014 and 2016. In contrast, the values of Effective Spawning Habitat generally oscillated between ~5,000 and ~10,000 m^2d, except in 2015 and 2018, when they peaked at ~20,000 and ~15,000 m^2 (Table 21).

Table 21. Effective Spawning Habitat values of the Upper Campbell Reservoir in relation to Rainbow Trout abundance index for each age cohort.

Spawning Year		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
ESH (m^2d)		5,921	10,466	4,512	6,275	4,112	7,383	11,932	19,970	9,090	4,690	15,662
Fish Abundance Index (# of Fish/net hr)	0+							-	0.00	-	-	-
	1+							0.36	0.06	0.25	0.03	0.04
	2+							0.16	0.06	0.14	0.05	0.06
	3+							0.21	0.09	0.20	0.10	0.05
	4+							0.11	0.17	0.10	0.06	0.09
	5+							0.05	0.13	0.08	0.03	0.08
	≥6+							0.02	0.13	0.11	0.06	0.15

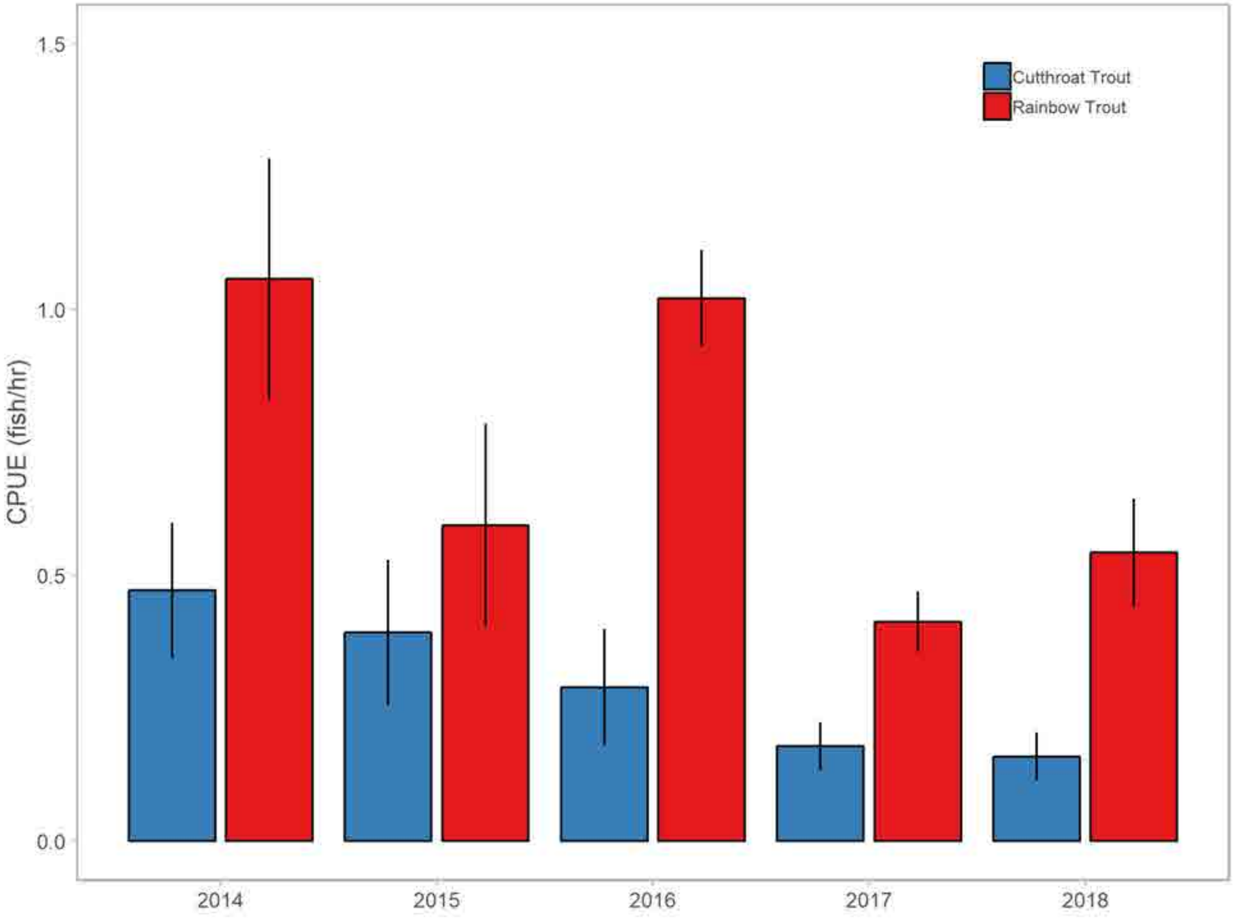
3.2.4. Historical Comparison

In this section, we provide brief summaries of historic gill net catch data for Cutthroat and Rainbow trout for both species for the Upper Campbell Reservoir overall, and by sample site for each species separately.

3.2.4.1. Upper Campbell Reservoir

Sampling results from Year 1 to Year 5 (2014 to 2018) suggest that mean Cutthroat Trout CPUE is in a declining trend, while average Rainbow Trout CPUE is highly variable (Figure 20) in the Upper Campbell Reservoir. Cutthroat Trout CPUE has declined since Year 1. Rainbow Trout CPUE is variable among years with no discernible trend. It is worth noting that 2017 CPUE for Rainbow Trout and Cutthroat Trout was the lowest on record since 2014, and by 2018 it recovered to a level similar to that in2015. Mean Cutthroat Trout CPUE (0.16 fish/net hour) in Year 5 was less than a third of mean Cutthroat Trout CPUE reported in Year 1.

Figure 20. Comparison of Cutthroat and Rainbow Trout CPUE from littoral gill net surveys in the Upper Campbell Reservoir among the five years of this program to date.

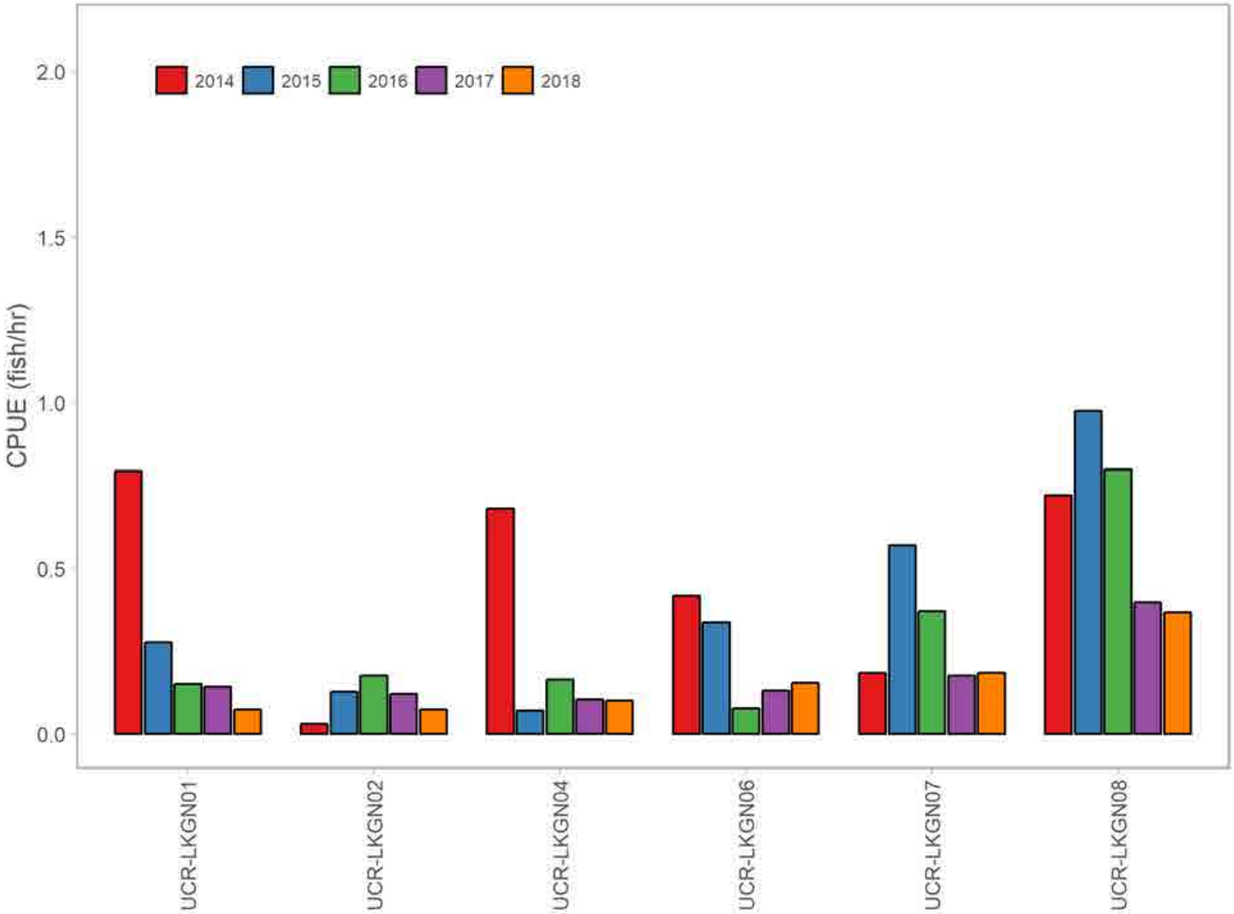


Cutthroat Trout

Results from the Year 5 Population Index were comparable to past years. UCR-LKGN02 had consistently lower Cutthroat Trout CPUE compared to the other sites, whereas UCR-LKGN08 had relatively moderate to high Cutthroat Trout CPUE for all five years.

Cutthroat Trout appeared to have a consistent preference for some sites over others, but few trends for Cutthroat Trout CPUE are apparent within sampling sites or across years. In fact, the only site with a consistent trend across all sampling years is UCR-LKGN01, for which CPUE has decreased annually since 2014. There was a clear decline in CPUE in 2017 at two sites (UCR-LKGN07 and UCR-LKGN08), and it stayed constant in 2018. Compared to 2017, CPUE values remained very similar across sites. Assuming CPUE is an indication of habitat preference, it would appear that habitat at UCR-LKGN08 is preferred over that at the other sites, while UCR-LKGN02 and UCR-LKGN04 are less-preferred sites.

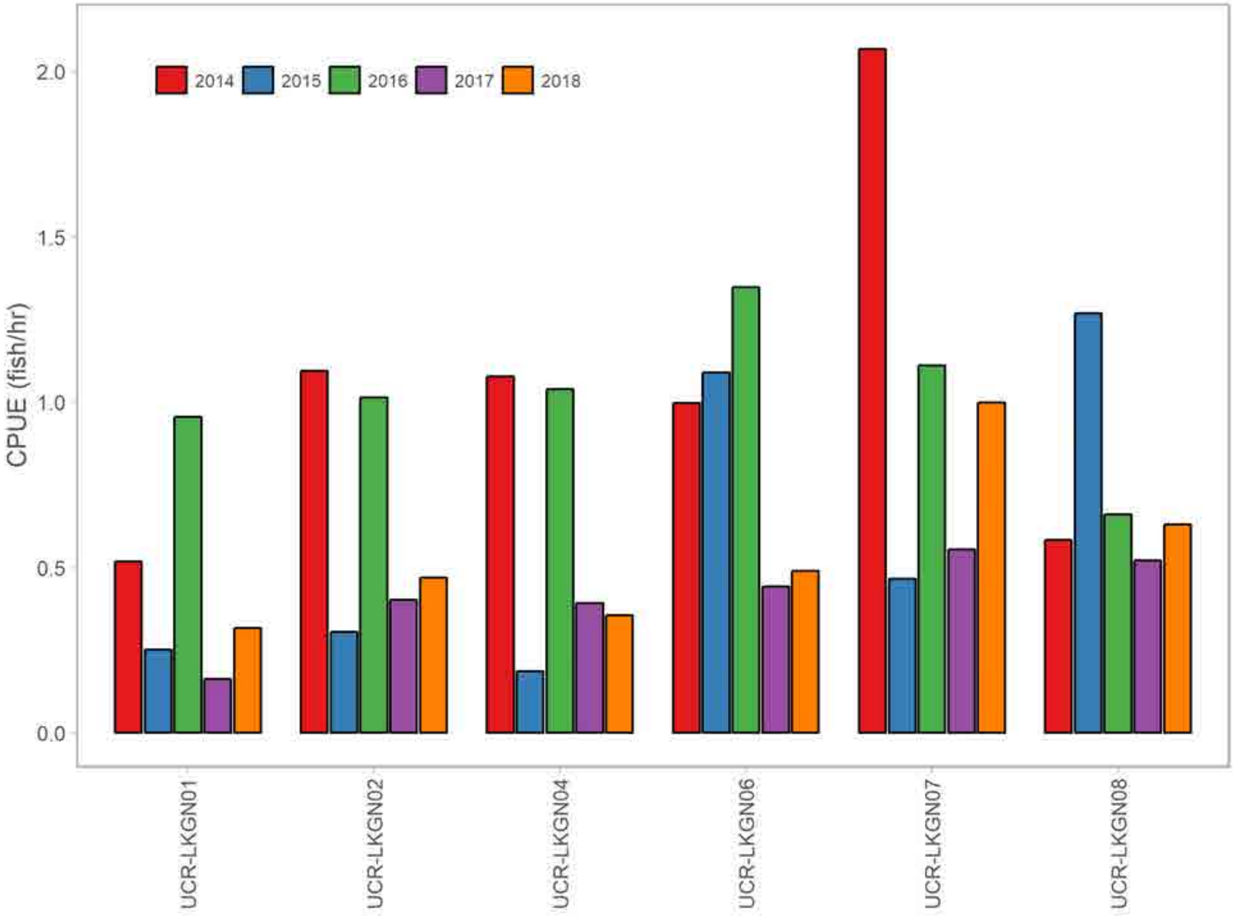
Figure 21. Comparison of Cutthroat Trout CPUE from littoral RISC gill net surveys by sample site among the five years of this program to date (2014, 2015, 2016, 2017, and 2018).



Rainbow Trout

There was no consistent trend in CPUE results for Rainbow Trout among the sampling sites or across sampling years. In general terms, CPUE has been lower in 2017 and 2018 when compared to the previous 3 years. The CPUE in 2018 increased at all sites but one (UCR-LKGN04). This increase was marginal at most sites, except for UCR-LKGN01 and UCR-LKGN07 where it almost doubled.

Figure 22. Comparison of Rainbow Trout CPUE from littoral RISC gill net surveys by sample site among the five years of this program to date (2014, 2015, 2016, 2017, and 2018).



3.3. Snorkel Survey of Spawners in Reservoir Tributaries

3.3.1. Survey Conditions

Survey conditions between the spring and summer surveys were relatively comparable. Details of survey locations, dates, effort, and conditions are presented for each separate survey during spring (Table 22) and summer (Table 23). All parameters (discharge, visibility, and temperature) during the spring surveys were influenced by seasonal freshet and precipitation with varying effective visibility from 4 m in March to 6.0 m in April and with temperatures ranging between 3.5°C and 4.8°C (Table 22). Relative to the spring, increased water temperature and visibility was experienced during summer surveys (Table 23). Representative photographs collected during snorkel surveys are presented in Appendix G.

Table 22. **Sampling effort and conditions for Year 5 snorkel surveys in tributaries of the Lower Campbell Reservoir during spring surveys in 2018. Survey distances for Fry and Miller Creek are from LKT (2015) and Greenstone River survey distances are based on satellite images.**

Watershed	Stream	Survey Distance (km)	Date	Survey Duration (hrs)	Total Effort (hrs)	Water Temp. (°C)	Air Temp (°C)	Estimated Visibility (m)	Mean Daily Discharge (m^3/s)[1]	Weather
Lower Campbell	Fry Creek	1.2	9-Mar-2018	0.6	1.2	4.8	3.0	4.0	9.7	Partly Cloudy/Rain
	Greenstone River	2.4	16-Apr-2018	1.5	3.0	3.5	6.0	6.0	10.2	Partly Cloudy
	Miller Creek	0.4	9-Mar-2018	2.6	5.1	3.0	-0.5	4.0	9.7	Partly Cloudy/Rain

[1] Data from the Gauge 08HD018 form Government of Canada Wateroffice site

Table 23. **Sampling effort and conditions for Year 5 snorkel surveys during summer 2018. Survey distances are from LKT (2015).**

Watershed	Stream	Survey Distance (km)	Date	Survey Duration (hrs)	Total Effort (hrs)	Water Temp. (°C)	Air Temp (°C)	Estimated Visibility (m)	Mean Daily Discharge (m^3/s)[1]	Weather
Buttle Lake	Henshaw Creek	0.5	4-Jun-2018	0.5	1.0	5.0	8.0	6.0	16.8	Partly Cloudy
	Phillips Creek	0.3	5-Jun-2018	0.5	0.9	5.5	8.0	6.0	17.0	Overcast/Rain
	Ralph River	0.9	4-Jun-2018	0.4	0.9	6.0	12.0	6.0	16.8	Partly Cloudy
	Thelwood Creek	2.5	7-Jun-2018	0.8	1.6	7.5	9.5	6.0	15.5	Light Rain
	Wolf River	0.3	5-Jun-2018	0.6	1.1	5.5	9.5	6.0	17.0	Overcast/Rain
Upper Campbell	Lower Elk River	5.4	6-Jun-2018	2.1	4.1	8.5	12.0	6.0	16.2	Partly Cloudy
	Upper Elk River	6	6-Jun-2018	1.0	2.1	7.0	10.0	6.0	16.2	Partly Cloudy

[1] Data from the Gauge 08HD018 form Government of Canada Wateroffice site.

3.3.2. Survey Results

3.3.2.1. Cutthroat Trout Results

Year 5 snorkel survey data during the Cutthroat Trout spring spawning period are summarized below (Table 24); comparative figures and maps are presented in Appendix H. Redds observed during March and April were assumed to be Cutthroat trout redds, even if no fish were observed.

Snorkel surveys for spawning Cutthroat Trout were conducted in tributaries of the Lower Campbell River in March and April, 2018. During these Lower Campbell River snorkel surveys adult Cutthroat Trout were observed in Miller Creek and Greenstone River; however, redds were observed in all three tributaries of Lower Campbell Reservoir (Table 24).

Densities of Cutthroat densities were low in all tributaries, reaching maximums of 40 fish/km and 38 fish/km in Wolf River and Greenstone River, respectively (Figure 23). The majority of adult Cutthroat observed in 2018 were either bright (*n* = 73) or moderately coloured (*n* = 88) (Figure 26). Only a few fish in mid-spawn condition (*n* = 14) were observed, mostly in Greenstone River, and only 2 fish in post-spawn condition (Figure 26).

Table 24. **Cutthroat Trout counts during 2018 snorkel surveys in the tributaries of Upper and Lower Campbell Reservoirs and Buttle Lake.**

Watershed	Month	Waterbody	Date	Cutthroat Trout Observations (# of fish)[1]							Redds[2]
				Total	Fry	Parr	151-250	251-350	351-450	450+	
Buttle Lake	June	Henshaw Creek	4-Jun-2018	1	0	0	0	1	0	0	n/a
		Phillips Creek	5-Jun-2018	2	0	0	0	1	1	0	n/a
		Ralph River	4-Jun-2018	5	0	0	0	2	3	0	n/a
		Thelwood Creek	7-Jun-2018	28	0	0	2	13	11	2	n/a
		Wolf River	5-Jun-2018	12	0	0	0	7	5	0	n/a
Lower Campbell	March	Fry Creek	9-Mar-2018	0	0	0	0	0	0	0	59
		Miller Creek	9-Mar-2018	5	0	0	3	2	0	0	117
	April	Greenstone River	16-Apr-2018	92	0	0	4	41	41	6	18
Upper Campbell	June	Lower Elk River	6-Jun-2018	19	0	0	2	12	5	0	n/a
		Upper Elk River	6-Jun-2018	13	0	0	0	4	8	1	n/a

[1] Fry = <80 mm fork length, Parr = 81-150 mm fork length, All others are categorized as mm fork length

[2] All redds observed in March and April are assumed to be Cutthroat Trout redds. Redds observed in June are assumed to be Rainbow Trout. "n/a" reflects no sampling for redds since sampling occurred outside of spawning period.

Figure 23. Cutthroat Trout observed density (fish/km; all life stages) during Year 5 snorkel surveys in the tributaries of Buttle Lake, Lower Campbell Reservoir and Upper Campbell Reservoir.

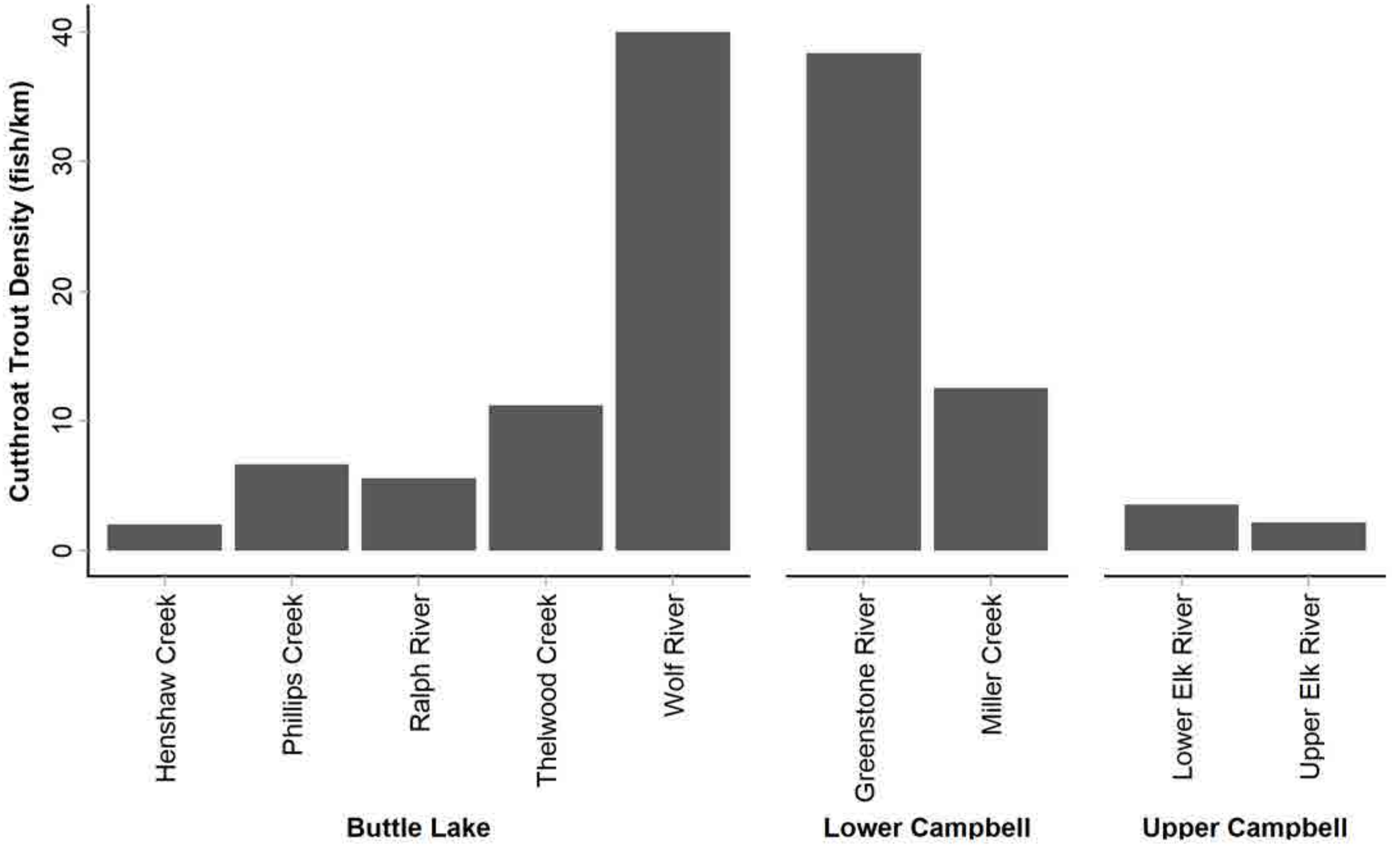
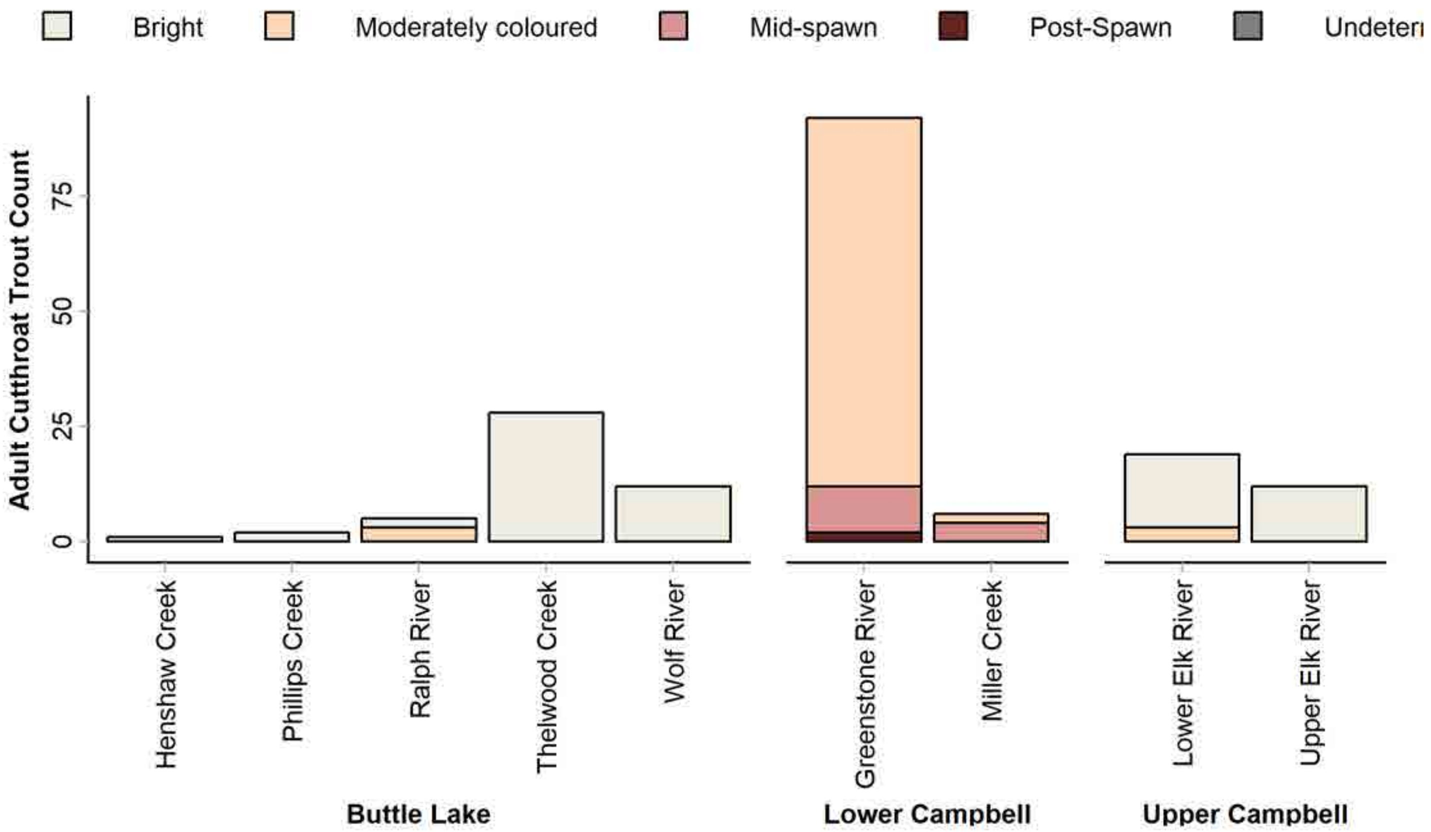


Figure 24. Counts of adult Cutthroat Trout observed during Year 5 snorkel surveys in the tributaries of Buttle Lake, Lower Campbell Reservoir and Upper Campbell Reservoir, by condition classes.



3.3.2.2. Rainbow Trout Results

Rainbow Trout redds were recorded in all surveyed tributaries of Upper Campbell and Buttle Lake (Table 25). The highest number of redds was observed in Thelwood Creek (1519 redds), followed by lower Elk River (1235 redds). The number of Rainbow Trout redds recorded in Thelwood Creek in Year 5 were higher than in Year 4 (576, Bayly *et al.* 2018), and similar to the counts in Year 2 and Year 3 (1,441 and 1,217, respectively, Hatfield *et al.* 2016 and Smyth and Hatfield 2017)[5]. The total number of Rainbow Trout redds recorded in the Elk River in Year 5 (2110) was higher than in the previous 3 years (Year 4: 1,087, Year 3: 1,833, Year 2: 1,846) (Hatfield *et al.* 2016, Smyth and Hatfield 2017, Bayly *et al.* 2018). Redds were observed during snorkel surveys in tributaries of the Lower Campbell Reservoir in March and April; however, they are assumed to have been excavated by Cutthroat Trout.

Total Rainbow Trout density per km of stream (juvenile and adult fish combined) varied considerably among stream reaches, with observed densities greatest in Wolf River (2,083 fish/km), Ralph River (721 fish/km), Thelwood Creek (628 fish/km), and Lower Elk River (471 fish/km) (Figure 25). When interpreting these results, note that variability in channel width hinders direct comparison of this metric between tributaries.

Adult Rainbow Trout counts were much higher than Cutthroat Trout, which may have been a result of effective survey timing in relation to Rainbow Trout spawning, or due to differences in effective population size between the species. Highest count numbers of adult Rainbow Trout observations were recorded from lower Elk River (2,541 fish); Thelwood Creek (1,571 fish); and upper Elk River (1,164 fish) (Figure 26). These watercourses also correspond to the highest counts from the Year 1 (Hatfield *et al.* 2015), Year 2 (Hatfield *et al.* 2016), Year 3 (Smythe and Hatfield, 2017), and Year 4 surveys (Bayly *et al.* 2018). The majority of the observed Rainbow Trout were in mid-spawn (60%) or of moderately coloured (20%) condition, suggesting that these surveys occurred during spawning (Figure 26). Appreciable numbers of fish in post-spawn condition were observed in Lower Elk River (*n* = 457, 8% of adult Rainbow Trout in that stream), Upper Elk River (*n* = 345, 6% of adult Rainbow Trout in that stream), and Thelwood Creek (*n* = 342, 6% of adult Rainbow Trout in that stream) (Figure 26).

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[5] Redd counts were not consistently recorded for all survey reaches in Year 1 hence no comparison is made with Year 1 data here.

Table 25. **Rainbow Trout counts during 2018 snorkel surveys in the tributaries of Upper and Lower Campbell Reservoirs and Buttle Lake.**

Watershed	Month	Waterbody	Date	Rainbow Trout Observations (# of fish)[1]							Redds[2]
				Total	Fry	Parr	151-250	251-350	351-450	450+	
Buttle Lake	June	Henshaw Creek	4-Jun-2018	27	0	1	0	26	0	0	35
		Phillips Creek	5-Jun-2018	93	0	0	13	80	0	0	99
		Ralph River	4-Jun-2018	649	0	2	38	609	0	0	198
		Thelwood Creek	7-Jun-2018	1,571	0	0	69	1,425	77	0	1,519
		Wolf River	5-Jun-2018	625	0	0	113	512	0	0	623
Lower Campbell	March	Miller Creek	9-Mar-2018	3	0	0	2	1	0	0	n/a
	April	Greenstone River	16-Apr-2018	3	0	2	1	0	0	0	n/a
Upper Campbell	June	Lower Elk River	6-Jun-2018	2,541	0	0	71	2,328	142	0	1,235
		Upper Elk River	6-Jun-2018	1,164	0	0	117	990	57	0	875

[1] Fry = <80 mm fork length, Parr = 81-150 mm fork length, All others are categorized as mm fork length

[2] All redds observed in June are assumed to be Rainbow Trout redds

"n/a" reflects no sampling for redds since sampling occurred outside of spawning period

Figure 25. **Rainbow Trout observed density (fish/km; all life stages) during Year 5 summer snorkel surveys in the tributaries of Upper Campbell Reservoir and Buttle Lake. Rainbow Trout observed incidentally during snorkel surveys for Cutthroat Trout in the Lower Campbell Reservoir are not included.**

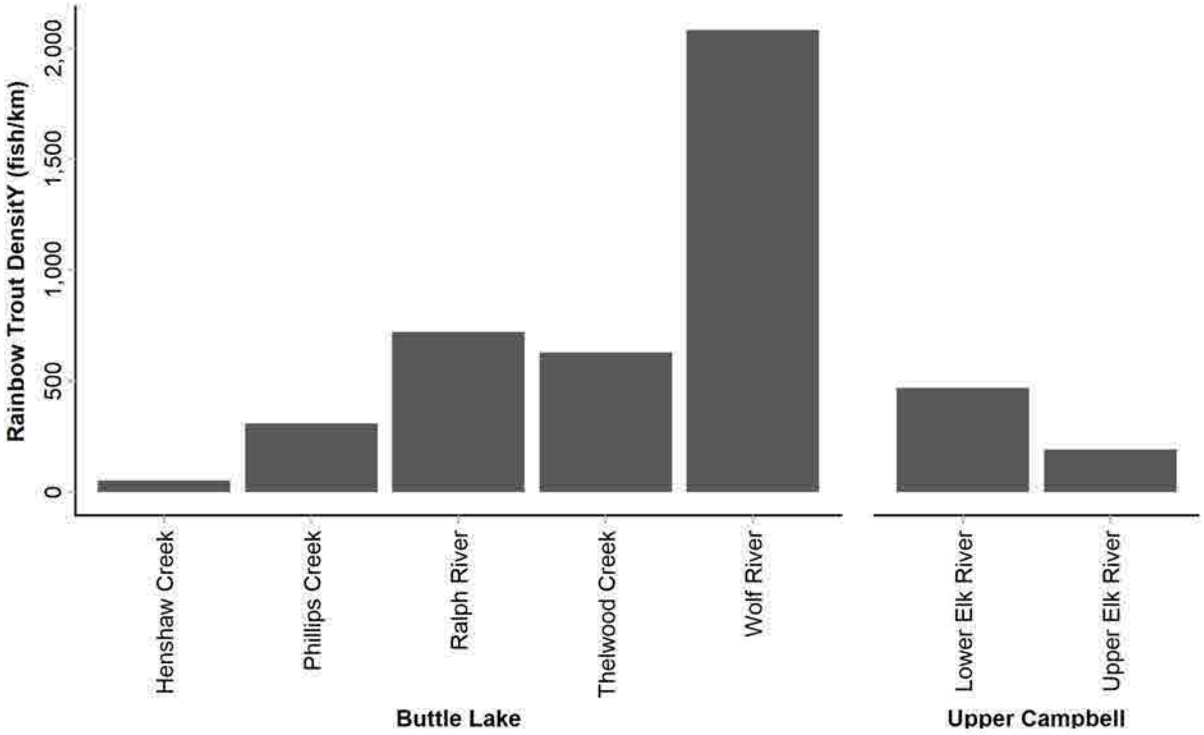
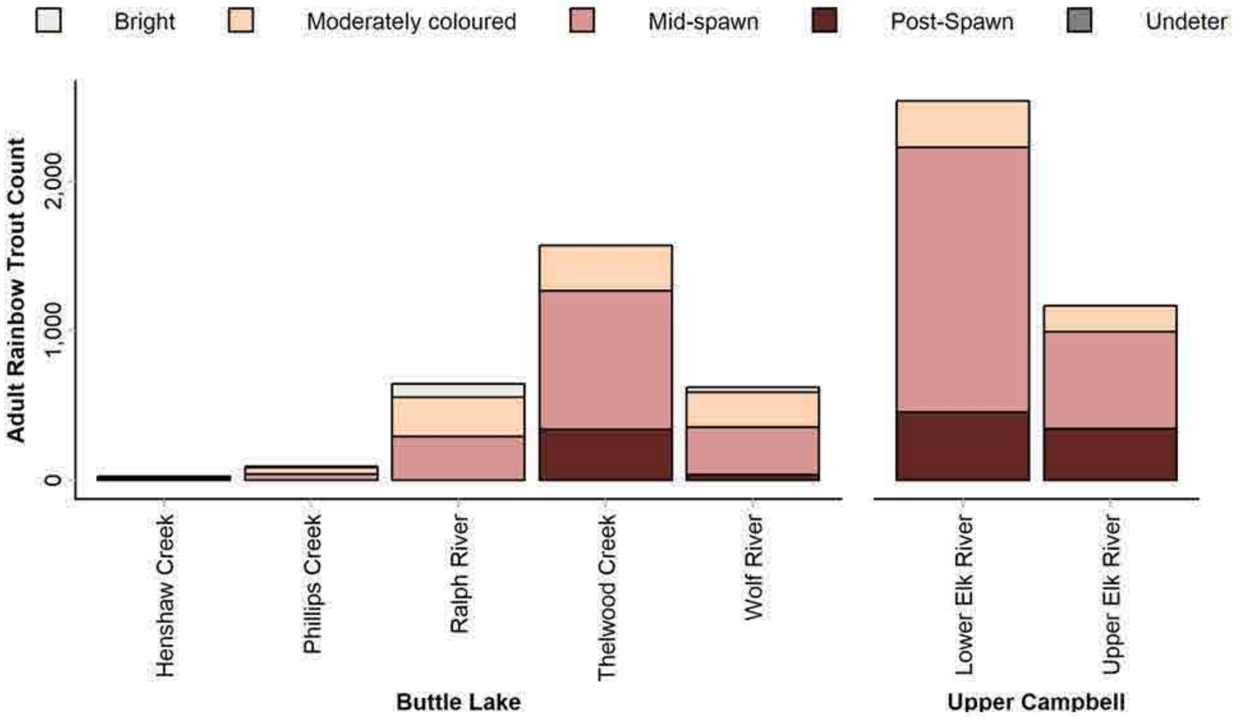


Figure 26. **Counts of adult Rainbow Trout observed during Year 5 summer snorkel surveys in the tributaries of Upper Campbell Reservoir and Buttle Lake, by condition classes. Rainbow Trout observed incidentally during snorkel surveys for Cutthroat Trout in Lower Campbell Reservoir are not included.**



3.3.2.3. Dolly Varden and Unidentified Salmonids

The numbers of adult Dolly Varden observed were much lower than the number of observed Cutthroat or Rainbow trout. This reflects the timing of the surveys, which targeted Cutthroat Trout and Rainbow Trout spawning during the spring and summer, respectively. Snorkel surveys targeting the Dolly Varden spawning period (October to early December) were not undertaken and are not within the scope of this monitoring program; therefore, all observations of Dolly Varden are classified as incidental.

Dolly Varden were not recorded during the spring surveys and limited observations occurred during the summer surveys (Table 26). The greatest number of adult Dolly Varden were observed in Wolf River (29 fish) which held the highest number of incidental Dolly Varden observations in the Year 1 (Hatfield *et al.* 2015), Year 2 (Hatfield *et al.* 2016), and Year 4 (Bayly *et al.* 2018), and the second highest number in Year 3 (Smyth and Hatfield 2017). In Year 5, the density of Wolf River Dolly Varden (97 fish/km) was smaller than in Year 4 (170 fish/km), but surpassed all previous density records and was an order of magnitude greater than densities reported in Year 3 (Hatfield *et al.* 2015, 2016 and Smyth and Hatfield 2017). Densities observed in other streams were below 10 fish/km, and were comparable to those recorded previously.

Figure 27. Dolly Varden observed density (fish/ km) from 2018 summer snorkel surveys in the tributaries of Upper Campbell Reservoir and Buttle Lake. No Dolly Varden were observed in Lower Campbell Reservoir tributaries.

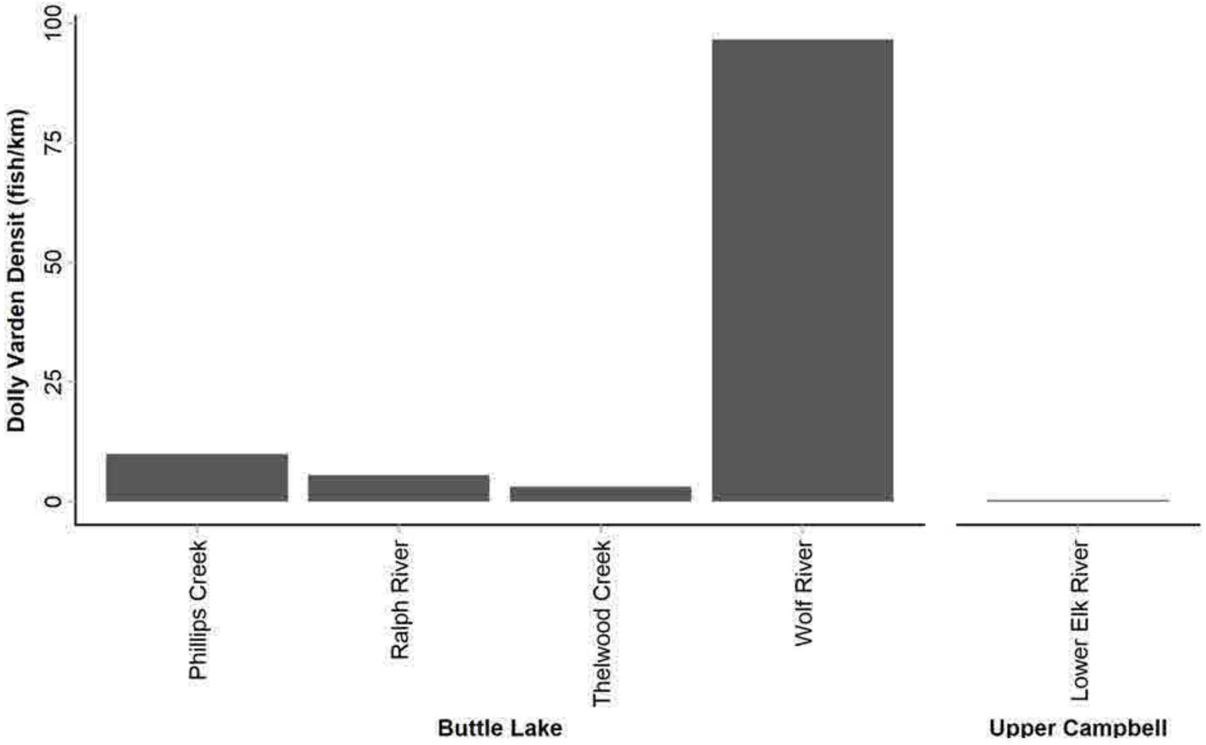


Table 26. Dolly Varden population counts (incidental) from 2018 snorkel surveys in the tributaries of Upper and Lower Campbell Reservoirs and Buttle Lake.

Watershed	Month	Waterbody	Date	Dolly Varden Observations (# of fish)						
				Total	Fry	Parr	151-250	251-350	351-450	450+
Buttle Lake	June	Phillips Creek	5-Jun-2018	3	0	0	1	2	0	0
		Ralph River	4-Jun-2018	5	0	0	1	4	0	0
		Thelwood Creek	7-Jun-2018	8	0	0	1	7	0	0
		Wolf River	5-Jun-2018	29	0	0	6	22	1	0
Upper Campbell	June	Lower Elk River	6-Jun-2018	2	0	0	2	0	0	0

[1] Fry = <80 mm fork length, Parr = 81-150 mm fork length, All others are categorized as mm fork length

"n/a" reflects no sampling for redds since sampling occurred outside of spawning period

3.3.3. Comparison with Historic Data

3.3.3.1. Overview

Snorkel surveys targeting the Rainbow Trout spawning period have been undertaken to enumerate adult spawning fish in the six tributaries of Buttle Lake and Upper Campbell Reservoir since 1990. In recent years, prior to 2014, these surveys were completed by BCCF with funding from BC Hydro (Pellett 2013). The frequency of snorkel surveys has not been consistent from year to year for several of the tributaries. The size limit used to define "adult" fish during historic surveys is not known, with the exception of Fry Creek (fork length > 100 mm). Fish count data for the six tributaries that are part of this monitoring program (data for the survey reaches in the upper and lower Elk River are presented separately) are presented in Table 27; of the three species enumerated, counts have historically been highest for Rainbow Trout, which was also true for the June 2018 surveys.

Regular annual snorkel surveys have not been undertaken in the three sampled tributaries of Lower Campbell Reservoir, and no historical data are available for Miller Creek (Strathcona Dam tailrace); however, surveys were undertaken in Fry Creek in 2003 and 2004 and were re-commenced as part of the JHTMON-3 monitoring program in 2014 (Pellett 2013). These historic data are derived from surveys undertaken across a range of months and are thus presented separately in Table 28; note that only one fish has been recorded since 2014.

Table 27. Summary of adult fish count data in six tributaries of Upper Campbell Reservoir and Buttle Lake that were surveyed (1990–2018). Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

Watershed[1]	Waterbody	Species[2]	Year																												
			1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013		2014	2015	2016	2017	2018
Upper Campbell[3]	Upper Elk	RB	n/a	436	1,475	487	960	542	370	n/a	n/a	n/a	n/a	428	168	337	728	n/a	1,586	1,066	1,562	1,847	1,445	n/a	716	551	877	1,147	764	900	1304	1164
		CT	n/a	8	7	0	19	11	1	n/a	n/a	n/a	n/a	3	2	0	5	n/a	4	0	2	5	10	n/a	11	10	8	2	3	2	21	13
		DV	n/a	0	5	0	0	2	n/a	n/a	n/a	1	n/a	6	0	0	0	n/a	6	1	1	1	2	n/a	1	0	1	1	1	0	0	0
	Lower Elk	RB	823	1,134	1,087	1,194	1,411	773	1,044	n/a	n/a	n/a	n/a	1,089	1,184	1,259	1,784	n/a	5,340	4,862	5,630	2,501	3,919	n/a	3,980	1,537	1,204	1,742	886	2104	2774	2541
		CT	7	16	11	1	26	2	8	n/a	n/a	n/a	n/a	3	2	1	3	n/a	3	3	11	4	20	n/a	5	5	7	2	4	6	11	19
		DV	0	0	4	0	13	0	n/a	n/a	n/a	0	n/a	6	2	1	2	n/a	9	2	0	2	1	n/a	0	1	0	0	1	2	0	2
Buttle	Ralph	RB	n/a	300	1,300	965	2,100	n/a	n/a	n/a	2,620	n/a	1,175	420	724	532	910	n/a	650	690	1,103	1,181	708	n/a	479	536		835	407	419	421	647
		CT	n/a	0	0	4	0	n/a	n/a	n/a	2	n/a	2	0	0	2	10	n/a	2	0	2	0	0	n/a	1	2		1	0	3	8	5
		DV	n/a	10	10	4	4	n/a	n/a	n/a	30	n/a	8	0	3	0	17	n/a	4	56	0	9	4	n/a	0	13		4	1	3	4	5
	Thelwood	RB	n/a	1,000	2,500	3,220	3,975	n/a	2,300	n/a	n/a	4,915	2,840	2,501	3,374	3,032	2,590	n/a	3,105	3,921	4,408	4,128	4,892	1,123	3,748	4,104		2,567	800	1110	1633	1571
		CT	n/a	200	15	88	347	n/a	53	n/a	n/a	141	53	441	34	64	20	n/a	25	10	12	4	17	32	26	15		0	11	11	14	28
		DV	n/a	225	1	0	30	n/a	2	n/a	n/a	28	0	0	8	3	6	n/a	24	6	4	9	5	2	0	0		0	7	8	3	8
	Wolf	RB	n/a	n/a	n/a	n/a	n/a	800	n/a	n/a	n/a	450	n/a	361	228	170	576	335	n/a	n/a	1,250	1,210	1,590	140	192	666		384	410	345	327	625
		CT	n/a	n/a	n/a	n/a	n/a	2	n/a	n/a	n/a	1	n/a	3	0	0	0	0	n/a	n/a	6	1	0	0	2	3		3	0	10	26	12
		DV	n/a	n/a	n/a	n/a	n/a	30	n/a	n/a	n/a	12	n/a	4	0	30	41	23	n/a	n/a	25	90	90	30	5	18		30	25	5	51	29
	Phillips	RB	n/a	n/a	750	n/a	n/a	800	n/a	n/a	n/a	500	148	132	111	65	109	94	n/a	n/a	162	624	540	106	145	191		223	157	153	79	93
		CT	n/a	n/a	0	n/a	n/a	6	n/a	n/a	n/a	2	0	6	0	5	1	0	n/a	n/a	1	0	0	0	2	0		2	0	0	1	2
		DV	n/a	n/a	20	n/a	n/a	50	n/a	n/a	n/a	10	1	16	1	5	0	11	n/a	n/a	3	4	40	21	3	8		18	0	0	0	3
	Henshaw	RB	n/a	98	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	4	24	7	78	n/a	5	42	24	93	27	n/a	8	37		26	29	44	17	26
		CT	n/a	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	0	n/a	0	0	1	0	0	n/a	0	0		0	0	0	3	1
		DV	n/a	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0	0	0	2	n/a	0	0	0	0	0	n/a	0	0		0	0	0	0	0

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[1] Historical data for Fry Creek (Lower Campbell Reservoir) are presented separately.

[2] RB - Rainbow Trout, CT - Cutthroat Trout, and DV - Dolly Varden.

[3] Elk River reaches were sampled on June 11 and June 12, 2013. Both values are presented.

"n/a" indicate that surveys were not undertaken.

Table 28. Historic adult fish count data for Fry Creek, from survey dates 2003, 2004, 2014, 2015, 2016, 2017 and 2018. Data collected in 2003 and 2004 were provided by BCCF (Pellett 2013).

Waterbody	Year	Month	Fish Count[1,2]		
			RB	CT	DV
Fry Creek	2003	February	0	18	0
		March	0	287	0
		April	0	9	0
		May	48	573	1
		June	20	3	0
		October	0	140	0
	2004	February	0	15	0
		April	0	3	0
		May	0	185	14
	2014	June	0	0	0
	2015	June	1	0	0
	2016	March	0	0	0
	2017	March	0	0	0
	2018	March	0	0	0

[1] Fish counts for 2003 and 2004 include fish ≥ 100 mm and fish counts from 2014 onwards include fish ≥ 150 mm

[2] RB - Rainbow Trout, CT - Cutthroat Trout, and DV - Dolly Varden

3.3.3.2. Cutthroat Trout

The data presented here for June 2018 are from Rainbow Trout spawning surveys, so any trends in Cutthroat Trout should be interpreted cautiously. Adult Cutthroat Trout counts in 2018 (ranging from 1 to 13 fish) are generally consistent with historic observations for the period 1990 to 2016 (Table 27). Noteworthy are Thelwood Creek, where an order of magnitude decrease was recorded in 2002, and counts have remained low since, Lower Elk River where there is an increasing trend in the number of Cutthroat Trout since 2014, and Wolf River where over 10 fish have been observed for the past 3 years (maximum observed prior to 2016: 6 fish, mean observed prior to 2016: 1.5 fish).

In Fry Creek, comparable survey data for March are only available in 2003 when 287 Cutthroat Trout were observed, and in 2016 and 2017 when no fish were observed (Table 28). However, as mentioned in Section 3.3.2.1, surveys were likely conducted following 2018 Cutthroat Trout spawning which means that the 2018 counts are not an accurate measure of the spawner abundances in Fry Creek.

3.3.3.3. Rainbow Trout

There is high variability in adult Rainbow Trout counts among years for individual tributaries, and no clear trends in any of the tributaries (Table 27, Figure 28 to Figure 34). Counts of Rainbow Trout were close to the 75th percentile in three of the streams surveyed: Upper Elk River, Lower Elk River, and Wolf River (Figure 28 to Figure 30), at or close to the 50th percentile in two streams: Ralph River and Henshaw Creek (Figure 31 and Figure 32), and below the 25th percentile in the remaining two streams: Thelwood Creek and Phillips Creek (Figure 33 and Figure 34). No adult Rainbow Trout were recorded in Fry Creek in March 2018; however, this was comparable to sampling results from March in previous years (Table 28).

Figure 28. Adult Rainbow Trout counts on Upper Elk River (1990-2018). No surveys were completed in 1990, 1997, 1998, 1999, 2000, 2005, and 2011. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

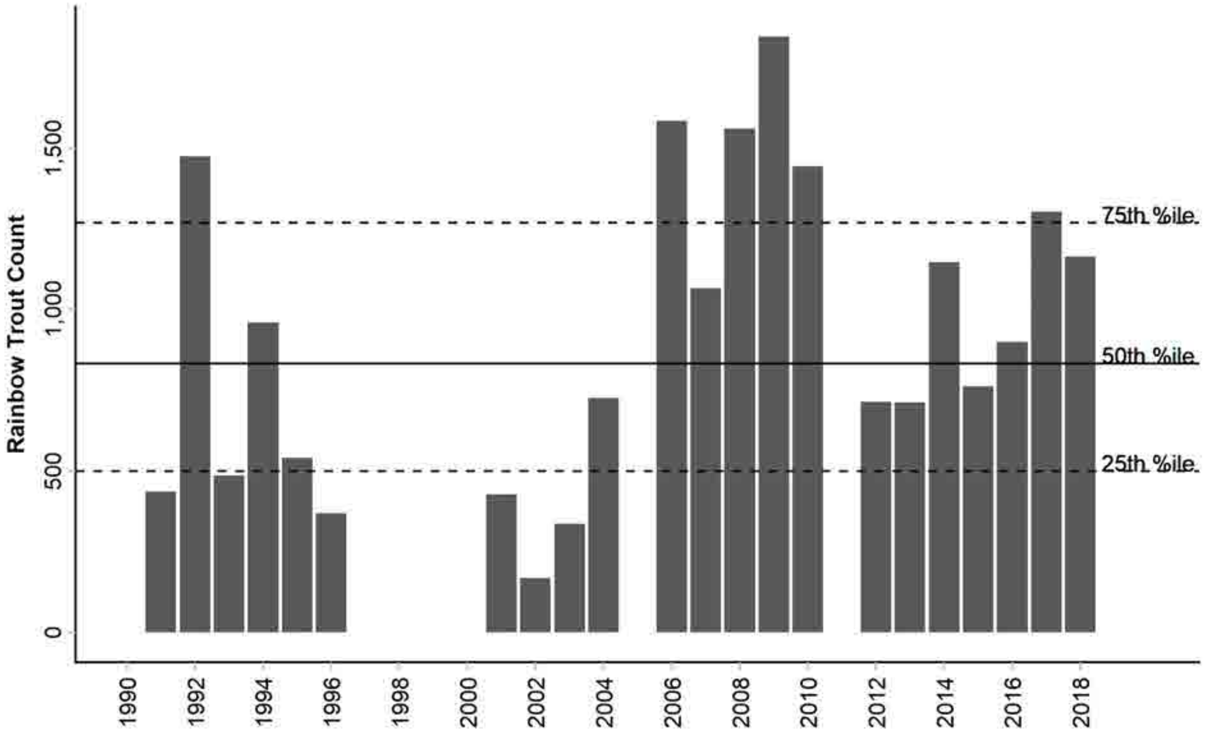


Figure 29. Adult Rainbow Trout counts on Lower Elk River (1990-2018). No surveys were completed in 1997, 1998, 1999, 2000, 2005, and 2011. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

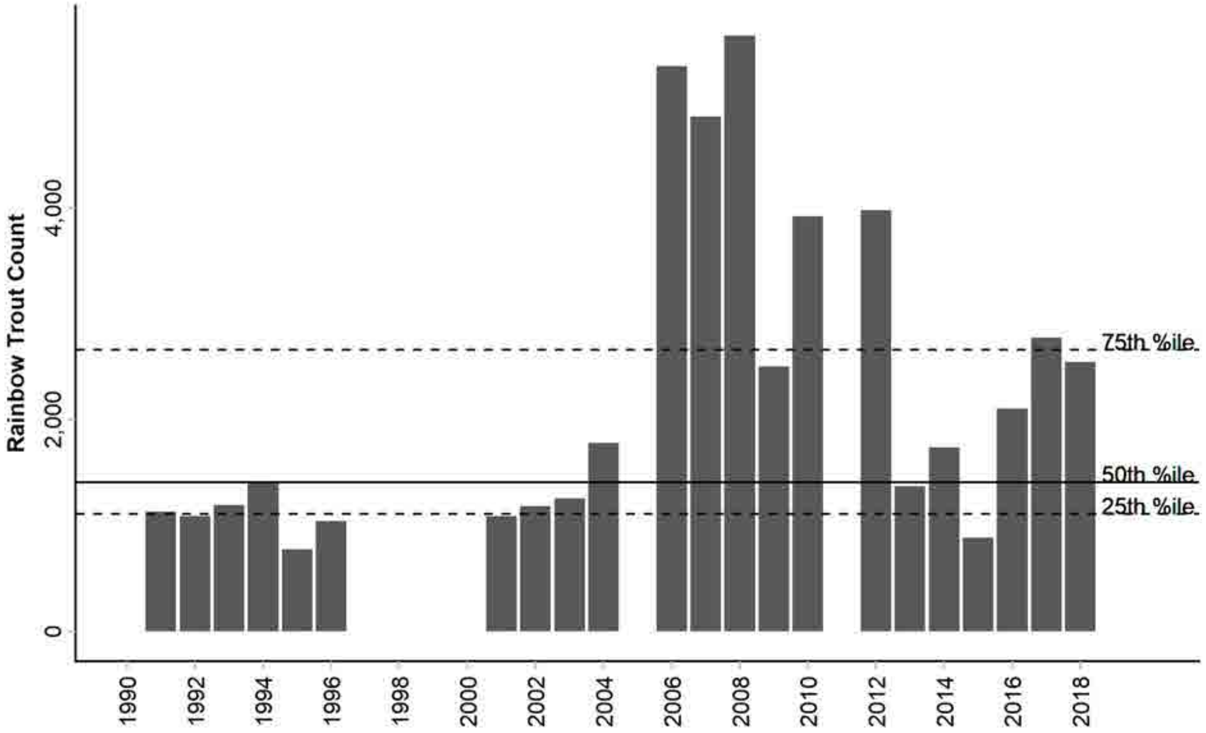


Figure 30. Adult Rainbow Trout counts in Wolf River (1990-2018). No surveys were completed in 1990-1994, 1996-1998, 2000, and 2006-2007. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

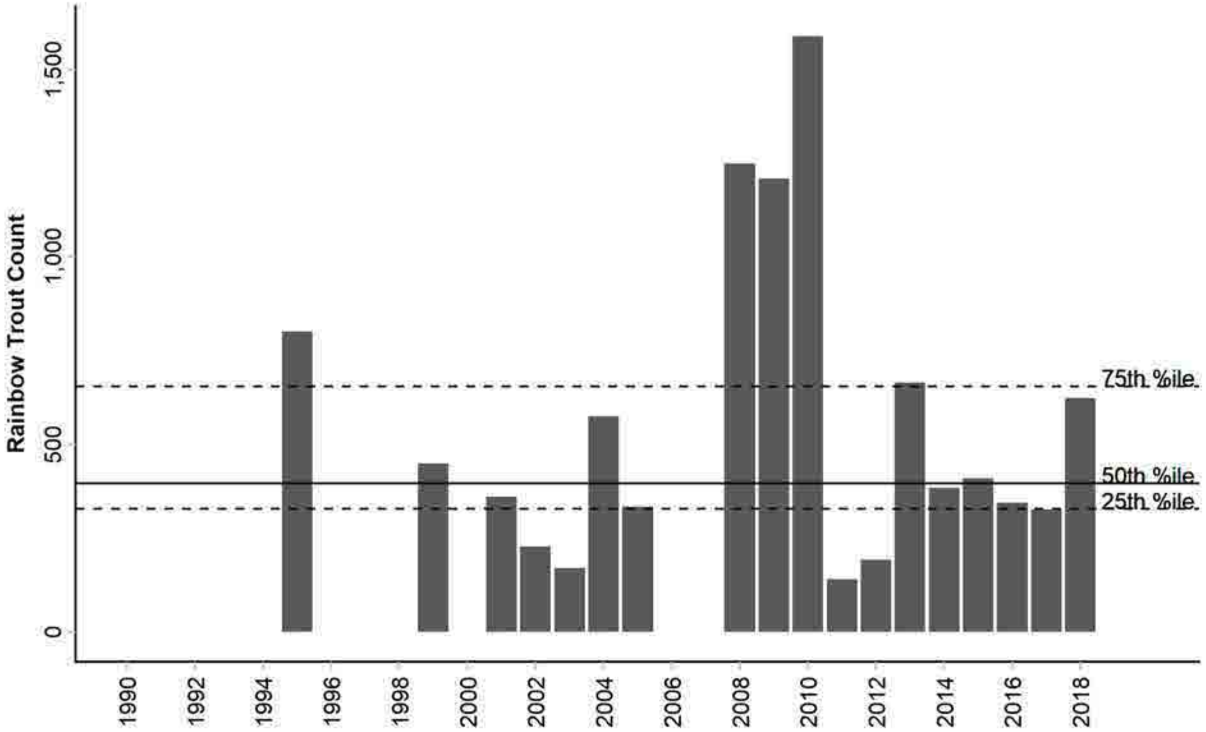


Figure 31. Adult Rainbow Trout counts in Ralph River (1990-2018). No surveys were completed in 1990, 1995-1997, 1999, 2005, and 2011. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

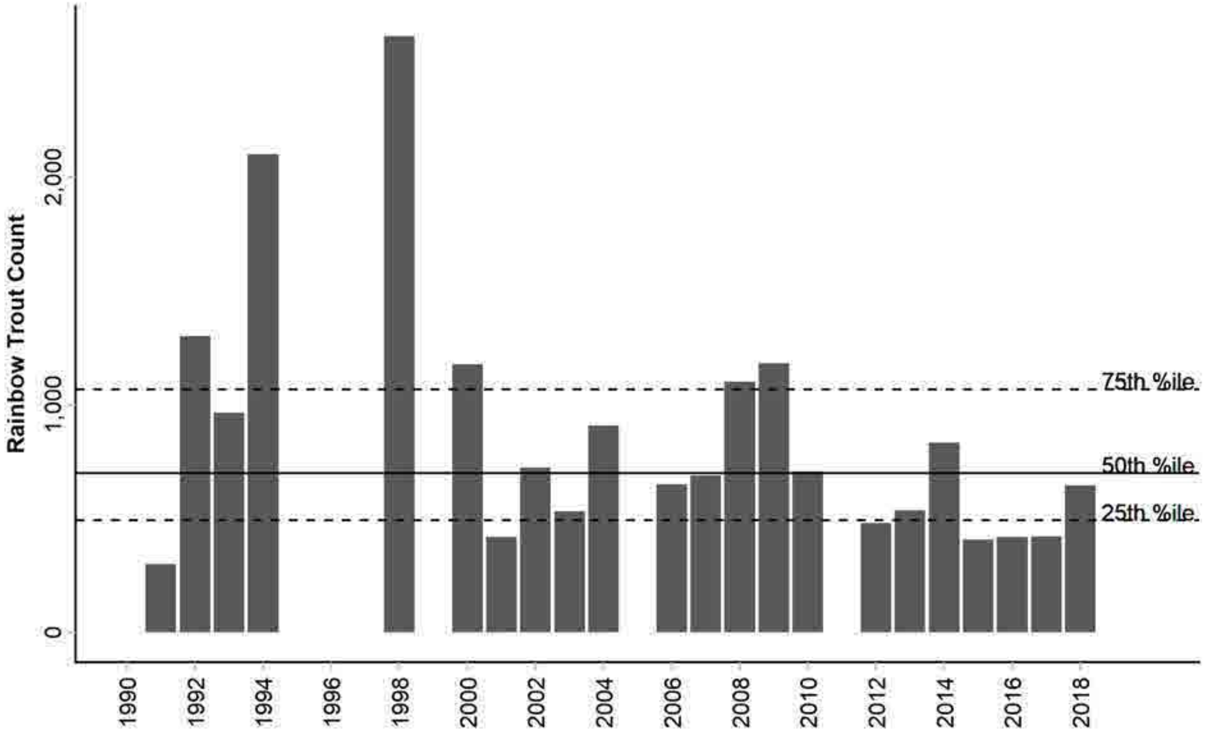


Figure 32. Adult Rainbow Trout counts in Henshaw Creek (1990-2018). No surveys were completed in 1990, 1992-2000, 2005, and 2011. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

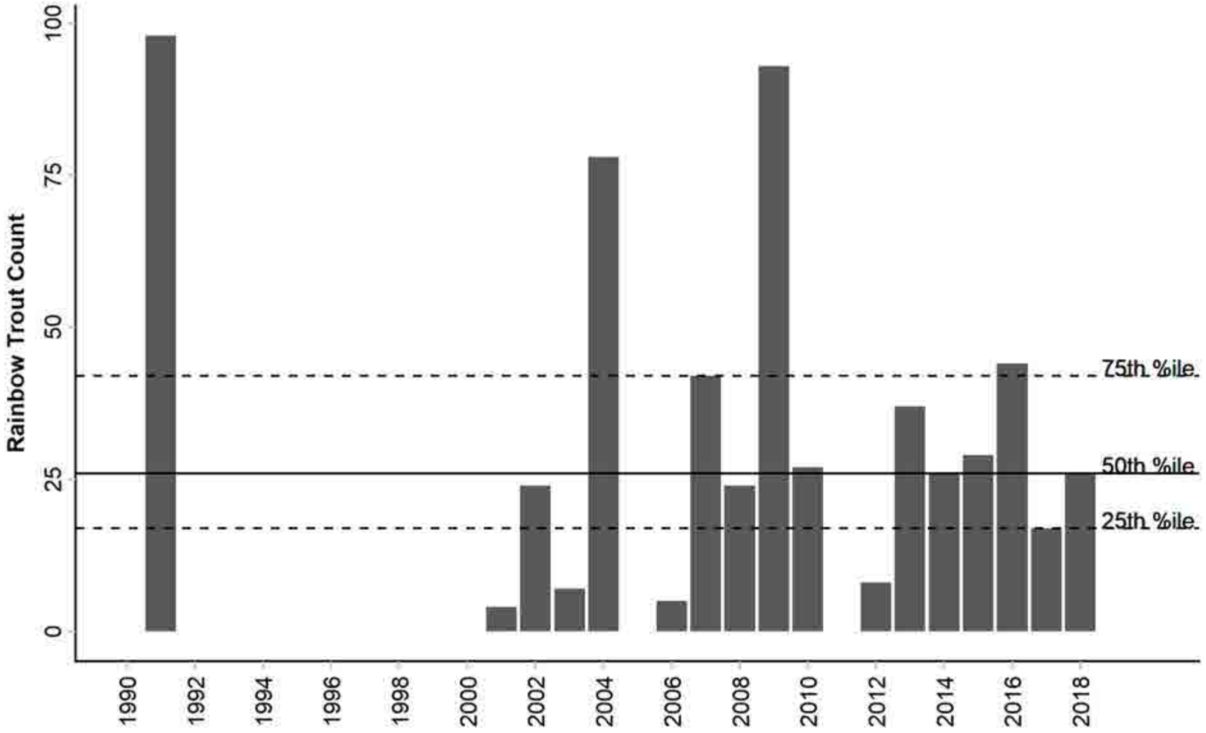


Figure 33. Adult Rainbow Trout counts in Thelwood Creek (1990-2018). No surveys were completed in 1990, 1995, 1997, 1998, and 2005. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).

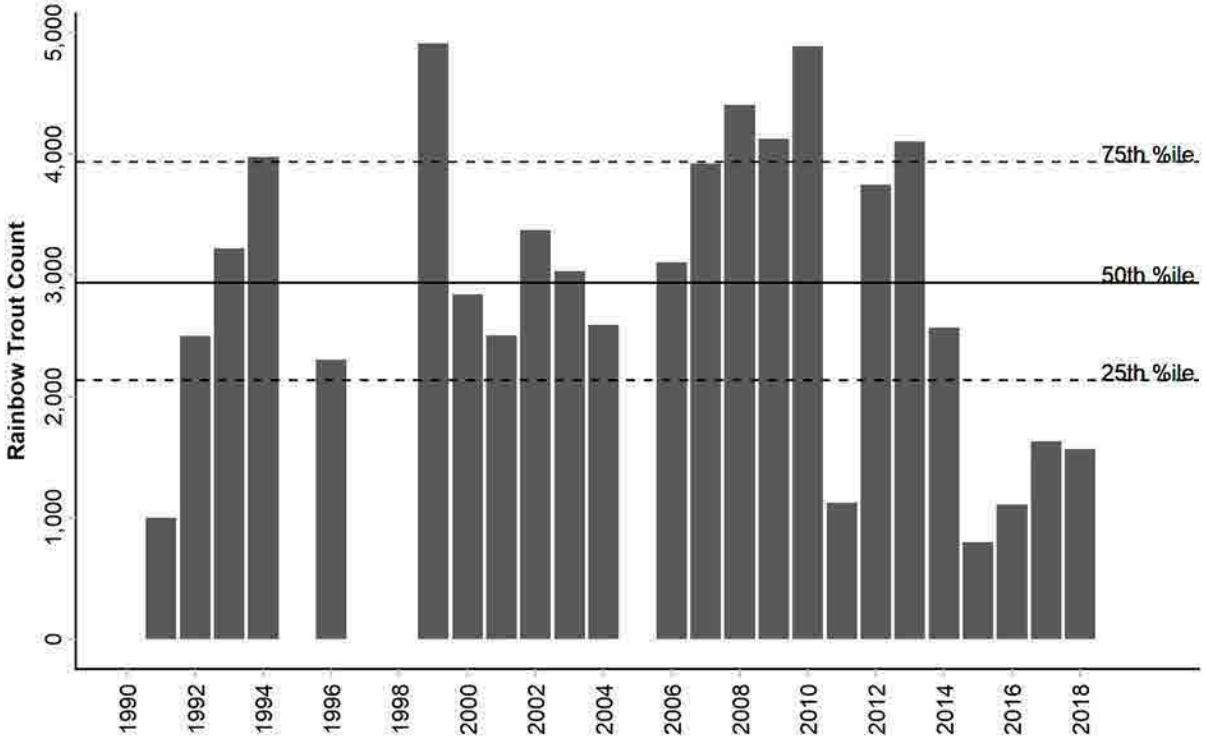
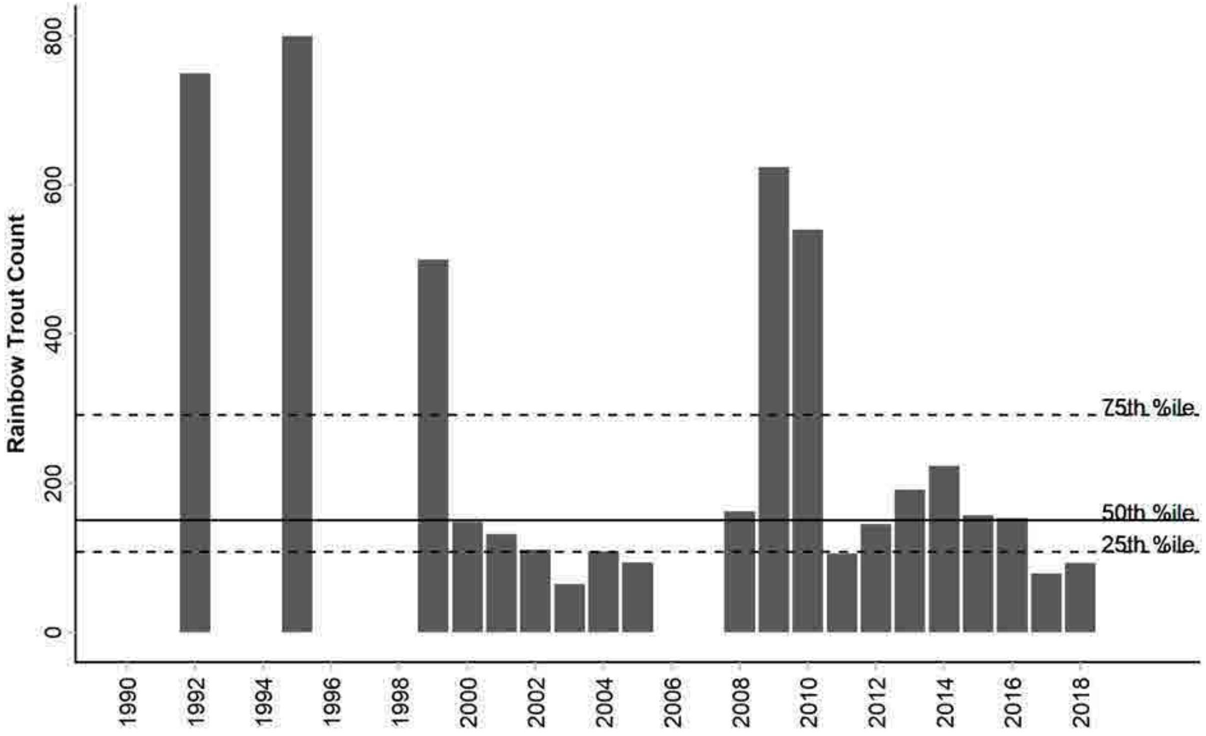


Figure 34. **Adult Rainbow Trout counts in Phillips Creek (1990-2018). No surveys were completed in 1990-1991, 1993-1994, 1996-1998, and 2006-2007. Historic data (prior to 2014) were provided by BCCF (Pellett 2013).**



3.3.3.4. Dolly Varden

The data presented here are from surveys completed during the month of June which targeted Rainbow Trout spawning, so trends in Dolly Varden should be interpreted cautiously as Dolly Varden are fall spawners. The 2018 adult Dolly Varden counts were generally low (range = 0 to 29), similar to the results of the surveys carried out since 2014, and broadly comparable with historic surveys (Table 27). Of the seven survey reaches in Buttle Lake and Upper Campbell Reservoir, the 2017 adult Dolly Varden counts were in line with the median values for the majority of tributaries (Table 27), but was substantially below the historical median value for Phillips Creek (2018, *n* = 3; historical range = 0 to 50; median = 9). No adult Dolly Varden were counted in Fry Creek in 2018, consistent with the previous surveys conducted in the month of March (Table 28).

3.4. Spawning Habitat Availability

3.4.1. Habitat Surveys

Spawning habitat availability was summarized for tributary areas within the drawdown zone and upstream of the drawdown zone for each major waterbody (Lower Campbell, Upper Campbell, and

Buttle Lake). Spawning habitat availability summaries were also generated individually for each tributary. Although Buttle Lake and the Upper Campbell Reservoir are effectively one reservoir, habitat availability summaries are separated for each of these waterbodies for ease of interpretation. Redd counts within each area were provided as an additional spawning habitat metric, but their results are described in further detail in Section 3.5. Spawning habitat availability and use summaries were not species specific, but instead were designed to be generalizable across target fish species (i.e., Cutthroat Trout, Rainbow Trout and Dolly Varden). Overall, we identified a larger portion (approximately 77% across metrics) of available spawning habitat upstream of the drawdown zones relative to areas within the drawdown zones (Table 29). However, for all three tributaries within Buttle Lake, a larger portion of available spawning habitat was located within the drawdown zones. Overall differences between spawning habitat availability in the drawdown zones and upstream areas were generally consistent across each of the different metrics (Table 29). From the Spawning Potential metric, the largest portion of spawning habitat classified as 'High' and 'Medium' was located within the mainstem of the Elk River.

Table 29. Generalized spawning habitat availability summaries for all tributaries within the Upper and Lower Campbell Reservoirs and Buttle Lake.

Reservoir	Zone	Linear Distance (m)	Wetted Area (m^2)	Channel Width (m)	Bankfull Area (m^2)	Spawning Potential (m)			Redd Count (n)[3]
						Low	Medium	High	
Upper Campbell	Upstream	18,404	378,282	16.8	813,244	3,592	7,141	5,568	6,794
Upper Campbell	Drawdown	3,798	85,018	40.1	152,300	-	-	-	50
Buttle Lake	Upstream	1,226	16,084	20.9	22,297	264	505	415	453
Buttle Lake	Drawdown	2,134	65,424	49.3	106,831	-	-	-	1,605
Lower Campbell	Upstream	5,008	31,891	9.3	46,601	1,845	2,042	997	742
Lower Campbell	Drawdown	1,042	11,583	14.1	13,172	-	-	-	199
Total	Upstream	24,638	426,257	15.7	882,142	5,701	9,688	6,980	7,989
	Drawdown	6,974	162,025	34.5	272,303	-	-	-	1,854

[1] Direct measurements from UAV aerial imagery.

[2] Estimated channel widths, wetted area and spawning potential based on field surveys.

[3] Redd counts (2017+2018) considering total redds upstream across all tributaries

3.4.2. Lower Campbell Reservoir

Linear distance, bankfull area and redd counts were greatest above the drawdown zone for the three tributaries surveyed on the Lower Campbell Reservoir, Miller Creek, Greenstone Creek, and Fry Creek (Table 30). Fry Creek was the only tributary within the Lower Campbell Reservoir that could be surveyed entirely with the UAV. Spawning habitat upstream of the drawdown zones for Greenstone Creek and Miller Creek consisted of narrower streams; however, the extended length of these streams provided a large area of available spawning habitat. Upstream sections of Greenstone Creek had the largest quantity of spawning habitat followed by Fry Creek and then Miller Creek (Table 30).

Qualitative Spawning Potential delineations suggested that Fry Creek had the largest portion of 'low' quality spawning habitat in upstream areas, whereas upstream sections of Miller Creek and Greenstone Creek consisted mostly of 'Medium' or 'High' quality spawning habitat.

3.4.2.1. Tributaries of the Lower Campbell Reservoir

Surveys of Fry Creek were completed up to the south end of Gray Lake prior to reaching any impassable or obstructions barriers. This potentially underestimated the full extent of upstream spawning habitat in Fry Creek. The drawdown zone of Fry Creek was characterized by a poorly defined shallow channel and large quantity of fines covering the substrate. There was only a small section of the drawdown zone characterized as having moderately suitable spawning habitat, whereas all other sections would likely have insufficient flow and heavy deposition of fines. Suitable spawning habitat in upstream sections of Fry Creek was limited to locations immediately downstream of lake outflows. Some of these areas have been modified by habitat enhancement projects (e.g., spawning habitat enhancement near the outlet of Brewster Lake; Pellet 2012).

Upstream sections of Greenstone Creek had the largest quantity of high-quality spawning habitat, but proportional to its length, most sections of Greenstone Creek consisted of low or medium quality habitat. Field surveys of Greenstone Creek were also concluded prior to reaching impassable barriers/obstructions, suggesting that additional spawning habitat may be present further upstream beyond the field survey endpoint. The drawdown section of Greenstone Creek was small and truncated by a poorly defined channel and large alluvial fan.

Miller Creek had the most clearly defined channel within the drawdown zone and lake confluence. This defined channel was expected to contribute to higher quality spawning habitat; however, lower sections of the Miller Creek drawdown zone had considerably more fines covering the substrate.

Table 30. Generalized spawning habitat availability summaries for tributaries of the Lower Campbell Reservoir.

Tributary	Zone	Linear Distance (m)	Wetted Area (m^2)	Channel Width (m)	Bankfull Area (m^2)	Spawning Potential (m)			Redd Count $(n)^3$
						Low	Medium	High	
Fry Creek	Upstream[1]	1,307	13,286	12.8	16,730	721	372	197	473
Fry Creek	Drawdown	218	4,017	18.7	4,077	-	-	-	9
Greenstone Creek	Upstream[1]	17	242	7.6	129	0	20	0	2
Greenstone Creek	Upstream[2]	2,886	15,242	7.9	22,799	1,024	1,300	500	76
Greenstone Creek	Drawdown	269	2,639	13.8	3,712	-	-	-	9
Miller Creek	Upstream[2]	798	3,121	8.7	6,943	100	350	300	191
Miller Creek	Drawdown	555	4,927	9.7	5,384	-	-	-	181

[1] Direct measurements from UAV aerial imagery.

[2] Estimated channel widths, wetted area and spawning potential based on field surveys.

[3] Redd counts (2017+ 2018)

3.4.3. Upper Campbell Reservoir

The mainstem of the Elk River contained the largest overall quantity of spawning habitat for target fish species across all waterbodies and all spawning habitat indicators evaluated. The drawdown zone of the Elk River also contained a large portion of potentially suitable spawning habitat, roughly equivalent to combined tributaries of the Elk River (Table 31). Upstream sections of the Elk River and Elk River tributaries collectively had the largest amount of 'High' and 'Medium' quality habitat identified from the Spawning Potential metric (Figure 36).

Of all five tributaries of the Elk River, Cervus Creek and Filberg Creek were characterized as having the largest amount of 'High' quality habitat identified from the Spawning Potential metric (Table 31, Figure 36). Drum Creek, Tlools Creek, and Isardi Creek all had relatively similar quantities of accessible spawning habitat (Table 31), but these areas were characterized as being of lower quality based on gravel availability and other habitat attributes (Figure 36).

Table 31. Spawning habitat availability summaries, and number of redds observed in tributaries of the Elk River (Upper Campbell Reservoir).

Tributary	Zone	Linear Distance (m)	Wetted Area (m^2)	Channel Width (m)	Bankfull Area (m^2)	Spawning Potential (m)			Redd Count (n)[3]
						Low	Medium	High	
Drum Creek	Upstream[1]	649	6,147	14.1	9,151	290	277	45	205
Drum Creek	Upstream[2]	382	2,461	15.0	5,730	112	236	0	94
Isardi Creek	Upstream[1]	432	3,194	11.9	5,141	328	130	10	13
Isardi Creek	Upstream[2]	34	95	15.0	510	17	8	0	0
Cervus Creek	Upstream[1]	615	6,955	13.7	8,426	85	64	301	646
Filberg Creek	Upstream[2]	844	5,064	8.0	6,752	85	300	400	2
Tlools Creek	Upstream[1]	446	3,883	11.5	5,129	288	147	19	26
Tlools Creek	Upstream[2]	761	3,793	8.2	6,240	209	478	50	74
Elk River Mainstem	Upstream[1]	14,241	346,690	53.8	766,166	2,178	5,501	4,743	5,734
Elk River	Drawdown	3,798	85,018	40.1	152,300	-	-	-	50

[1] Direct measurements from UAV aerial imagery.

[2] Estimated channel widths, wetted area and spawning potential based on field surveys.

[3] Redd counts (2017+ 2018)

3.4.4. Buttle Lake Tributaries (Upper Campbell Reservoir)

In contrast to the Elk River and tributaries within the Lower Campbell Reservoir, Wolf Creek and Phillips Creek (and to some degree Ralph River) had a larger portion of spawning habitat available in the drawdown zones relative to upstream areas (Table 32). This trend was consistent across all spawning habitat metrics evaluated (including linear and area-based summaries). The relative quantity of spawning habitat availability in the drawdown zone of Ralph River was variable depending on which spawning habitat indicator was considered (Table 32). The Ralph River had a larger portion of spawning habitat located in the drawdown zones relative to upstream area, according to spawning bankfull area and median channel width, but not linear distance (Table 32).

The larger portions of spawning habitat located in the drawdown zones relative to upstream areas in Buttle Lake tributaries were partially the result of barriers/obstructions to fish passage located only a short distance upstream from the lake. Drawdown zones of Buttle Lake tributaries also had deep clearly defined channel, with large quantities of spawning gravel/cobble, free of fine sediments.

3.4.4.1. Tributaries of Buttle Lake

Wolf Creek had no upstream reaches and was characterized as being entirely within the drawdown zone of Buttle Lake. The upstream extent of spawning habitat is limited by falls/cascades immediately upstream from the drawdown zone. The majority of the drawdown reach of Wolf Creek was characterized as having high quality spawning habitat anecdotally from field observations.

Phillips Creek was characterized by 'High' to 'Medium' quality spawning habitat throughout from the Spawning Potential metric and anecdotally from field observations (Table 32). Upstream reaches of Phillips Creek were truncated due to a steep gradient barrier (15% - 20%) preventing fish access to additional spawning further upstream beyond the drawdown zone.

Similar to Wolf Creek and Phillips Creek, Ralph River also had an extended drawdown followed by barriers located only a short distance upstream above the drawdown zone. The mainstem of Ralph River forks into Sheppard Creek upstream from the drawdown zone. Accessible spawning habitat in Sheppard Creek is limited by a bedrock canyon and the mainstem of the Ralph River was limited by a boulder cascade gradient barrier (~ 20%).

Table 32. Spawning habitat availability summaries for Buttle Lake tributaries (Upper Campbell Reservoir).

Tributary	Zone	Linear Distance (m)	Wetted Area (m^2)	Channel Width (m)	Bankfull Area (m^2)	Spawning Potential (m)			Redd Count (n)[3]
						Low	Medium	High	
Wolf Creek	Drawdown	950	37,571	56.6	53,770	-	-	-	1,249
Phillips Creek	Upstream[1]	157	2,640	21.4	3,360	73	77	7	11
Phillips Creek	Drawdown	638	12,628	34.9	22,266	-	-	-	175
Ralph Creek	Upstream[1]	295	7,380	27.2	8,024	127	94	75	331
Ralph Creek	Upstream[2]	774	6,064	14.1	10,913	64	334	333	111
Ralph Creek	Drawdown	546	15,225	56.4	30,794	-	-	-	181

[1] Direct measurements from UAV aerial imagery.

[2] Estimated channel widths, wetted area and spawning potential based on field surveys.

[3] Redd counts (2017+ 2018)

3.4.5. Habitat Availability in the Drawdown Zones During the Spawning Period

Reservoirs levels were lower in both waterbodies in the 2018 spawning period than they were in the 2017 (Table 33). The difference between 2017 and 2018 was larger for the Upper Campbell reservoir (2.35 m) than for the Lower Campbell reservoir (0.18 m).

For the Upper Campbell, the higher reservoir levels during the 2017 spawning period resulted in a larger portion of the drawdown zone being inundated and therefore a smaller portion of spawning channels remaining above the water line (Table 34, Figure 36). In 2018, the lower reservoir levels during the spawning period provided a larger amount of spawning habitat channels in the drawdown zones that were free from the lake backwatering effect (Table 34). The same trends were observed for the Lower Campbell reservoir; however, the magnitude of these trends was reduced as a result of the water level differences between years being small (0.18 m).

The microtopography and gradient of the spawning channels in the drawdown zones resulted in large differences between tributaries in each reservoir. For example, the Ralph River drawdown zone had over five times as much spawning habitat free of the lake backwatering in 2018 than it did in 2017, while this ratio was closer to four to one for Phillips Creek (Table 34, Figure 37). Additionally, for the Upper Campbell reservoir a water level of 217.16 m resulted in approximately 20% of the Elk and Ralph River drawdown zones becoming inundated but this water level inundated 63% of the spawning channels in the Phillips Creek drawdown zone (Table 34, Figure 35, Figure 37). The drawdown zone channel of Wolf Creek is situated at the base of a falls. The low elevation and shallow gradient of this channel suggests that it is permanently backwatered; however, the steep confined banks and large discharge of Wolf Creek is believed to minimize the lake backwatering effect.

Table 33. Reservoir level in the Upper and Lower Campbell reservoirs during the 2017 and 2018 spawning period.

Reservoir	Spawning Period[1]	Reservoir Level (m)[2]					
		2017			2018		
		Median	Min	Max	Median	Min	Max
Lower Campbell	Feb 1 – March 24	177.57	177.11	177.67	177.38	176.89	177.61
Upper Campbell[3]	May 25 – July 31	219.50	218.30	219.76	217.16	216.81	217.47

[1] Spawning periods defined from the fish periodicity used in the BC Hydro Water Use Plan.

[2] Daily water level during the spawning period recorded from BC Hydro and Water Survey Canada gauging stations.

[3] Buttle Lake included within Upper Campbell as a single connected waterbody.

Table 34. Habitat availability in the drawdown zone during the 2017 and 2018 spawning periods.

Reservoir	Tributary	Total Channel Area Available In the Drawdown Zones (m^2) [1]	Channel Area Inundated (m^2)[2]		Percentage of Channel Above the	
			2017	2018	2017	2018
Lower Campbell	Fry Creek[4]	4,017	-	-	-	-
	Greenstone Creek	2,639	2,049	1,835	22%	30%
	Miller Creek	4,927	4,606	4,493	7%	9%
Upper Campbell	Elk River	85,018	72,008	14,686	15%	83%
Buttle Lake	Wolf Creek[5]	37,571	37,571	37,571	0%	0%
	Phillips Creek	12,628	11,597	7,936	8%	37%
	Ralph Creek	15,225	13,042	2,429	14%	84%

[1] Total available drawdown zone spawning habitat defined as the area of the defined channel between the upper and lower limits of the drawdown zone.

[2] Quantity of the defined channel in the drawdown zone inundated during the spawning period based on the reservoir level.

[3] Percentage of the channel in drawdown zones remaining above the reservoir water line.

[4] LiDAR elevation data coverage incomplete for the drawdown zone of Fry Creek.

[5] Drawdown zone section of Wolf Creek experiences persistent backwatering due to its lower elevation below falls.

Figure 35. **Inundated spawning habitat in the Lower Campbell Reservoir drawdown zones during the 2017 and 2018 spawning periods. Stream channels inundated by the reservoir are shaded pink and sections above the reservoir elevation are shaded blue.**

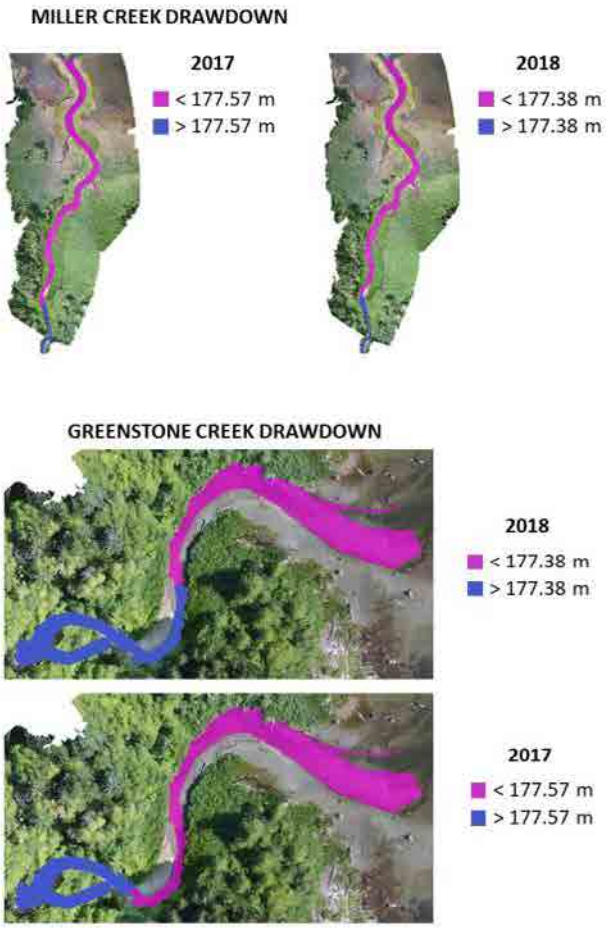


Figure 36. Inundated spawning habitat in the Upper Campbell Reservoir drawdown zones during the 2017 and 2018 spawning periods. Stream channels inundated by the reservoir are shaded pink and sections above the reservoir elevation are shaded blue.

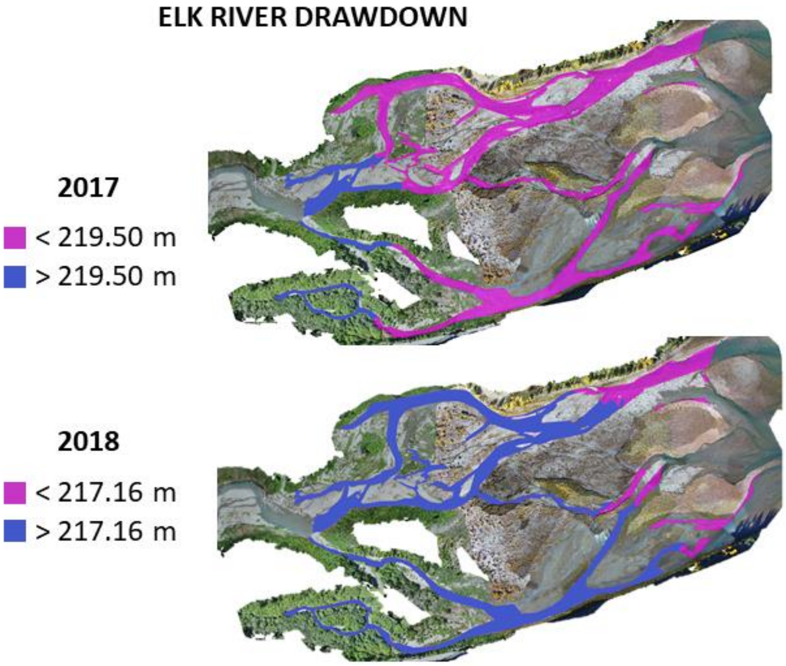
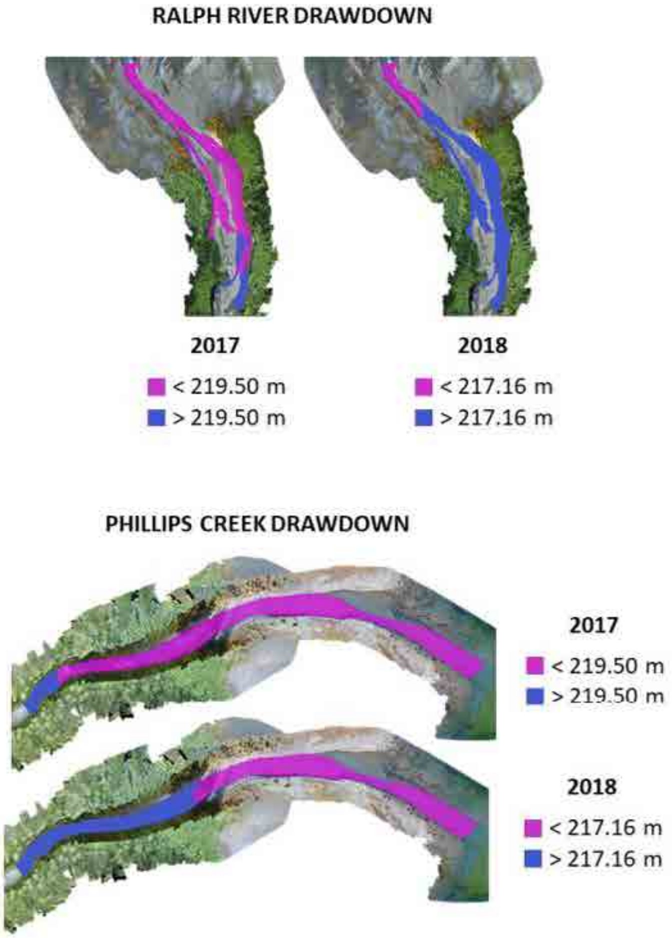


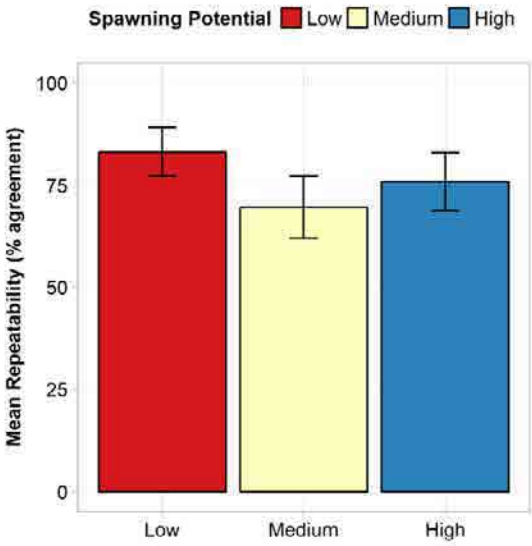
Figure 37. **Inundated spawning habitat in the Buttle Lake drawdown zones during the 2017 and 2018 spawning periods. Stream channels inundated by the reservoir are shaded pink and sections above the reservoir elevation are shaded blue.**



3.4.6. Repeatability of Spawning Potential Classifications

Repeatability of qualitative Spawning Potential delineations ranged from 69% to 83% per category across stream reaches (*n* = 38, Figure 38) between fisheries biologists (Section 2.4). Differences in Spawning Potential classification between individuals were mainly due to uncertainties in classifying reaches as either 'Medium' or 'High' spawning potential. However, even if reaches classified as 'Medium' or 'High' are reclassified into a single group, our overall results and conclusions of spawning habitat potential in the drawdown zones vs upstream areas remain unchanged.

Figure 38. Repeatability of qualitative spawning habitat delineations between two fisheries biologists. Error bars show 95% confidence intervals for percent similarity within each habitat rating class across 100 m long stream reach segments (n = 38).



3.5. Spawning Habitat Use

3.5.1. Redd Survey Summaries

Spawning habitat use was summarized with counts of redds for areas within the drawdown zones and upstream of the drawdown zone for each major reservoir (Lower Campbell, Upper Campbell, and Buttle Lake). The distribution (within and upstream of the drawdown zones) were also summarized for each tributary within each reservoir. Although Buttle Lake and the Upper Campbell Reservoir are effectively one reservoir, habitat use summaries are separated for each of these waterbodies for ease of interpretation.

Results of spawning habitat use were largely consistent with spawning habitat availability (Section 3.4). We identified a higher prevalence of redds in upstream areas relative to areas within the drawdown zones for the Elk River (Upper Campbell Reservoir) and all waterbodies within the Lower Campbell Reservoir (Table 35, Table 36). Tributaries to Buttle Lake had a higher abundance of redds in the drawdown zones relative to upstream areas (Table 35, Table 36). Area-based redd density estimates suggest that the limited overall habitat availability and use within the drawdown zones is likely a result of the smaller relative area of the drawdown zones, rather than the quality of habitat within the drawdown zones (Table 36) . Maps showing the distribution and abundance of redds throughout each waterbody are provided in Appendix H. Overall more redds were recorded in 2018 than in 2017 in both the drawdown zone and upstream of the drawdown zone. Although survey efforts were similar between years, interannual differences in redd abundance could be the result of a combination of external factors such as demographic processes, environmental conditions, and others.

Physical habitat attributes of redds within the drawdown zones were distinct from redds located in upstream areas. The distribution of redds within the drawdown zones was limited to the deep channel (i.e., the channel thalweg when the reservoir is drawn down) in deep (1 - 3 m), slow moving water (Table 35). Conversely, in areas upstream of the drawdown zone, redds were distributed throughout the available spawning habitat in shallow (0.5 – 0.8 m), medium to high velocity runs, glides, and riffles (Table 35). These differences are thought to reflect the relative availability of mesohabitats within the drawdown zones rather than habitat preference. Redds upstream of the drawdown zones were located at the margins of the main channel rather than within the main thalweg (Table 35). These differences are believed to be the result of different physical conditions between the drawdown zone and upstream areas rather than habitat selection by individuals.

Table 35. Redd survey attribute summary table for Buttle Lake and the Upper and Lower Campbell reservoirs.

Reservoir		**Buttle Lake**		**Upper Campbell**		**Lower Campbell**		**All Reservoirs**	
Zone		**Drawdown**	**Upstream**	**Drawdown**	**Upstream**	**Drawdown**	**Upstream**	**Drawdown**	**Upstream**
Redd Count	(n)	1,605	453	50	6,794	199	742	1,854	7,989
Median Depth	(m)	1.1	0.43	0.5	0.45	1.04	0.505	1	0.46
Location	Margin	9%	31%	18%	53%	11%	51%	13%	45%
	Thalweg	91%	69%	82%	47%	89%	49%	87%	55%
Velocity[1]	Low	60%	8%	42%	38%	77%	17%	60%	21%
	Medium	38%	85%	58%	59%	22%	65%	39%	70%
	High	2%	7%	-	4%	1%	18%	-	10%
Habitat[2]	PO	3%	14%	-	4%	1%	4%	-	7%
	RF	3%	20%	-	16%	4%	14%	4%	17%
	RN	67%	66%	72%	79%	9%	32%	49%	59%
	GL	27%	-	-	2%	87%	50%	57%	26%
	ES	-	-	28%	-	-	-	28%	-
Substrate[3] (Dominant)	BO	-	-	-	-	-	-	-	-
	LGCO	-	-	-	-	-	-	-	-
	LGGR	97%	40%	72%	72%	83%	56%	84%	56%
	SMCO	-	-	-	17%	1%	-	1%	17%
	SMGR	3%	59%	28%	11%	17%	44%	16%	38%
Substrate[3] (Subdominant)	BO	-	-	-	-	-	-	-	-
	LGCO	-	-	-	-	-	-	-	-
	LGGR	3%	60%	28%	27%	17%	45%	16%	44%
	SMCO	-	-	-	1%	1%	3%	1%	2%
	SMGR	97%	40%	72%	72%	82%	51%	84%	54%
Portion New[4]		99%	94%	100%	>99%	100%	100%	100%	97%
Redds 2017 (Yr 4)		536	55	-	2,603	95	301	631	2,959
Redds 2018 (Yr 5)		1,069	398	50	4,191	104	441	1,223	5,030

[1] Velocity estimate (0-0.10 m/s Low, 0.10-0.50 m/s Medium, >0.50 High)

[2] Habitat (PO = pool, RF = riffle, RN = run, GL = glide, ES=estuary).

[3] Substrate (BO = boulders LGCO = large cobble, LGGR = large gravel, SMCO = small cobble, SMGR = small gravel)

[4] Portion of observed redds classified as 'new' out of all new and old redds.

Table 36. Redd densities based on available spawning habitat metrics

Reservoir	Tributary	Zone	Redd Densities		
			Linear Distance[1]	Wetted Area[2]	Bankfull Area[3]
Upper Campbell	Elk River Tributaries	Upstream	0.255	0.034	0.023
	Elk River Mainstem	Upstream	0.403	0.017	0.007
	Elk River	Drawdown	0.013	0.001	0.000
Buttle Lake	Wolf Creek	Drawdown	1.315	0.033	0.023
	Phillips Creek	Upstream	0.070	0.004	0.003
	Phillips Creek	Drawdown	0.274	0.014	0.008
	Ralph Creek	Upstream	0.413	0.033	0.023
	Ralph Creek	Drawdown	0.332	0.012	0.006
Lower Campbell	Fry Creek	Upstream	0.362	0.036	0.028
	Fry Creek	Drawdown	0.041	0.002	0.002
	Greenstone Creek	Upstream	0.027	0.005	0.003
	Greenstone Creek	Drawdown	0.283	0.003	0.002
	Miller Creek	Upstream	0.239	0.061	0.028
	Miller Creek	Drawdown	0.326	0.037	0.034

[1] Redd Density = Redd Count (n) / Linear Distance (m)

[2] Redd Density = Redd Count (n) / Wetted Area (m^2)

[3] Redd Density = Redd Count (n) / Bankfull Area (m^2)

3.5.2. Lower Campbell Reservoir

In all three tributaries of the Lower Campbell Reservoir, redd counts were higher in upstream areas relative to areas within the drawdown zone (Table 30). Most redds upstream of the drawdown zones were located at least 200 m upstream beyond the high-water line of the WUP annual maximum operating level (178.3 m; Appendix H). All redds in Fry Creek and Greenstone Creek were vertically distributed above the preferred summer minimum (176.5 m). 252 redds surveyed with the TST in Miller Creek were below the WUP preferred summer minimum water level (Appendix H) but all redds were above the minimum annual operating level of 174.0 m. Despite the high total count of redds in upstream sections, redd densities were still relatively high within the drawdown zones (Table 36).

3.5.3. Upper Campbell Reservoir

The upstream mainstem of the Elk River contained more redds than all other waterbodies combined (*n* = 5,734 Table 31). 50 redds were identified in the drawdown zone section of the Elk River in 2018, but none in 2017. Most redds within upstream sections of the Elk River were found between 3.5 km and 12 km upstream from the drawdown zone (Appendix H). Redd densities based on the total area of available habitat were also much higher for upstream of reaches of the Elk River and its tributaries (Table 36).

3.5.4. Buttle Lake Tributaries (Upper Campbell Reservoir)

In contrast to the Elk River and tributaries within the Lower Campbell Reservoir, Wolf River, and Phillips Creek both had a higher portion of redds located within the drawdown zone relative to areas above the drawdown zones (Table 32, Table 35, Table 36). Redds upstream of the drawdown zone in Buttle Lake were located less than 200 m (Phillips Creek) to 600 m (Ralph Creek) upstream from the high water line of the WUP annual maximum operating level (220.5 m). Redds within Ralph River, surveyed with the TST, were all vertically distributed above the WUP preferred summer minimum operating level (217 m). Most redds surveyed in Wolf Creek and Phillips Creek were below the preferred summer minimum operating level (Appendix H).

3.5.5. Redd Elevation Differences Between 2017 and 2018

Relatively consistent patterns were identified for the lateral distribution (upstream vs downstream) of redds within the drawdowns between 2017 and 2018. But in 2017, redds were deposited at higher elevations relative to redds locations in 2018 (Figure 39, Figure 40). These trends closely matched the differences in reservoir water levels during the spawning periods of 2017 and 2018 (Section 3.4.5), although effect sizes were minimal (~ 0.1 m). In 2017, higher reservoir levels during the spawning period were associated with redd depositions located at higher elevations within the drawdown zones (Table 33, Figure 39, Figure 40). The magnitude of this affect was also related to the relative water level differences between years for the Upper Campbell reservoir and the Lower Campbell reservoir. Interestingly, the vertical distribution of redds (upstream and downstream) in the drawdown zone did not show any clear associated patterns (Appendix H).

Figure 39. Vertical distribution of redds within the drawdown of the Lower Campbell Reservoir in 2017 and 2018.

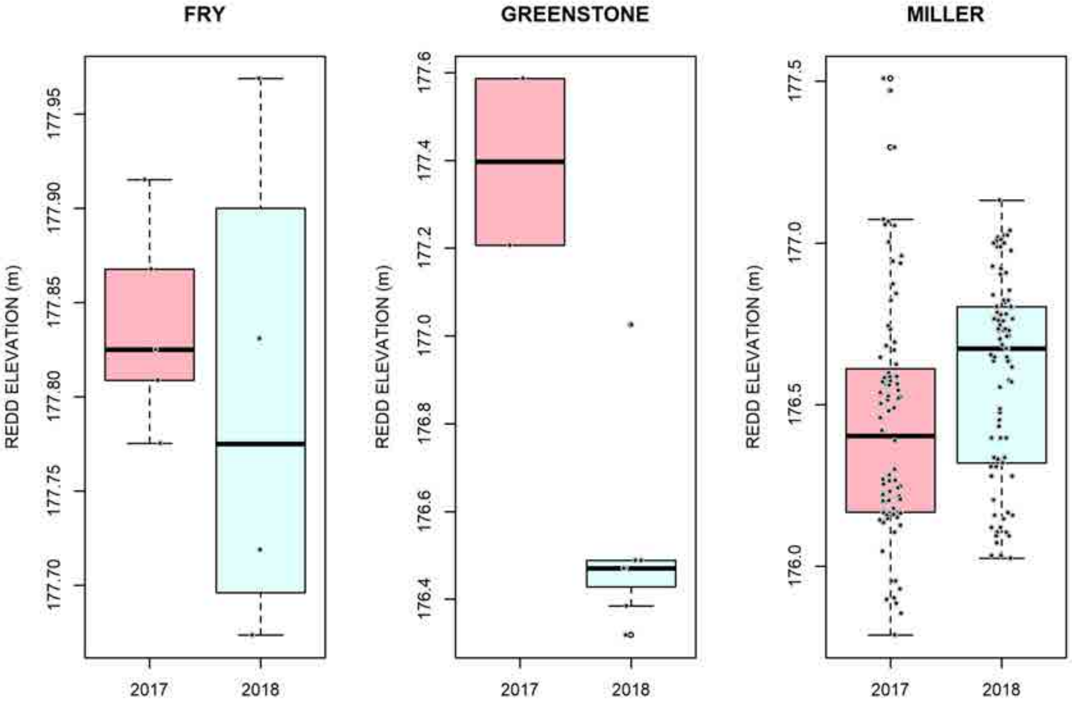
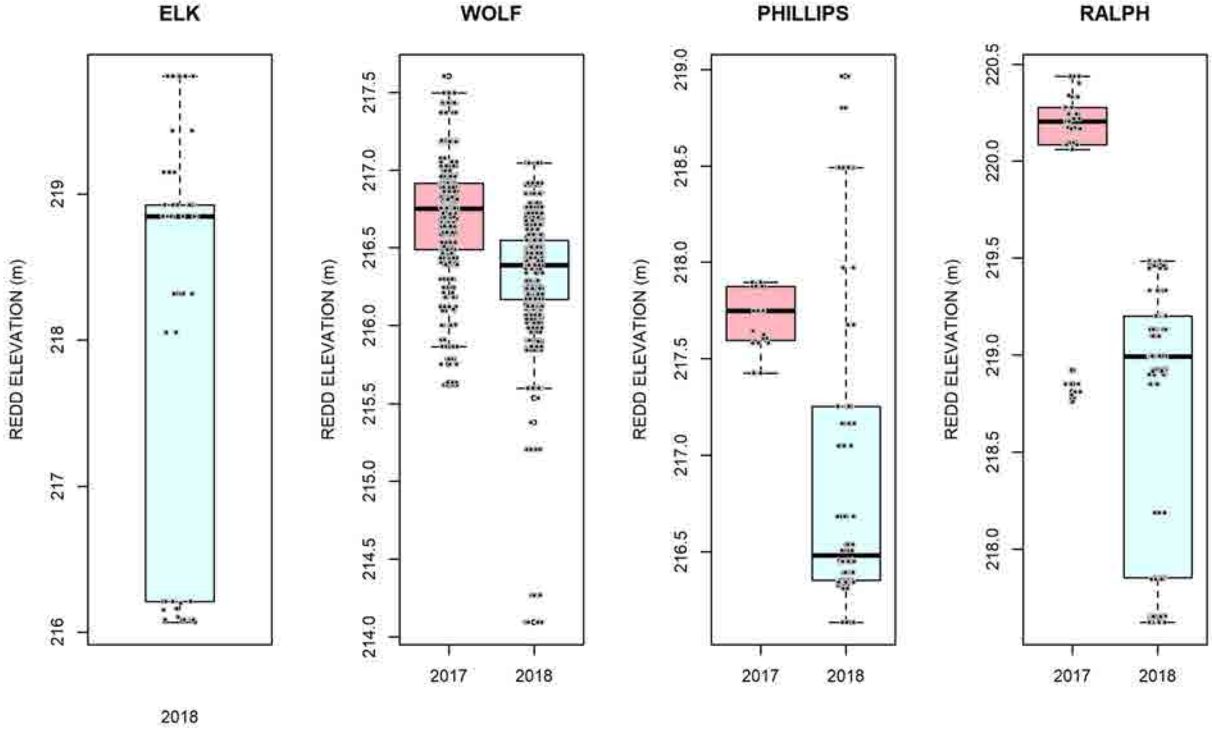


Figure 40. Vertical distribution of redds within the drawdown of the Upper Campbell Reservoir in 2017 and 2018.



3.6. Incubation Experiments

3.6.1. Incubation Tests

Hatch rates and survival rates showed similar responses to the treatments (Figure 41). The vast majority of mortality occurred at the egg, rather than the fry or alevin stages.

Mean survival rates were close to 100% in the hatchery and transport controls, as well as in sites above reservoir water levels. The observed response differed among streams and inundation depths, from almost no effect at all depths in Ralph River to a moderate effect at 1 m and substantial effect at 3 m below reservoir water level in Elk River.

Mean survival rates at sites below reservoir water level in the Ralph River ranged between 96% and 97.5%, with individual replicate values ranging from 94% to 100%. Mean survival rate at the site above water reservoir level was 97%, with individual replicate values ranging from 92% to 100%. Mean survival rate at the 1 m site in Elk River was 86%, with values ranging from 76% to 96%. No eggs hatched or survived at the 3 m site in Elk River (Figure 41). There was deposition of fine substrate and algae growth on the incubator devices at time of retrieval from this site. This may have impeded oxygen transfer to the eggs, and may also point to a potential lack of flow.

Mean weight of surviving fish varied from 0.11 to 0.17 g, and there were no clear patterns between control and experimental depths below reservoir water elevation, except slightly higher weights at the 3 m site at Ralph River (Figure 42).

Figure 41. **Hatch and survival rates, by river and treatment. Estimates are shown as mean ± 2SD. RWL: Reservoir Water Level.**

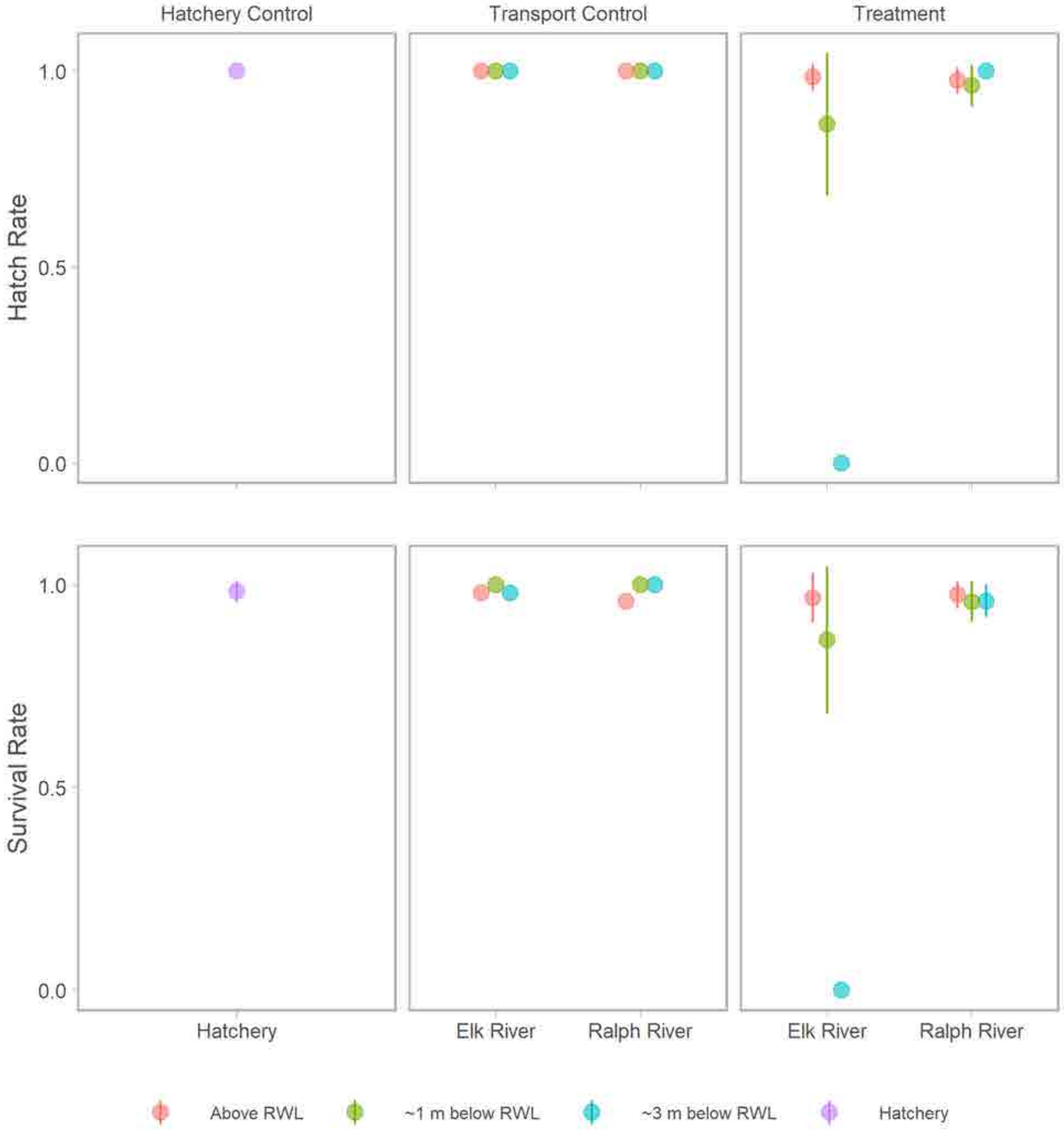
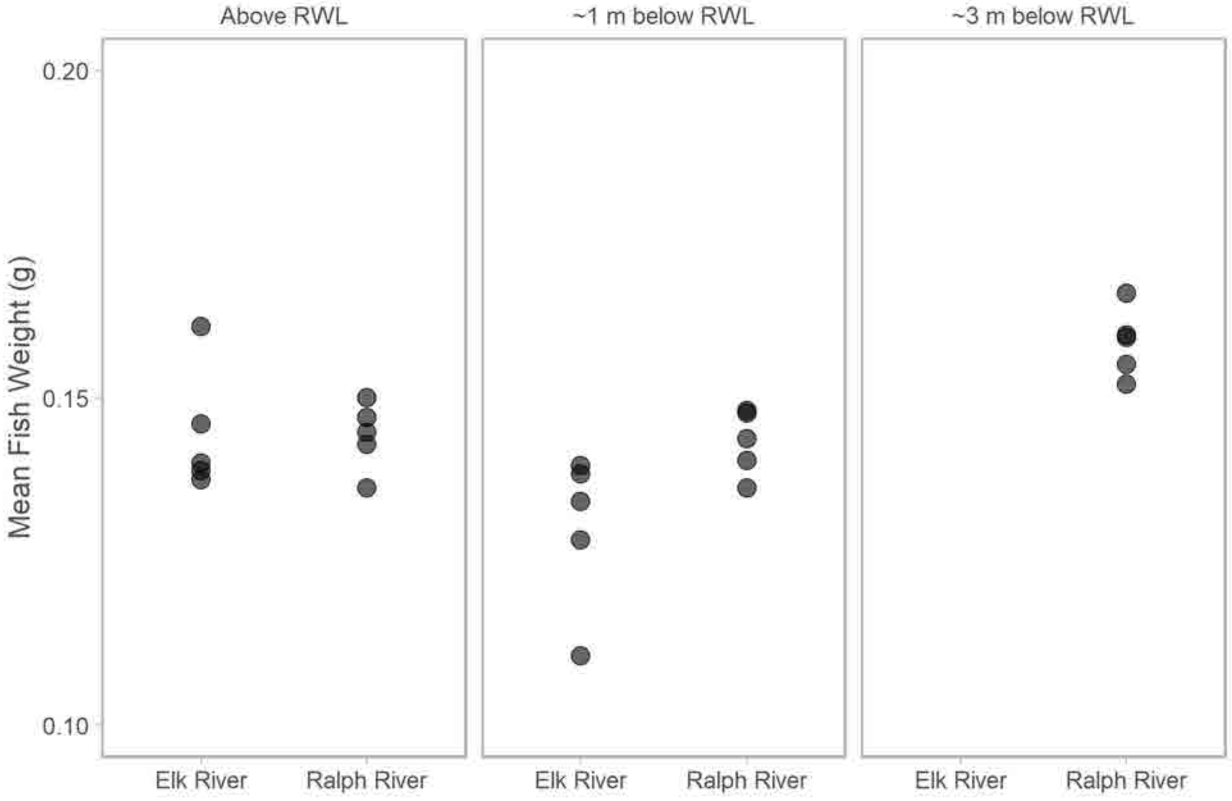


Figure 42. **Mean fish weight, by river and treatment. Weight of hatchery and transport control fish are not shown. RWL: Reservoir Water Level.**



3.6.2. Incubation Habitat and Seepage Conditions

Included here is a summary of key results of the incubation habitat and seepage conditions most relevant to the incubation test results. Details of all incubation habitat and seepage condition results are provided in Appendix E

3.6.2.1. Substrate Composition

Substrate composition results for each site at Elk River and Ralph River are presented in Table 37. The substrate at all sites was predominantly comprised of gravel. Elk River sites generally contained more sand and had a lower porosity compared to Ralph River sites. Sites containing sand generally had a higher percent of fines (< 2 mm) and lower porosity.

Values of thermal conductivity and sediment heat capacity were used in the temperature tracer method to determine seepage rates (see Section 3.6.2.2) and are provided in Table 37.

Table 37. Substrate and thermal properties of seepage monitoring sites.

Watercourse	Site[1]	Description	Porosity[2] (-)	Thermal Conductivity[3] (J/(s•m•°C))	Sediment Heat Capacity[3] (J/(m^3•°C))	Dispersivity[4] (m)	Geomorphic Unit	Substrate class (dominant, subdominant)	% Fines (Average, < 2 mm)
Elk River	ELK-WT04 ELK WT04B	above reservoir water level	0.14	3.01	2.2 x 10^6	0.001	Mid-riffle	Gravel, sand	10.9
	ELK-WT03B	1 m below reservoir water level	0.24	2.43	2.3 x 10^6	0.001	Pool tailout	Gravel, NA	2.6
	ELK-WT02B	3 m below reservoir water level	0.24	2.43	2.3 x 10^6	0.001	Lake bed / alluvial fan	Gravel, sand	11.7
Ralph River	RAL-WT04	above reservoir water level	0.28	2.22	2.4 x 10^6	0.001	Pool tailout	Gravel, NA	6.4
	RAL-WT03 RAL-WT03B	1 m below reservoir water level	0.27	2.30	2.4 x 10^6	0.001	Pool / run	Gravel, NA	14.7
	RAL-WT02B	3 m below reservoir water level	0.28	2.22	2.4 x 10^6	0.001	Lake bed / alluvial fan	Gravel, trace sand	7.8

[1] Analyses were conducted for samples collected at sites where piezometers were installed (generally suffix "B"). Where two site locations are reported for a given site description (e.g., ELK-WT04 and ELK-WT04B), results were applied at both sites in the temperature tracer method.

[2] Porosity calculated by measuring volume of water that could be held in pore spaces of a sediment sample.

[3] Calculated using dry bulk density (derived from porosity and assumed 2.65 g/cm^3 grain density), and scaling from plot in Lapham (1989).

[4] Assumed uniform throughout all study sites, using the same value as Biacnchin *el al.* (2010) (transverse) and Birkel *et al.* (2016).

3.6.2.2. Seepage

Included here is a summary of key results based on the temperature tracer method used to calculate seepage that were most relevant to the incubation test results. Details of all seepage results, including those obtained using Darcy's Equation are provided in Appendix E. The seepage rates computed from the piezometers and Darcy's Equation were highly variable due to the heterogenous conditions found across the sample sites. This variability and the inability to measure seepage from the 3 m above reservoir elevation sites meant that definitive conclusions could not be made to evaluate the incubation results. Further, details with respect to uncertainties in the seepage rate calculations are provided in Appendix E.

Temperature Tracer Method

Seepage rates (q) determined using the temperature tracer method during the incubation period are presented in Table 38. Pre-incubation results (i.e., Periods 1-3) are provided in Appendix E.

Seepage rates in Elk River above reservoir water level (ELK-WT04B) ranged from -30.2 m/d to -12.9 m/d during the incubation period, with an average of -18.1 m/d (Table 38). In Elk River, seepage rates 1 m below the reservoir level (ELK-WT03B) were comparatively less and ranged from -8.7 m/d to -0.01 m/d, with an average of -2.2 m/d during the incubation period. Seepage rates 3 m below reservoir water level (ELK WT02B) ranged from 0.01 m/d to 0.05 m/d, with an average of 0.03 m/d. Seepage rates in Elk River were generally greater during incubator installation (Period 4, June 20 to June 23) compared to the incubation period (Period 5, June 24 to June 28) and incubator removal (Period 6, June 29 to July 6).

In Ralph River, seepage rates above the reservoir water level (RAL-WT04) ranged from -41.8 m/d to -17.3 m/d, with an average of -34.3 m/d during the incubation period (Table 38). Seepage rates in Ralph River 1 m below reservoir level (RAL-WT03/B) were comparatively less and also indicative of weak upwelling, with an average of 0.09 m/d. Seepage rates 3 m below the reservoir level (RAL-WT02B) ranged from -12.6 m/d to -9.29 m/d, with an average of -11.0 m/d. Seepage rates in Ralph River were fairly consistent throughout the incubation study (i.e., between different periods).

Table 38. Average seepage rates at Elk River and Ralph River study sites during the incubation period, modelled using 1DTempPro.

Watercourse	Site[1]	Description	Sensor Depths (m)	Incubation Period Average	Period 4 (June 20 to June 23)[2]			Period 5 (June 24 to June 28)			Period 6 (June 29 to July 6)[3]		
				q (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)
Elk River	ELK-WT04	above reservoir water level	All	-	-	-	-	-	-	-	-	-	-
	ELK-WT04B		All	-18.1	-30.2	0.04	11.5	-16.6	0.03	4.0	-12.9	0.04	1.91
	ELK-WT03B	1 m below reservoir water level	0, 0.1, 0.3	-2.2	-8.7	0.09	3.2	-0.52	0.25	NA[4]	-0.01	0.33	0.05
			All	-0.04	-0.04	0.69	0.08	-	-	-	-	-	-
	ELK-WT02B	3 m below reservoir water level	All	0.03	0.01	0.18	0.01	0.02	0.18	0.01	0.05	0.15	0.04
Ralph River	RAL-WT04	above reservoir water level	All	-34.3	-40.4	0.12	30.1	-17.3	0.12	12.45	-41.8	0.12	33.0
	RAL-WT03		All	-	-	-	-	-	-	-	-	-	-
	RAL-WT03B	1 m below reservoir water level	0.1, 0.3, 0.5	0.09	0.08	0.05	0.01	0.08	0.03	0.01	0.10	0.03	0.01
			All	0.13	-	-	-	-	-	-	0.13	0.13	0.02
	RAL-WT02B	3 m below reservoir water level	All	-11.0	-12.3	0.19	3.9	-12.6	0.14	3.42	-9.29	0.14	2.76

[1] Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018); however, some sites needed to be relocated slightly due to site dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Only sites for which viable data were obtained have been included.

[2] RAL-WT02B trial started on June 21 at 00:00

[3] RAL-WT03B (All depths) went from July 6 00:00 to July 9 00:00; ELK-WT04B ends on July 6 at 09:30; ELK-WT03B (0, 0.1, 0.3 m depths) ends on July 6 at 11:50.

[4] NA = Not applicable. Each interation resulted in a root mean square error (RMSE) that was less than 1.1 times the final RMSE value, indicating the confidence algorithm did not complete. However, overall the accuracy of this measurement was considered strong because the RMSE was 0.25°C and there was substantial difference between the temperature series at each depth.

3.6.2.3. *In situ* Water Quality

A summary of key *in situ* water quality results most relevant to incubation test results are provided below. All *in situ* water quality results for each site at Elk River and Ralph River are presented in Appendix E.

Dissolved Oxygen

In Elk River, DO concentrations remained above the instantaneous minimum BC WQG (6 mg/L) at all locations and depths. Compared to the 30-day minimum guideline (8 mg/L), DO concentrations in Elk River above reservoir water level (ELK-WT04B) remained above the guideline whereas concentrations 1 m below reservoir water level (ELK-WT03B) were generally close to or below the guideline, suggesting that if these concentrations were experienced over the long-term, adverse effects to buried life stages may occur (MOE 2017). To apply the long-term guidelines, however, samples are typically collected weekly over a 30-day period.

In Ralph River, DO concentrations generally remained above the instantaneous minimum BC WQG (6 mg/L). Compared to the 30-day minimum guideline (8 mg/L), DO concentrations in Ralph River above reservoir water level (RAL-WT04) were above the guideline during incubator installation (June 2018); however, were generally below the guideline during incubator removal (July 2018). DO concentrations in Ralph River 1 m below reservoir water level (RAL-WT03B) were generally below the 30-day guideline (8 mg/L).

Temperature

In Elk River, subsurface water temperature was generally outside of the provincial optimum water temperature ranges (either above or below) for Cutthroat and Rainbow Trout. Water temperature in Elk River sites generally decreased with depth in the substrate.

In Ralph River, subsurface water temperature was generally above the provincial optimum water temperature ranges for Cutthroat and Rainbow Trout. Water temperature with depth in the substrate was more variable in Ralph River compared to Elk River.

Water temperatures at all Elk and Ralph River locations were above the provincial optimum water temperature range for Dolly Varden[6] (equivalent temperature requirements as Bull Trout).

3.6.2.4. Surface Hydrology

A summary of key surface hydrology results most relevant to incubation test results are provided below. Details of surface hydrology results for each site at Elk River and Ralph River are presented in Appendix E.

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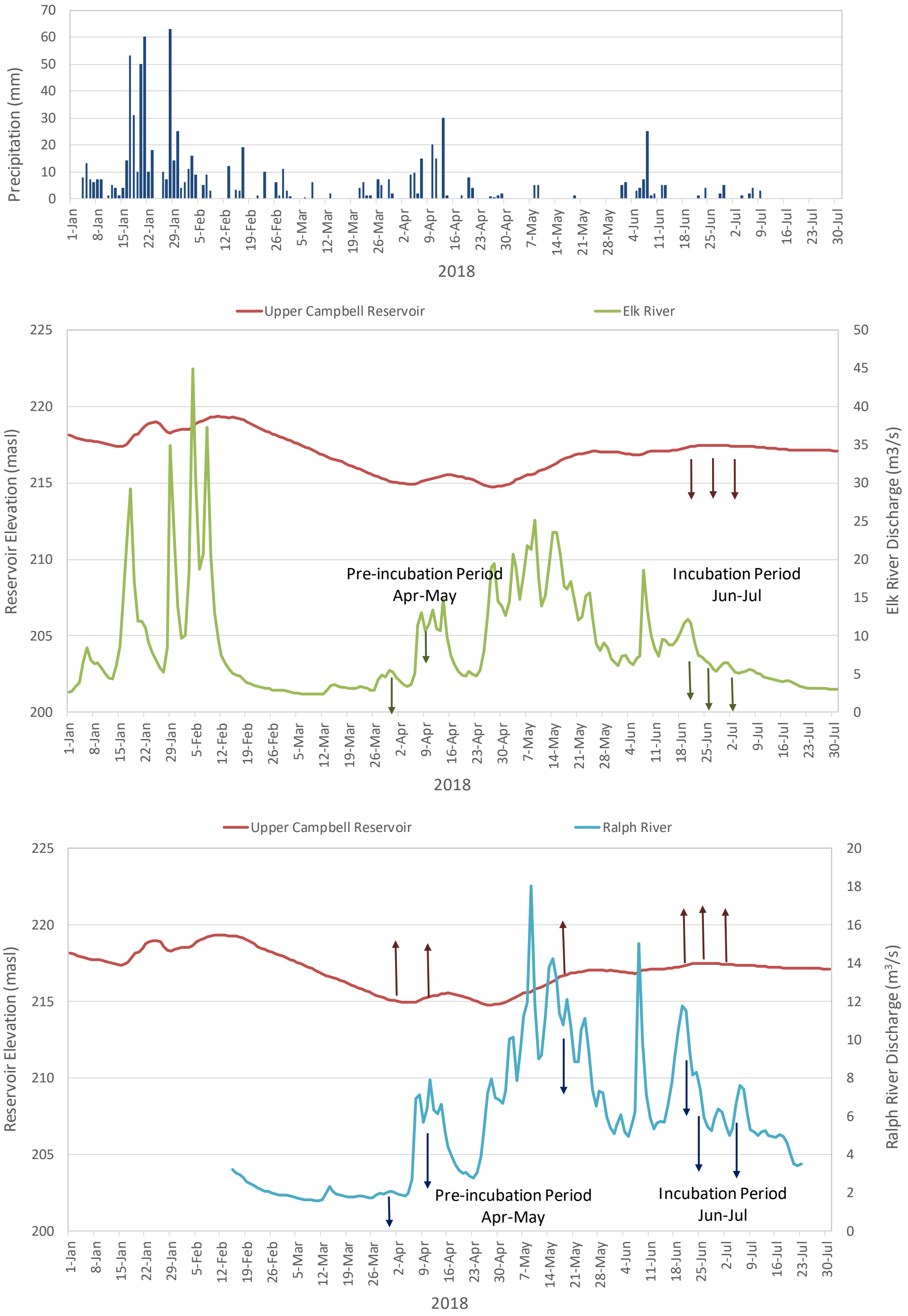
[6] Note that incubation tests and incubation habitat and seepage condition measurements were not conducted during the Dolly Varden spawning and incubation period.

Elk River and Ralph River flow are presented in Figure 43 with Upper Campbell Reservoir elevation and daily precipitation measured at the BC Hydro climate station 'Elk River above Campbell Lake.' Elk River flow (11.60 m^3/s) was similar to flow at Ralph River (11.74 m^3/s) during incubator installation in June, and less (5.38 m^3/s) than Ralph River flow (7.38 m^3/s) during incubator removal in July.

Based on the Temperature Tracer Method, seepage rate directions in sites above reservoir water level and 1 m below reservoir water level were consistent in both Elk River and Ralph River across variable flow conditions (Figure 43). At sites above reservoir water level downwelling conditions were observed in both Elk River and Ralph River (ELK-WT04B and RAL-WT04). Downwelling conditions were observed in Elk River 1 m below the reservoir water (ELK-WT03B) level whereas upwelling conditions were observed in Ralph River 1 m below the reservoir level (RAL-WT03B).

Figure 43. Precipitation (mm) (top plot), and reservoir elevation (masl) and Elk River discharge (middle plot) and Ralph River discharge (bottom plot). Seepage directions (upwelling/downwelling) are indicated with arrows. Above reservoir water level sites (WT04/B) depicted with river discharge data and 1 m below reservoir level sites (WT03B) depicted with reservoir data.



3.6.3. Water Temperature

The longest incubation period in Year 5 was observed in Miller Creek (MLR-LKWT) with water temperatures greater than 7°C observed for 101 days. The shortest incubation period, 16 days, was observed at Wolf Creek (WOL-WT). However, at many sites where the incubation period was comparatively short (e.g., Ralph River; Phillips Creek), the number of days with valid data was also fewer than in waterways with longer incubation periods (Table 39). Thus, a lack of reliable data has influenced these results.

Table 39. Incubation period and cumulative degree days at monitoring stations in John Hart Reservoir, 2018.

Site	Location	Year	Number of days with valid data	Growing Season Data Summary				
				Start Date	End Date	Length (days)	Gap (days)	Degree Days
ELK-LKWT	Elk River, lake	2018	186	5-May	9-Jul	65	1	569
ELK-WT	Elk River, creek	2018	189	5-May	12-Jul	68	1	590
FRY-LKWT	Fry Creek, lake	2018	67	-	-	-	-	-
FRY-WT	Fry Creek, creek	2018	67	-	-	-	-	-
GRN-LKWT	Greenstone Creek, lake	2018	62	12-May	12-Jul	61	1	597
GRN-WT	Greenstone Creek, creek	2018	126	-	-	-	-	-
MLR-LKWT	Miller Creek, lake	2018	182	2-Apr	12-Jul	101	1	1,393
MLR-WT	Miller Creek, creek	2018	70	-	-	-	-	-
PHL-LKWT	Phillips Creek, lake	2018	190	13-Jun	13-Jul	30	1	212
PHL-WT	Phillips Creek, creek	2018	190	13-Jun	13-Jul	30	1	208
WOL-LKWT	Wolf Creek, lake	2018	190	16-May	10-Jun	26	0	186
WOL-WT	Wolf Creek, creek	2018	190	17-May	1-Jun	16	0	113
RAL-WT	Ralph River, creek	2018	189	13-May	31-May	19	0	135

3.7. Statistical Catch-at-age Models

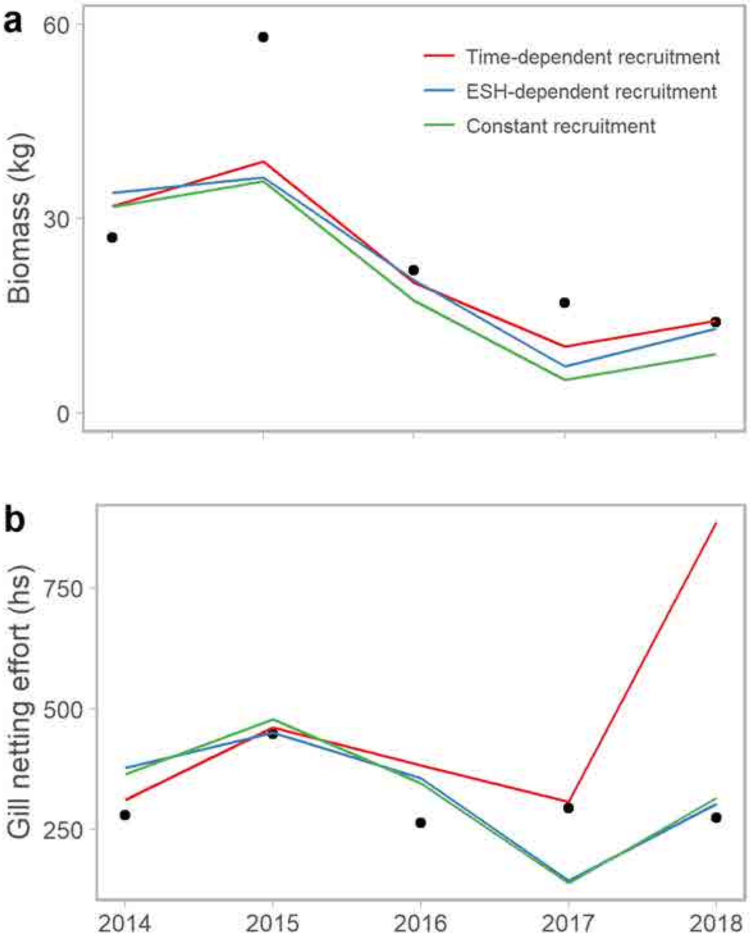
The most parsimonious statistical catch-at-age model was the time-dependent recruitment model, followed by the ESH-dependent recruitment model (ΔAIC = 23.9), and lastly the constant recruitment model (ΔAIC = 27.5) (Table 40). This can be interpreted as strong empirical support for variable cohort strength. Despite having low empirical support the ESH-dependent recruitment model is more parsimonious than the constant recruitment model.

Table 40. Model selection statistics for statistical catch-at-age statistical models (*LLH*: log-likelihood, *p*: number of parameters, ΔAIC: Change in Akaike Information Criterion). Models are ranked by ΔAIC scores. The model with the lowest ΔAIC is the best model.

Model	*LLH*	*p*	ΔAIC
Time-dependent recruitment	-34.8	18	0
ESH-dependent recruitment	-49.8	15	23.9
Constant recruitment	-52.6	14	27.5

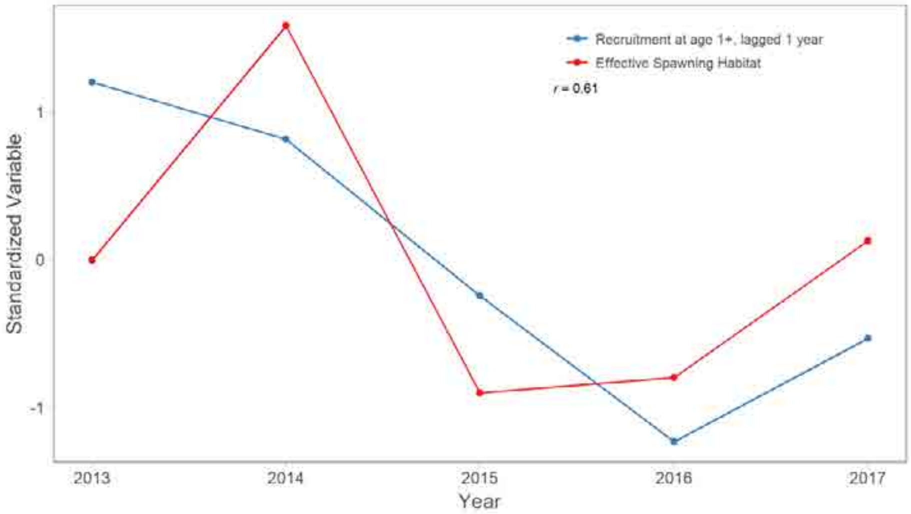
Figure 44 shows the fit of the three models to the response variables that informed the statistical catch-at-age models: total catch biomass (B_y), and gill netting effort. The total catch biomass is estimated as the product between the estimated catch-at-age ($\hat{C}_{a,y}$) and the observed annual individual mean weight at age ($\bar{w}_{a,y}$) $B_y = \sum_a \hat{C}_{a,y} \bar{w}_{a,y}$. The three models captured the same patterns in total catch biomass, i.e., a peak biomass in 2015, with subsequent decline and slight improvement during 2018 (Figure 44a). The constant and ESH-dependent recruitment models consistently underestimated the total catch biomass (except in 2014), while the time-dependent recruitment model performed better every year, except in 2014 (Figure 44a). The gill netting effort is estimated as $\hat{E}_y = \hat{F}_y / \hat{q}$. The three models predicted the increase in effort from 2014 to 2015, and a subsequent decrease. Starting in 2016 the predictions of the models diverged; the constant and ESH-dependent recruitment models predicted virtually identical effort and differ from those of the time-dependent recruitment model (Figure 44b). The two former models overestimated effort in 2016 and 2018, and underestimated effort in 2017. The latter model accurately predicted effort in 2017, and overestimated effort in 2016 and 2018 (Figure 44b).

Figure 44. Fit of the 3 statistical catch-at age models, showing a) observed and estimated total catch biomass (total catch biomass is defined as the product of catch at age and mean annual individual weight at age), and b) observed and estimated gill netting effort (effort is estimated as $\widehat{F}_y/\widehat{q}$).



We evaluated the recruitment at age 1+ ($\widehat{R}_y$) estimated from the time dependent model, and compared it to the values of effective spawning habitat the year prior, as the effects on recruitment at age 1+ will be realized a year later. These variables were standardized to visualize coherence in trends, and are shown in Figure 45. There is a strong correlation ($r = 0.61$) between the two variables, which suggests that effective spawning habitat affects the recruitment of Cutthroat Trout in the Upper Campbell Reservoir.

Figure 45. Estimated recruitment at age 1+ ($\hat{R}_y$) from the time-dependent model (blue), and Effective Spawning Habitat for Cutthroat Trout in the Upper Campbell Reservoir (red). To aid visualization, recruitment at age 1+ has been lagged by 1 year to match the year of effective spawning habitat (i.e., recruitment at age 1+ in year *y* is affected by ESH in year *y*-1).



4. SUMMARY

Comparisons of measurements of fish abundance and spawning success before and after the WUP implementation were conducted to test the assumption that salmonid recruitment is limited by availability of effective spawning habitat. In 2018 (Year 5) we successfully collected the planned datasets, developed a protocol to assign fish ages based on fork length that makes use of all data available from the monitoring program, carried out field experiments to test the effects of inundation on the survival of salmonid eggs, and developed and implemented an integrated model to test the influence of effective spawning habitat on the dynamics of salmonids in the Campbell River System.

4.1. Effective Spawning Habitat (ESH)

The Year 5 ESH study builds on results from previous years and was successful in providing an improved understanding of trends in habitat loss and ESH for the two target species, Cutthroat Trout and Rainbow Trout, and additionally for Dolly Varden.

The work plan focuses on Cutthroat Trout in Upper Campbell Reservoir because the potential population response is expected to be greatest due to the considerably larger drawdown and the general trend of rising water levels during the Cutthroat Trout incubation period (Figure 1). Any effect observed in Upper Campbell Reservoir is assumed to apply to Lower Campbell and John Hart reservoirs; however, the magnitude of response is expected to be less due to the more stable water levels in these two reservoirs (Figure 2). Additionally, it is advisable to focus on one reservoir rather than spread the same effort across two or more reservoirs, because this approach will yield more samples for an individual reservoir, which we expect will improve the statistical strength of any relationship observed between ESH and fish CPUE.

We carried out a preliminary analysis of the relationship between ESH and fish population index for Cutthroat trout in the Upper Campbell Reservoir. Given the successful implementation of this statistical model, we suggest that this component be continued in future years, given that any ESH trends across fish age and abundance are anticipated to become increasingly more informative.

4.2. Population Index for Upper and Lower Campbell Reservoirs

The Year 5 sampling results (2018) provide a fifth year of data on population abundance, recruitment, and effective spawning metrics. The results allow for the preliminary determination of an abundance index for each age cohort for both trout species. This approach will be built upon in future years to develop abundance measures for individual ages and test the management hypotheses noted in Section 1.4. We expect that tools developed in Year 5 (species-specific inverse von Bertalanffy growth function and statistical catch-at-age models) will make analysis more efficient in future years, as these will only need to be updated with the incremented data set.

We increased the effort in the reading of otoliths to enable the comparison of ageing using three different hard structures: scales, fin rays, and otoliths. Overall, we found good agreement among ages estimated from the different structures:

- Otoliths: Age reading in otoliths is more accurate, but it is more time consuming and expensive than the other methods.
- Scales: Scales are not as accurate, but they are less time consuming and cheaper to read.
- Fins rays: The accuracy, cost, and time needed to read fin rays are intermediate between the other hard structures. There is considerable variability in age assignment using fin rays, indicating they are of lower utility for accurate determination of age.

Given the rapid growth rate of young fish, ages read from scales yield ages with enough accuracy to determine age breaks of young fish. However, as fish age their growth rate decreases and therefore ages reading in scales do not yield measures accurate enough to differentiate age breaks at older ages.

We developed species-specific inverse von Bertalanffy growth function (ivBGF) to assign ages of unaged fish, based on their fork length. This approach makes use of all age and length information collected during this monitoring program. This method overcomes the difficulty found in earlier years when not all fish could be assigned an age because of poorly defined age bins. We assigned ages to all fish with a measured fork length captured during the five years of the monitoring program. These functions will be refined as more aging data are collected in later monitoring years and therefore resolution of age bins improved. Given that the method developed and implemented makes use of all data of the monitoring program, sampling can be designed to cover the age classes with fewer observations.

We therefore suggest focusing aging efforts on young (ages 0+ and 1+) and older fish (age ≥6+) to improve accuracy of the age bins. We suggest reading approximately 30 scales annually by age bin for the younger ages, and approximately 10 scales annually by age bin for the older age classes, with a few age readings for intermediate age classes. These age readings will incrementally add to the existing age readings. Therefore, we will assess the accuracy of the age bins annually to determine if the requirements for successfully implementing the ivBGF functions are met, or further age readings are needed.

The implementation of the ivBGF functions enabled us to estimate metrics of age-specific catch per unit effort for all years of the monitoring program. These were integrated with information on gill netting effort and effective spawning habitat on a statistical model that allows statistical analysis of the relationship between ESH of fish species and WUP operations.

This component is critical to addressing the management questions and testing the impact hypotheses. We therefore suggest that gill net surveys continue for the next five years as per the terms of reference.

4.3. Snorkel Survey of Spawners in Reservoir Tributaries

Snorkel surveys were completed in five tributaries to Buttle Lake, one tributary to Upper Campbell Reservoir, and three tributaries to Lower Campbell Reservoir during the Year 5 surveys in 2018. Spring snorkel surveys carried out in March and April targeted the Cutthroat Trout spawning period in the tributaries of Lower Campbell Reservoir. Few Cutthroat Trout were recorded during the spring snorkel surveys; however, high numbers of redds were identified, attributed to early Cutthroat Trout spawning.

The summer snorkel survey results for spawning Rainbow Trout in tributaries of Buttle Lake and Upper Campbell Reservoir identified counts below historical median averages in two streams: Thelwood Creek and Phillips Creek (Figure 33 and Figure 34). Counts were above historical median averages in three streams: Wolf River, and Upper and Lower Elk River (Figure 28, Figure 29 and Figure 30). In Henshaw Creek and Ralph River, counts were similar to median historical values (Figure 31 and Figure 32). No adult Rainbow Trout were recorded in Fry Creek (tributary to Lower Campbell Reservoir) during 2018, representing low count numbers that matched the previous reference number of zero Rainbow Trout observed in 2004, 2014, 2016 and 2017.

Overall, the 2018 snorkel surveys effectively enumerated spawning Cutthroat Trout in Lower Campbell Reservoir and Rainbow Trout in the Upper Campbell Reservoir and we suggest that the snorkel surveys continue for the next five years as per the terms of reference.

4.4. Spawning Habitat Availability

The quantity of available habitat was assessed within the Lower and Upper Campbell reservoirs (including Buttle Lake) and within each tributary of these systems. Overall, the total amount of available spawning habitat was greater in upstream areas than within the drawdown zones; however, tributaries in Buttle Lake had a greater portion of spawning habitat within the drawdown zone relative to upstream areas. Across all habitat metrics evaluated, areas within the drawdown zone accounted for approximately 16% - 19% of total available spawning habitat for tributaries in the Upper and Lower Campbell reservoirs and up to 63% – 82% for tributaries within Buttle Lake.

Major differences in habitat availability between the drawdown zones and upstream reaches were primarily a result of the limited size of the drawdown zones relative to upstream reaches. The mainstem of the Elk River had an overwhelming effect on our summaries of habitat availability due it its size. Buttle Lake tributaries were the only locations where we identified a higher quantity of spawning habitat within drawdown zones relative to areas upstream of the drawdown zones. This was a result of high-quality spawning habitat within the drawdown zones and impassible barriers located only a short distance upstream of the lake limiting the extent of upstream habitat. Although a majority of available spawning habitat identified in this study was located in upstream areas above the drawdown zones, spawning habitat within the drawdown zones accounted for 22% - 27% of the total available spawning habitat. In summary, the majority of spawning habitat occurs above the drawdown zone; however, a substantial portion (approximately 1/5th) of spawning habitat occurs within the drawdown zone subject to reservoir water elevation changes.

It is likely that the methods used in this study underestimated spawning habitat availability in areas above drawdown zones. In several instances the upstream survey end points were chosen in the field based on the absence of any redds or high-quality spawning habitat for an extended distance. In the absence of any barrier to fish passage, areas further upstream and beyond these endpoints were likely to contain additional spawning habitat, further increasing the ratio of spawning habitat availability above vs within the drawdown zones.

Results showed some variability depending on which spawning habitat indicator metric was considered, but overall differences between drawdown zones and upstream areas were generally consistent across each metric. This general consistency across metrics and positive correlation with counts of redd surveyed across each area suggests that habitat metrics developed in this study accurately reflected spawning habitat availability. Inconsistent trends across metrics were largely the result of differences between linear and area-based summaries (e.g., bankfull area and linear distance between the drawdown zones and upstream areas of Ralph River (Table 32). We expect area-based metrics to be more reliable indicators of spawning habitat. For example, the length of spawning habitat in Greenstone Creek extended for 2.8 km upstream of the drawdown zone; however, this creek is relatively narrow and therefore has a limited total spawning area (Table 30).

Quantifying available spawning habitat in the drawdown zones was challenging due to the large size of alluvial fans extending into lakes. We believe that the methods developed to quantify spawning habitat in these areas were adequate and accurately reflected spawning habitat availability for two reasons. By focusing on the defined tributary channels within the drawdown zone we excluded areas of the lake margin embedded with fines, woody debris and vegetated substrates that were devoid of spawning habitat. Spawning habitat availability results were also supported by the distribution and presence of redds within the drawdown zone being limited to the defined tributary channel instead of being distributed across the alluvial fan and lake shoreline. Estimates of qualitative spawning habitat potential are believed to have limited utility in the drawdown zones due to discrepancies in the reservoir level between the survey period and spawning period. Estimating habitat availability in the drawdown zone from the portion of the channel area inundated during the spawning period was believed to be more useful and closely matched trends and expectations from redd survey data.

Our conclusions of habitat availability were based on habitat indicator metrics developed in a GIS environment with aerial imagery (linear distance, wetted area, bankfull channel width/area and qualitative spawning potential). The advantage of these habitat indicator metrics is the ability to rapidly obtain complete survey coverage of each waterbody. By conducting UAV aerial surveys in combination with field surveys in areas with dense riparian cover we were able to fully survey the entire length of spawning habitat across all tributaries regardless of accessibility. High resolution UAV aerial imagery is also invaluable for ongoing and future studies such as change detection and/or developing and evaluating alternative habitat metrics.

An additional extension for continued studies could involve developing a modified FHAP procedure customized for the scale and resolution of our aerial imagery. This may help to further delineate and classify reaches based on mesohabitat characteristics. However, an FHAP procedure was not included in the original TOR budget, and due to the consistent differences between the drawdown zones and upstream areas across almost all tributaries, we do not expect these additional metrics to change general conclusions from this study. We believe the methods used to assess spawning habitat availability have adequately addressed the management questions.

4.5. Spawning Habitat Use

Results of spawning habitat use, based on the abundance and distribution of redds, were consistent with results of habitat availability, suggesting that spawning intensity is roughly correlated with habitat availability. The large spatial extent of the upstream sections supported more spawning habitat and therefore had higher habitat use relative to the drawdown zones. Overall, only 19% of all redds were located within drawdown zones; however, for each major waterbody the portion of redds within the drawdown zone ranged from 100% (Wolf River) to 0.7% (Upper Campbell Reservoir). Based on the relative density of redds across waterbodies and available spawning habitat, overall use of available spawning habitat in the drawdown zones is lower than upstream sections (especially for the Upper Campbell Reservoir); however, the drawdown zones still account for a large portion of spawning habitat.

The Elk River and Elk River tributaries accounted for a majority of all redds observed in this study, reinforcing its significance as a dominant source of spawning habitat. Despite the limited relative quantity of spawning habitat within drawdown zones of Buttle Lake, these tributaries still had over 1,605 redds. (For context, this is more than the sum of all redds observed within Lower Campbell Reservoir).

The abundance and high density of redds in the drawdown zones of Buttle Lake and near absence and low density of redds in the drawdown zone of the Elk River is likely the result of higher quality spawning habitat immediately upstream from the Elk River drawdown zone and higher quality of spawning habitat within the Buttle Lake drawdown zones. For example, Wolf Creek had a wide, well-defined channel with low to moderate compaction throughout and a substrate composition of cobble and gravel. Despite persistent lake backwatering at Wolf Creek, consistent flow through a confined channel is thought to maintain spawning habitat in this area. Most redds within Wolf Creek were located below the falls near the most upstream point of drawdown zone rather than further downstream in the drawdown zone towards the opening to the lake and alluvial fan (Appendix H). Similarly, for Phillips Creek and Ralph Creek, redds within the drawdown zone were primarily found in the upstream most sections. For tributaries of the Lower Campbell Reservoir, with the exception of Miller Creek, the drawdown zones were generally characterized by a moderately to poorly defined channel, decreased water velocities and heavy deposition of fines. Miller Creek had a moderately defined channel and consistent flow the in upstream sections of the drawdown zone.

Interannual variability of redd distributions in the DDZ between 2017 and 2018 were thought to reflect the reservoir levels during the spawning period. In 2017, higher water levels were associated with redd distributions at higher elevations in spawning channels within the drawdown zones. The magnitude of this effect also matched the relative 2017-2018 water level differences between the Upper and Lower Campbell reservoirs. Although there were more redds observed in 2018 than in 2017, we do not believe this to be related to reservoir water levels during the spawning period as more redds were observed in areas both upstream and within the drawdown zone.

Redd elevations, drawdown zone boundaries and reference water surface elevations were obtained from three different sources for this study (TST surveys with installed benchmarks; LiDAR sourced externally; water surface elevation from Water Survey Canada Gauging Stations). Although QA/QC procedures were undertaken for each of these sources there was no formal uncertainty analysis completed to better understand the relative error and offset between each of these sources. For example, the water elevation from the WSC gauging station is unlikely to exactly match the local water surface elevation of the entire reservoir perimeter due to waves, wind, narrows and other inputs. To quantify the potential differences between the WSC gauge station data and the local water surface elevations observed at individual sites, the water surface elevations observed at individual redds survey points could be compared to the relevant WSC gauge station data corresponding to the time the field measurement was recorded

4.6. Incubation Condition

4.6.1. Incubation Tests

During development of the WUP, it was assumed that reservoir inundation led to complete and instantaneous death of incubating embryos. We carried out incubation tests to assess this assumption, and found a high degree of spatial variation both within and between streams.

Survival and hatch rates differed among streams and depths, from almost no effect of inundation (close to 100 % hatch and survival rates in the Ralph River) to a substantial effect of inundation (0% hatch and survival rates in the 3m site at Elk River). It is noteworthy that there was deposition of fine substrate and algae growth on the incubator devices at time of retrieval from this site. This may have impeded oxygen transfer to the eggs, and may also point to a potential lack of flow at the site. In addition, there was a substantial number of dead eggs and alevins recorded in the Elk River drawdown zone (Marquardson, pers. comm. 2018), which suggests that operations affect survival rates.

We also assessed the sublethal effects of rearing conditions by examining mean weight of surviving fish. We did not find clear patterns in mean alevins weight neither within nor between streams. It therefore seems that there are no detectable sublethal effects on fish growth of reservoir inundation.

Results from the incubation tests suggest that the modeling assumptions used during the WUP were conservative and likely overestimated the effects of reservoir inundation. However, the high mortality observed at the site 3m below water reservoir level in the Elk River lends some support to the assumption. Our results indicate that the magnitude of effect of egg inundation on survival likely varies among tributaries and local conditions within the drawdown zone.

4.6.2. Incubation Habitat and Seepage Conditions

To support the incubation test study, we carried out seepage tests and collected substrate, water quality and hydrology data to evaluate which environmental factors are most likely to influence incubation conditions and impact egg survival. We carried out two types of seepage tests, one using a temperature tracer method and the other using Darcy's equation, to assess the influence of seepage on incubation survival, and found a high degree of spatial variation both within and between streams, particularly using the Darcy's Equation method (presented in Appendix E).

The results of the temperature tracer test generally supported the results of the incubation study, despite the spatial variability. A stronger groundwater exchange (-18.1 m/d on average) was observed at the Elk River above reservoir water level site (ELK-WT04B), where the majority of eggs/alevin survived, compared to the 1 m below reservoir water level site (ELK-WT03B, -2.2 m/d on average), where approximately 86% of the eggs/alevin survived. In further contrast, there was relatively no groundwater exchange at the 3 m below reservoir water level site (ELK-WT02B, 0.03 m/d on average), where the egg/alevin survival rate was nil.

In Ralph River, there was strong groundwater exchange at the above reservoir water level site (RAL-WT04, -34.3 m/d on average) and 3 m below reservoir water level site (RAL-WT02B, -11 m/d on average), and a weak upwelling (0.09 m/d on average) at the 1 m below reservoir water level site (RAL-WT03B). Egg/alevin survival was close to 100% at all Ralph River sites, despite the weak upwelling at the 1 m below reservoir water level site (RAL-WT03B). Flow was higher at Ralph River than at Elk River during incubator removal (7.38 m^3/s vs. 5.38 m^3/s). Higher flows may have helped circulate oxygen around the incubators despite relatively weaker groundwater exchange, thus improving egg/alevin survival. Flow directly affects the amount of DO in the water and impacts the amount of sediment carried in the stream (Water on the Web 2008). For example, high volumes of fast-moving water increase DO and keep fine sediment suspended in the water (Water on the Web 2008). Further, the % fines in Elk River at the 3 m below reservoir water level, ELK-WT02B) was relatively high (11.7%) compared to most other sites (2.6%-10.9%).

The exchange of oxygenated water with the riverbed (downwelling and upwelling), and the ability of the riverbed substrate to transport water, are critical to determining the level of DO available to eggs (Greig *et al.* 2007). In Elk River and Ralph River, DO concentrations in the subsurface generally remained above the instantaneous minimum BC WQG (6 mg/L) at all locations and depths with the following exception. During incubator removal, DO concentrations at 1 m below reservoir water level (RAL-WT03B; at depths below 0 cm) were below the instantaneous minimum BC WQG guideline. The lower DO at this site may be associated with the higher % of fines (14.7% at RAL-WT03B) relative to the other sites (ranged between 2.6% and 10.9%). A lack of water movement (zero-flow) and/or downwelling conditions (as calculated using Darcy's Equation), may have also contributed to the low DO observed. It is also worth noting that DO is likely to decrease with increasing depth in the stream bed assuming reduced gas exchange with the surface water or infiltration of groundwater (MOE 1997b).

Suitable DO levels and incubation habitat within the egg pocket are created as the female salmonid alters the hydraulic conductivity during redd construction (Tonina and Buffington 2009). This localized altered hydraulic conductivity is the primary factor for enhancing seepage rates and DO content within the egg pocket habitat of salmon redds (Tonina and Buffington 2009). Redd construction significantly enhances the seepage rate and oxygen concentration, that otherwise would not occur, increasing the potential for embryo survival. Thus, the very localized incubation habitat conditions within the egg pocket may be a better indicator of egg survival compared to the general (and variable) conditions observed at point measurements across the stream bed environment.

There may be insufficient groundwater movement in some areas of the Elk River drawdown zone to replenish local oxygen supply and flush away metabolic waste for trout spawning. Localized incubation habitat conditions and surface water flow conditions may; however, be favourable and promote egg/alevin survival in areas where groundwater movement is otherwise insufficient.

4.7. Statistical Catch-at-age Models

We integrated information on age, gillnet catch, gillnet effort, and effective spawning habitat on a statistical catch-at-age model to describe the population dynamics of Cutthroat Trout in the Upper Campbell Reservoir. This enabled us to test the effect of reservoir operations, via their effects on effective spawning habitat, on the dynamics of Cutthroat Trout.

We built three alternative models: 1) recruitment to age 1+ is constant, 2) recruitment to age 1+ is variable, and 3) recruitment to age 1+ is a function of the effective spawning habitat. These models reflect working hypotheses on the dynamics of Cutthroat Trout in the Upper Campbell Reservoir. The relative empirical support of these working hypotheses was appraised within an Information-Theoretic Approach (Burnham and Anderson 2002). The most parsimonious model was the variable recruitment scenario, followed by the ESH-dependent recruitment. Recruitment parameters from the time-dependent recruitment model were highly correlated with effective spawning habitat (accounting for the appropriate time lag).

Modelling results suggest the effects of reservoir operations are strong enough to be detectable in the population dynamics of Cutthroat Trout in the Upper Campbell Reservoir. Describing the dynamics of fish stocks typically requires time series much longer than 5 years, so results from this modelling exercise should be considered preliminary. We consider the implementation of the statistical catch-at-age model to have been successful, and captured reasonably well the time series of total catch and gill netting effort. The robustness of conclusions from this approach will improve as more data are collected through this monitoring program. The approach appears to have a reasonable likelihood of providing robust results with respect to the effect of reservoir elevation on the dynamics of salmonids in the Campbell River System by the end of the planned monitoring program.

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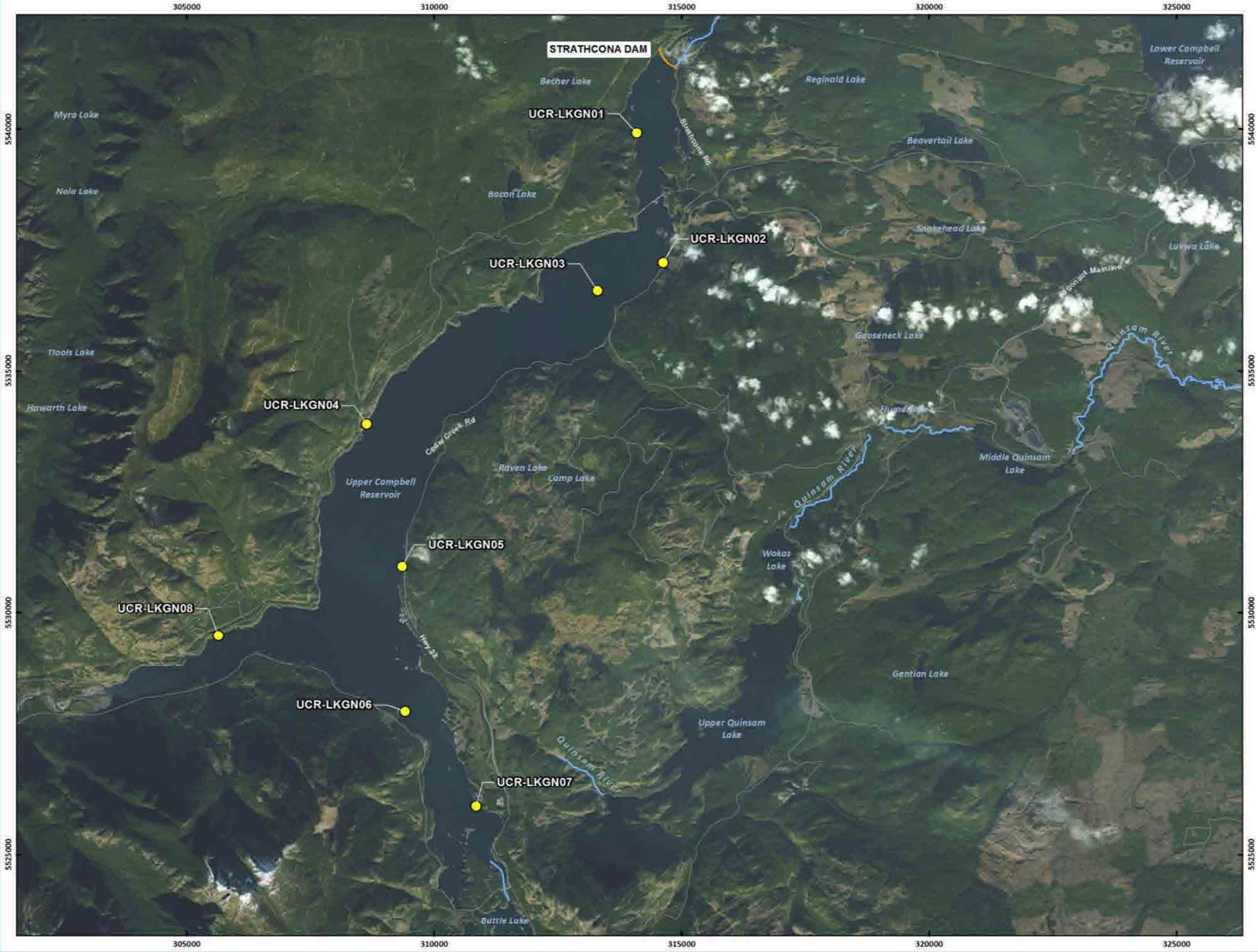
PROJECT MAPS

JHTMON Campbell River Water Use Plan

Upper Campbell Reservoir Gill Netting Locations



Legend

Sample Sites

● Gill Netting

— Dam

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 4 km

Scale: 1:75,000

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3			
4			
5			

Date Saved: 16/11/2016
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

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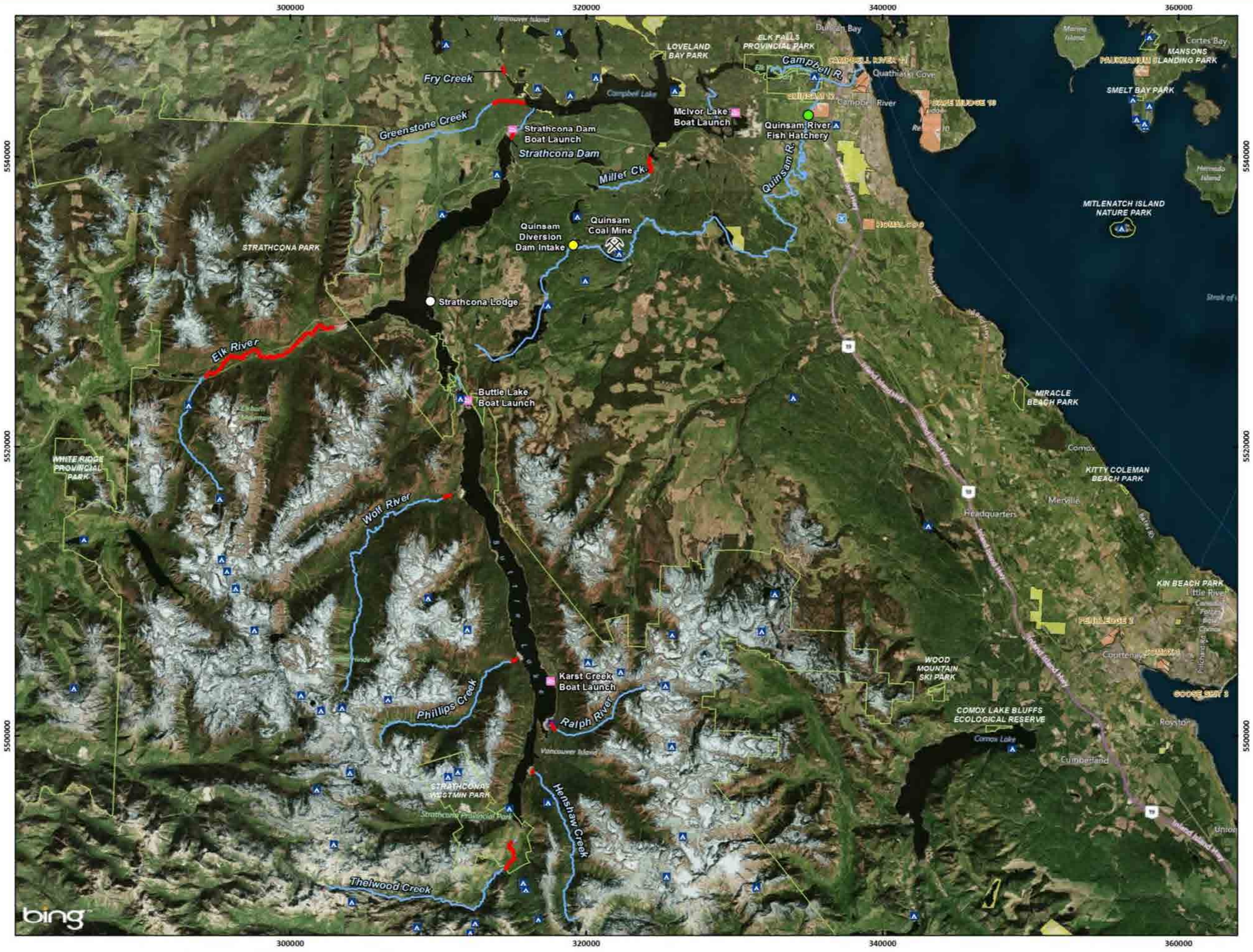
JHTMON Campbell River Water Use Plan

JHTMON-3
Snorkel Survey Reaches



Legend

- 🟥 Snorkel Survey Reach
- ▲ Campsites
- ■ Boat Launch
- ○ Strathcona Lodge
- ● Diversion Dam Intake
- ● Quinsam River Fish Hatchery
- ⚒ Quinsam Coal Mine
- ▨ First Nation Reserve
- ▨ Recreational Sites
- ☐ Parks and Protected Areas

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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ECOFISH RESEARCH

Map 3

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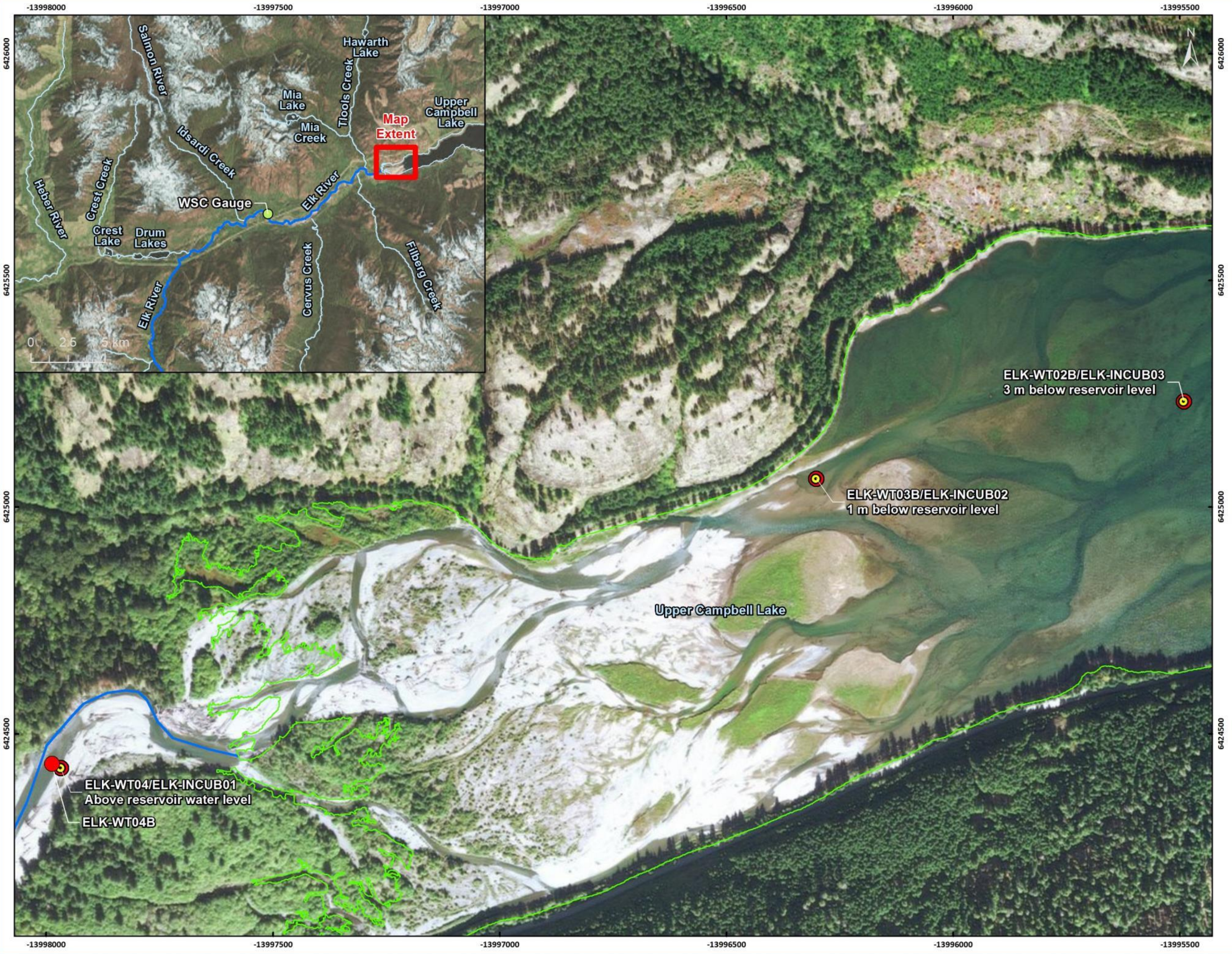
JHTMON CAMPBELL RIVER WATER USE PLAN

Elk River Incubation Test Sites and Seepage Measurements



Legend

- ⊙ Incubation Test Site
- ● Seepage Measurement
- ● Hydrometric Gauge
- — Drawdown Zone (220.5 m)
- — Elk River

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 40 80 160 240 320 400 m

Scale: 1:8,000

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Date Saved: 17/01/2019
Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

ECOFISH RESEARCH

Map 4

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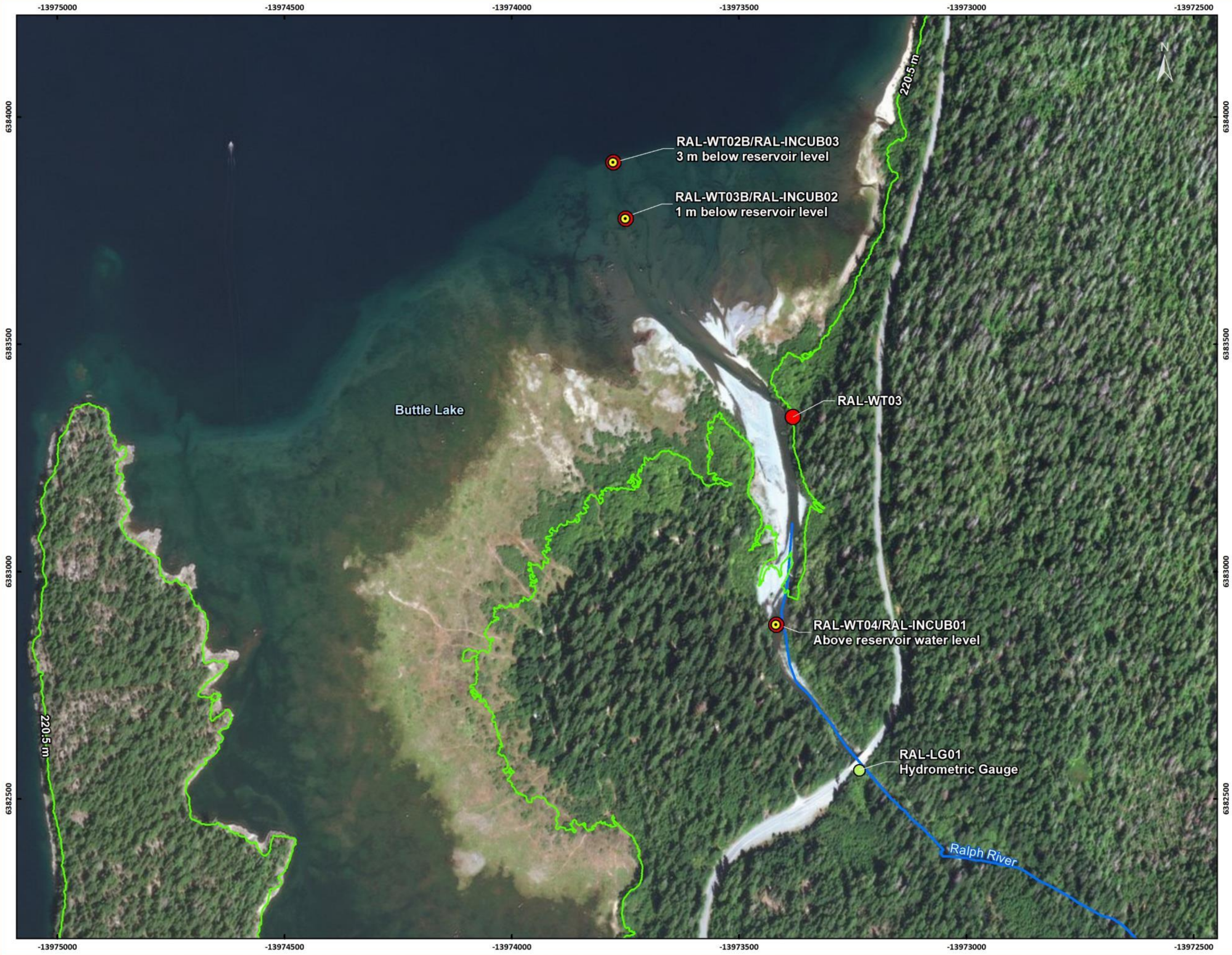

JHTMON CAMPBELL RIVER WATER USE PLAN

Ralph River Incubation Test Sites and Seepage Measurements

Legend

- ◉ Incubation Test Site
- ● Seepage Measurement
- ● Hydrometric Gauge
- — Drawdown Zone (220.5 m)
- — Ralph River

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

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ECOFISH RESEARCH

Map 5

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APPENDICES

Appendix A. Ecofish Aging Structure Collection and Analysis Protocol

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1. BACKGROUND

Fish scales, fin rays, otoliths, and other bony structures are commonly collected during fish sampling programs to determine fish age. Scales and fin rays can be collected without harming fish, while the fish must be killed to remove otoliths and other bony structures. Ideally, aging structures are collected from a representative sample of each size class and species during sampling programs. For a more complete discussion of the collection and preparation of aging structures see BC Resource Inventory Standards Committee Fish Collection Methods and Standards (RISC 1997) and Sjolund (1974).

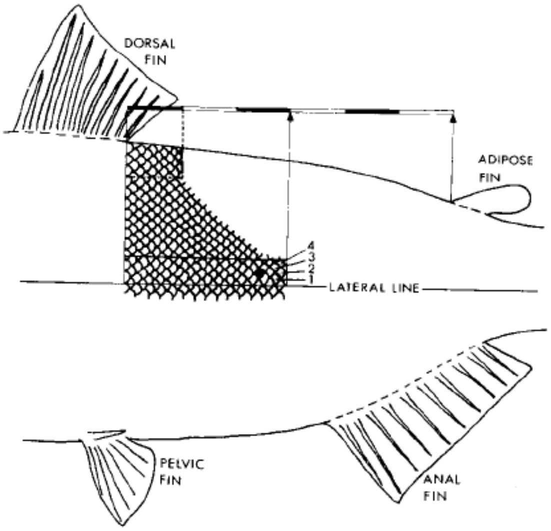
2. METHODS

2.1. Sample Collection and Preparation

2.1.1.Scales

The method for collecting scales depends on the size of the fish that is being sampled. For small and juvenile fish a few scales are scraped off with a scalpel from the area described in Figure 1. For larger fish tweezers are used to pull individual scales off the fish from the area described in Figure 1. The scales from the scalpel are smeared or placed onto a microscope slide, taking care to spread the scales out and avoid them overlapping. A second slide is placed over the scale to sandwich it between the two slides and the slides are taped together with scotch tape. Each sample is labelled and placed within a labelled scale envelope. Scale samples are stored in a plastic container that is specific to each project file, inside a locked metal filing cabinet.

Figure 1. The preferred area for removing scales from a fish (outlined in black) (Sjolund 1974).



2.1.2. Fin Ray

Fin ray samples can be taken from either the pectoral or pelvic fins. Two or three of the longest rays should be removed from the fin by clipping them off near the base of the fin and peeling the fin ray back. Fin rays should be placed in labelled scale envelopes.

Fin ray samples are dried in the laboratory and cut into 0.5 – 1.0 mm sections using a fine cut-off blade. If the fin rays are small and brittle they are to be covered in epoxy so that they stay together when cut. The sections are cut from the base of the fin ray and electricians tape is wrapped around the fin ray to prevent the cuttings from flying away. Eye protection must be worn when sectioning fin rays. The cut cross-sections are polished and mounted onto microscope slides with Krazy Glue. A drop of thin oil or water can be applied to the fin ray to enhance the appearance of winter annuli when viewing through the microscope.

2.1.3. Otoliths and Other Bony Structures

Fish must be dead to collect otoliths and other bony structures. Fish are typically euthanized by overdosing in anaesthetic. Once euthanized, the structures are removed by dissecting the fish as per the methods outlined in Section 6 of the BC Resource Inventory Standards Committee Fish Collection Methods and Standards (RISC 1997). Bony structures are stored dry in labelled scale envelopes, or in labelled vials filled with a solution of glycerine and water.

Otoliths and other bony structure samples are dried in the lab and are processed in a similar fashion to fin rays.

2.1.4. Sample Archiving

For each sample, a minimum of two scales or fin ray sections, or one otolith section, are photographed from each individual fish using a digital camera and a compound microscope. The two photographed scales or fin rays should be representative of the sample and not display any significant deformity or damage. Photographs are stored on the Ecofish Research Ltd. network in the appropriate Project folder, and all sample slides and structures are archived in a locked metal cabinet.

2.1.5. Aging

Fish age is determined by examining the structures for winter annuli. The winter annuli in scales is characterized by the noticeably tighter spacing of growth rings (circuli) that are formed during winter growth. In fin rays, otoliths and other bony structures, winter annuli are apparent as thin translucent bands. An example of each of these structures is given in Figure 2 (from Bilton and Jenkinson (1969)). Fish age is given as counts of winter annuli. Juveniles that emerged in the same year that they were collected and have not gone through a winter are classified as 0+; fish that exhibit one winter annulus are classified as 1+; and so on. Damaged structures that cannot be accurately aged are recorded as ‘damaged’.

Aging of fish samples is conducted by a minimum of two qualified technicians, one primary ager and one QA technician. Each technician ages the samples independently using only sampling date and biological data (length or weight) for the fish. The QA technician records the ages of the scales in an excel spreadsheet and compares these ages to the first agers' results entered into EcoDAT (or into an Excel file if done by external personnel, see example in Figure 3). Where ages for a single sample are different between technicians and an age cannot be agreed upon, the sample will be reviewed by a senior biologist. The Excel spreadsheet is saved in the same network folder as the scale images and TPS files.

Figure 2. Example of sockeye and chum salmon scales, otoliths and fin rays (from Bilton and Jenkinson 1969).

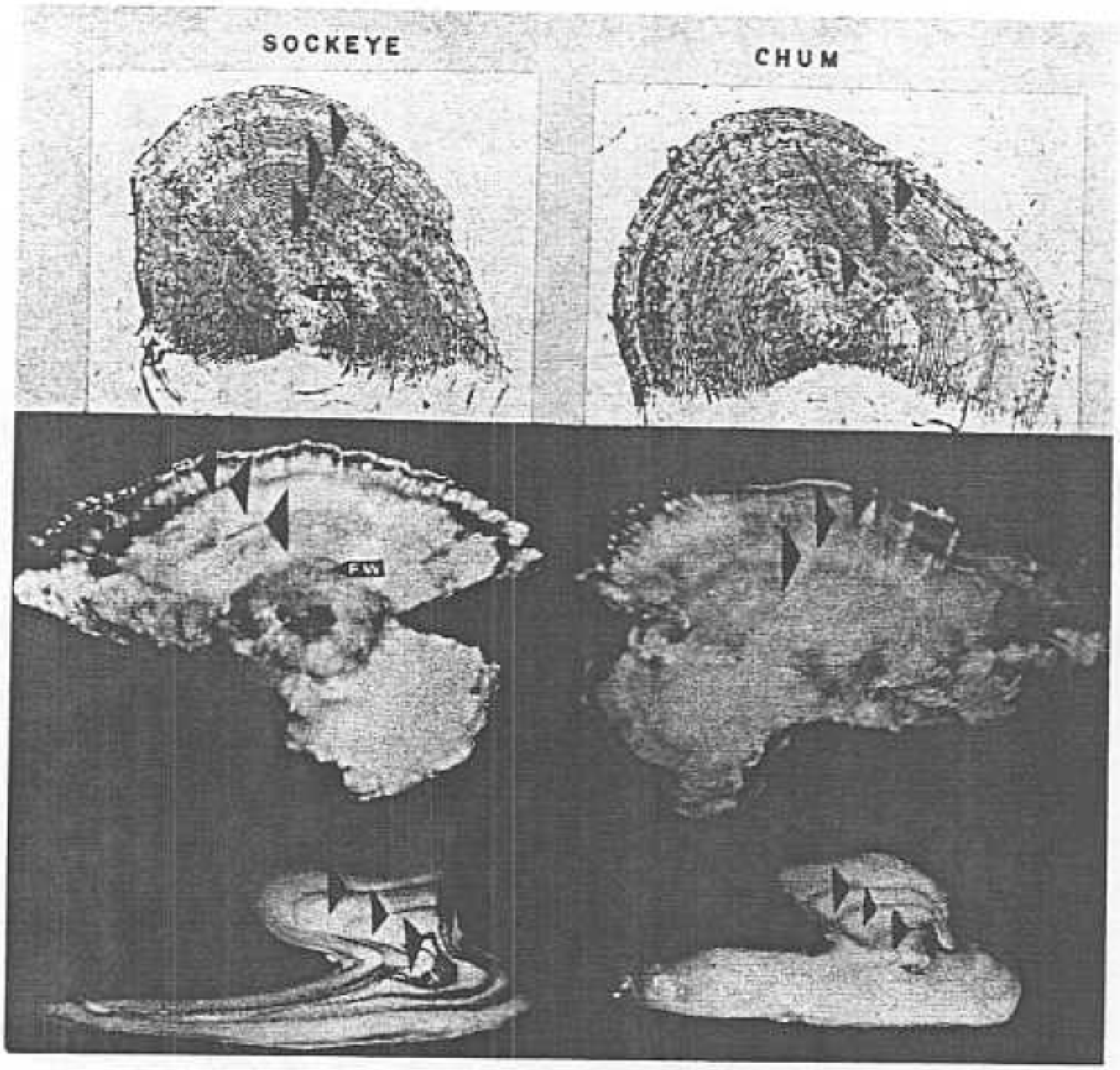


FIG. 4. Scale, otolith, and fin ray from a 1.3 sockeye and a 0.3 chum salmon: FW indicates freshwater annulus; arrows indicate ocean annuli.

Bilton and Jenkinson — J. Fish. Res. Bd. Canada

Figure 3. Example datasheet for age entry.

Technician: Date:

Location	Site	Date	Species	Length	Weight	Sample #	Age
North Creek	NTH-DVEF02	04-Oct-10	BT	169	53.1	FR-1	X

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Appendix B. Incubation Study Representative Photographs

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Figure 1. Loading incubators at the hatchery on June 19, 2018.

Figure 2. Loading incubators at the hatchery on June 19, 2018.

Figure 3. **Looking RR to RL at the Elk River Control Site ELK-INCUB01 install on June 19, 2018.**

Figure 4. **Looking at incubator at an Elk River Control Site ELK-INCUB01 installed on June 19, 2018.**

Figure 5. Looking at the Elk River incubators installed at ELK-INCUB02 on June 19, 2018.

Figure 6. Looking at the Elk River incubators installed at ELK-INCUB03 on June 19, 2018.

Figure 7. Looking at incubators installed Ralph River Control Site RAL-INCUB01 on June 20, 2018.

Figure 8. Looking at incubator installed Ralph River Site RAL-INCUB01 on June 20, 2018.

Figure 9. Looking at downstream at Ralph River Site RAL-INCUB02 install on June 20, 2018.

Figure 10. Looking at incubator install at Ralph River Site RAL-INCUB03 on June 20, 2018.

Figure 11. Looking RR to RL at the Elk River Control Site ELK-INCUB01 removal on July 6, 2018.

Figure 12. Looking upstream at the Elk River Control Site ELK-INCUB01 removal on July 6, 2018.

Figure 13. Looking downstream at the Elk River Control Site ELK-INCUB01 removal on July 6, 2018.

Figure 14. Looking Elk River Control Site ELK-INCUB01 incubator removal on July 6, 2018.

Figure 15. Looking Elk River Site ELK-INCUB02 incubator removal on July 6, 2018

Figure 16. Looking Elk River Site ELK-INCUB02 incubator removal on July 6, 2018

Figure 17. **Looking at downstream Ralph River Control Site RAL-INCUB01 removal on July 9, 2018.**

Figure 18. **Looking at RR to RL Ralph River Control Site RAL-INCUB01 removal on July 9, 2018.**

Figure 19. Looking at incubators at Ralph River Site RAL-INCUB02 prior to removal on July 9, 2018.

Figure 20. Looking Ralph River Site RAL-INCUB02 incubator removal on July 9, 2018.

Figure 21. Looking Ralph River Site RAL-INCUB03 incubator removal on July 9, 2018.

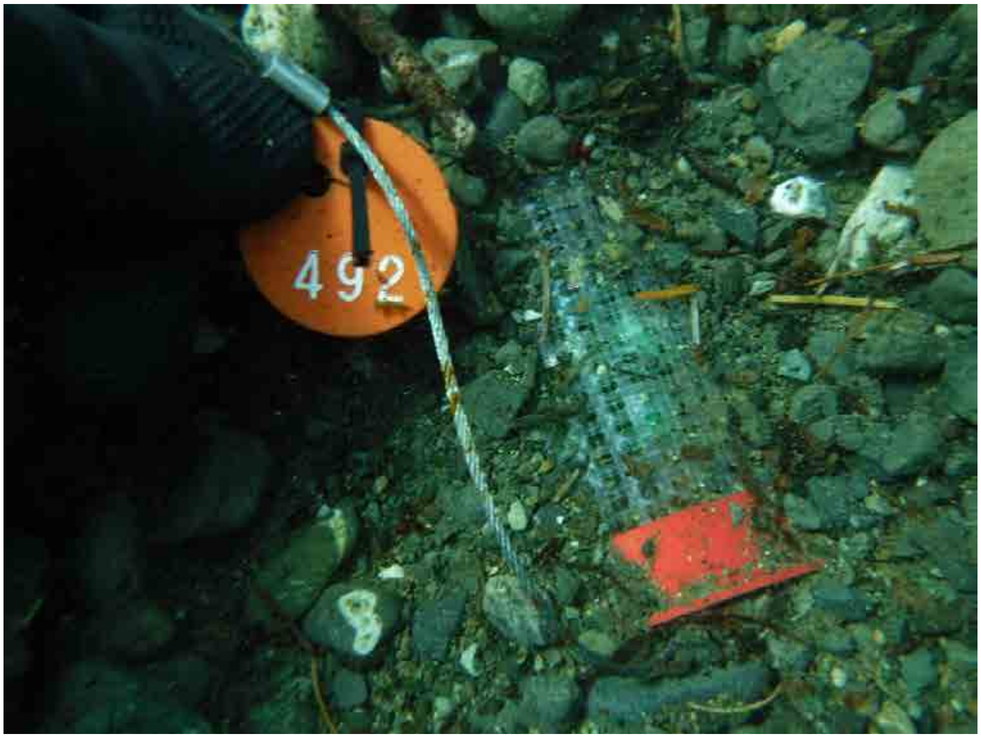

Figure 22. Looking Ralph River Site RAL-INCUB03 incubator removal on July 9, 2018.

Appendix C. Water Temperature Monitoring Data

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1. INTRODUCTION

Water temperature was measured in the mainstem of each of the incubation test study streams, in five other lake tributaries, and in the adjacent drawdown zone areas of all seven streams, with the intent of using similarities amongst streams to support extrapolating incubation test results across the reservoir tributaries

2. METHODS

Water temperature was monitored in the mainstem of each study stream as well as the drawdown zone area using self-contained TidbiT® v2 data loggers made by Onset® (**Map 1**). Two TidbiT® loggers were installed on separate anchors in each study creek. This redundancy ensured availability of data in case one of the loggers malfunctioned or was lost. In addition to the mainstem monitoring locations, a single temperature logger was installed in the drawdown zone area of each creek. TidbiT®'s were placed in the thalweg of the creek within the drawdown zone and were suspended approximately 0.3 m off the bottom to prevent them becoming buried and irretrievable. This also helped to ensure that representative water temperature near potential spawning locations in the drawdown zone were taken.

Remote time-lapse cameras were installed at the outlet of each study stream to collect two daily photos of the drawdown zone. This data was used to interpret the backwatering effects over redds.

2.1. Data Collection and Analysis

For the duration of the study, water temperature was recorded at intervals of 30 minutes, using self-contained TidbiT® v2 data loggers made by Onset®. The loggers are accurate to ±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 concurrently logged by two TidbiT® loggers installed on separate anchors, with the exception of the single loggers installed in the drawdown zone of each creek. This redundancy ensured availability of data in case one of the loggers malfunctioned or was lost. When water temperature data appeared anomalous (>0.2°C divergence from surrounding data) lake water level data and air temperature records were reviewed to determine if temperature loggers were frozen or out of the water.

Water temperature TidbiT® data were processed as follows. First, outliers were identified and removed. This was done for each logger by comparing temperature data from the duplicate station loggers and the loggers at nearby stations. For example, drops in reservoir elevations which exposed the temperature loggers to the air were considered as outliers and removed from the dataset. Second, the records from duplicate loggers 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 30 minutes (where data were not already logged on a 30-minute interval), starting at the full hour.

Analysis of the data involved computing the summary statistics described in **Table** 1.

Table 1. Description of water temperature metrics and methods of calculation.

Parameter	Description	Method of Calculation
Monthly water temperature statistics	Average, minimum, and maximum temperatures on a monthly basis	Calculated from temperatures observed at or interpolated to 15-min intervals.
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
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 7°C; the end of the growing season is defined as the last day of the first week that average stream temperature dropped below 7°C (modified from 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 7°C until the last day of the first week when weekly average temperature dropped below 7°C)
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 change 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.
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.

3. RESULTS

In Year 5, the period of record for analysis began on March 2, 2017 for sites Miller Creek, lake (MLR-LKWT), Miller Creek, creek (MLR-WT), and Ralph River, creek (RAL-WT); on March 23, 2017 at sites on Fry Creek, lake (FRY-LKWT) and Fry Creek, creek (FRY-WT); on May 3, 2017 at Greenstone Creek, creek (GRN-WT) and May 7, 2017 at Greenstone Creek, lake (GRN-LKWT); on May 4, 2017 for Elk River, lake (ELK-LKWT) and Elk River, creek (ELK-WT); and on October 28, 2017 for all other sites. The period of record ended on July 10, 2018 for all sites (Table 2).

Table 2. Period of record and percent (%) completion of the water temperature data record for monitoring sites in the John Hart Reservoir.

Monitoring Site	Location	Period of Record		% Complete
		Start	End Date	
ELK-LKWT	Elk River, lake	4-May-2017	6-Jul-2018	99
ELK-WT	Elk River, creek	4-May-2017	9-Jul-2018	99
FRY-LKWT	Fry Creek, lake	23-Mar-2017	9-Mar-2018	99
FRY-WT	Fry Creek, creek	23-Mar-2017	9-Mar-2018	99
GRN-LKWT	Greenstone Creek, lake	7-May-2018	9-Jul-2018	99
GRN-WT	Greenstone Creek, creek	3-May-2017	7-May-2018	99
MLR-LKWT	Miller Creek, lake	2-Mar-2017	9-Jul-2018	99
MLR-WT	Miller Creek, creek	2-Mar-2017	12-Mar-2018	99
PHL-LKWT	Phillips Creek, lake	28-Oct-2017	10-Jul-2018	99
PHL-WT	Phillips Creek, creek	28-Oct-2017	10-Jul-2018	99
WOL-LKWT	Wolf Creek, lake	28-Oct-2017	10-Jul-2018	99
WOL-WT	Wolf Creek, creek	28-Oct-2017	10-Jul-2018	99
RAL-WT	Ralph River, creek	2-Mar-2017	9-Jul-2018	99

Figure 1. Operational daily (a) average, (b) maximum, and (c) minimum water temperature data for the John Hart Reservoir from April 2017 to July 2018 at different monitoring sites.

(a) Daily Average

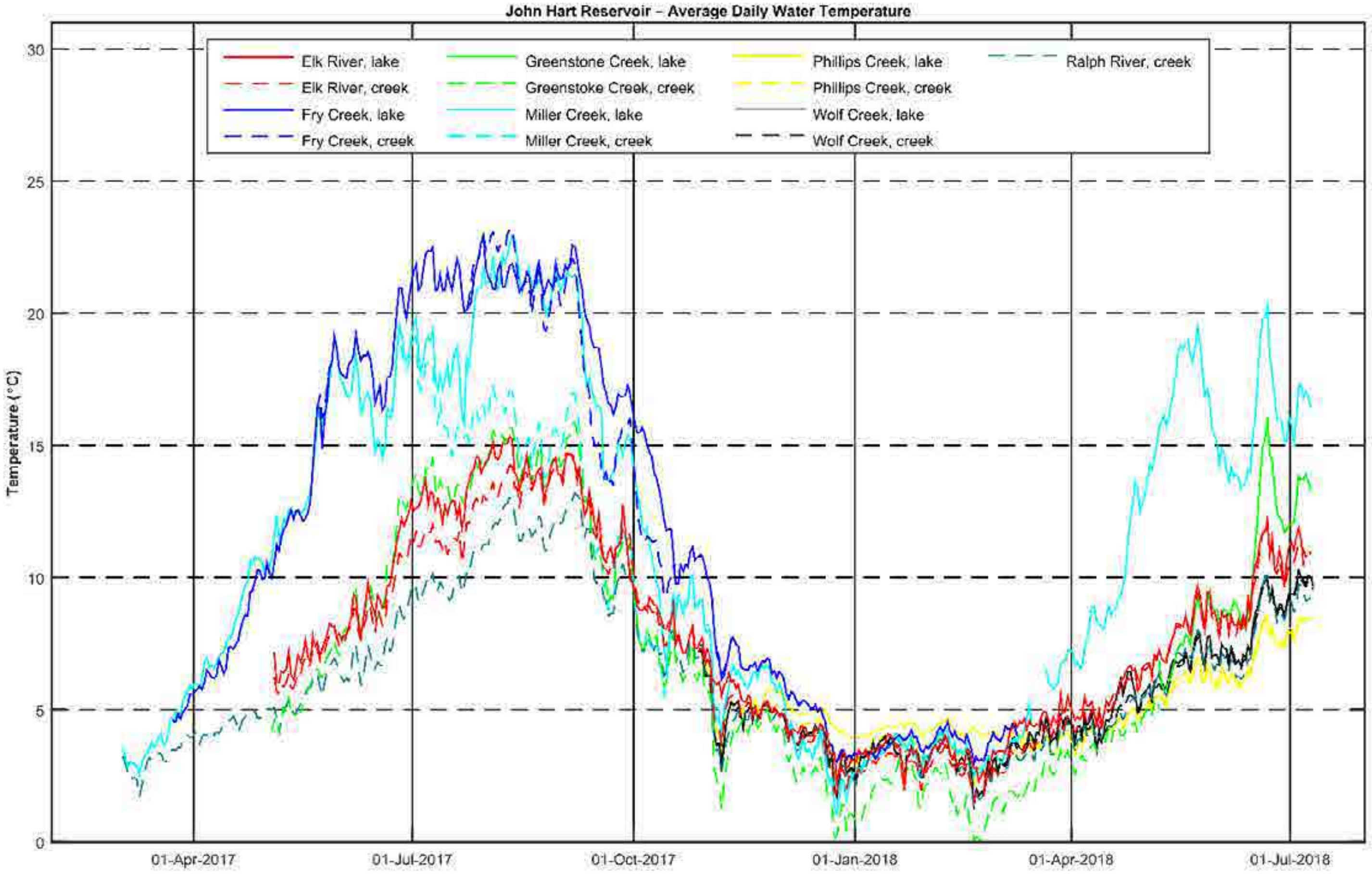


Figure 1. Continued.

(b) Daily Maximum

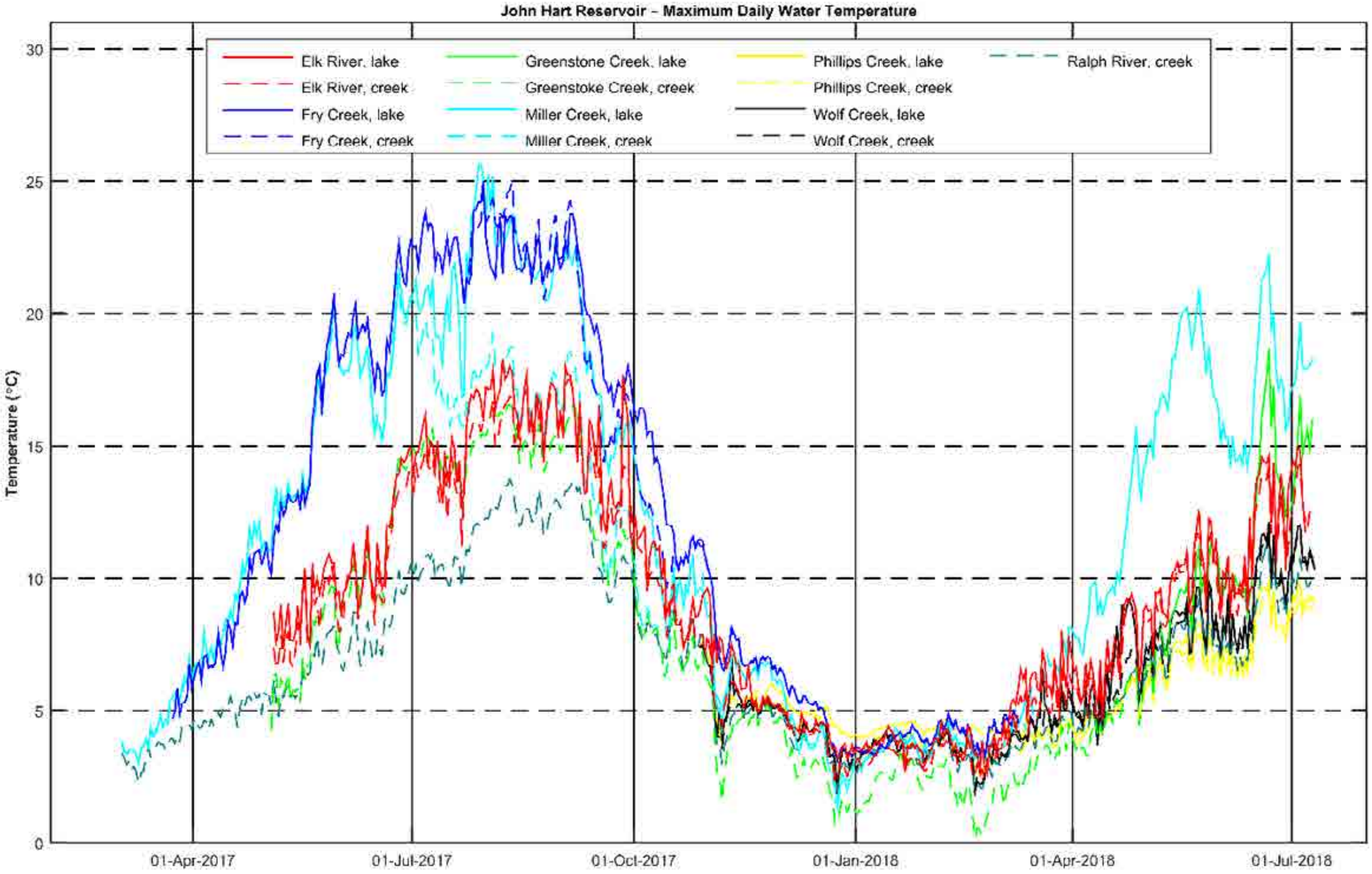
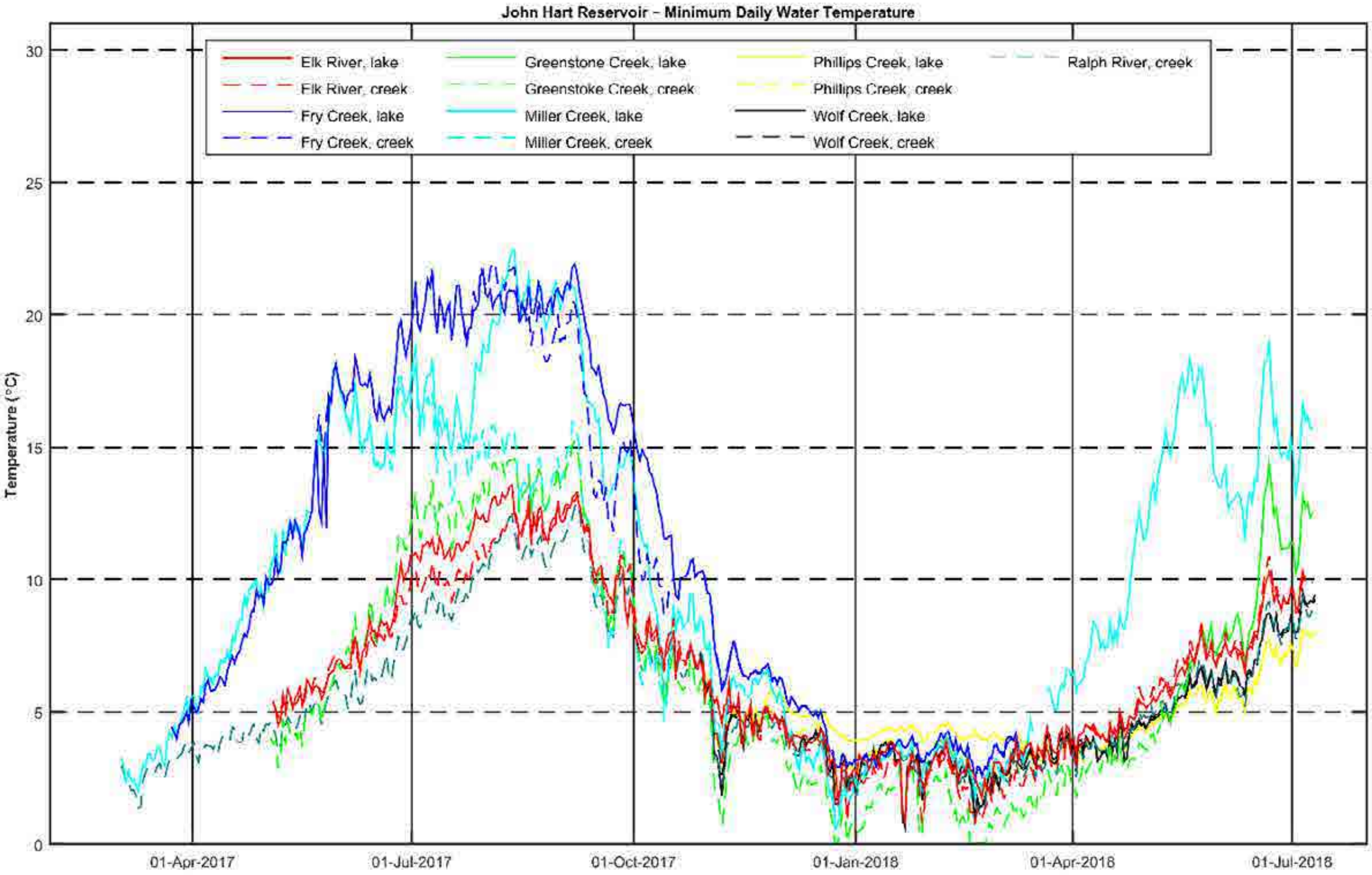


Figure 1. Continued.

(c) Daily Minimum



3.1. Monthly Statistics

In Year 5, July through September were the warmest months, corresponding to summer. Highest maximum water temperatures were observed at Miller Creek, lake (MLR-LKWT) and Fry Creek, lake (FRY-LKWT). Water temperatures in Miller Creek, lake (MLR-LKWT) increased faster compared to the other monitoring sites between April 2018 and July 2018, with maximum temperatures of just over 20°C observed in late May, when the majority of other monitoring sites were between approximately 8 to 12°C. Maximum water temperature briefly exceeded 25°C at this site in late July to early August, 2017. Coldest water temperatures were observed during winter, from December through March. Monthly average temperatures were always above freezing at all sites during winter. A monthly minimum temperature of 0°C was recorded at Greenstone Creek, creek (GRN-WT) during December to February (**Table** 3).

Table 3. **Operational monthly statistics for water temperature observed at monitoring stations in John Hart Reservoir from March 2017 to June 2018. Avg, Min, Max, and SD denote the monthly average, minimum, maximum, and standard deviation of water temperatures (°C). Statistics were not generated for months with less than 3 weeks of observations.**

3a)

Year	Month	Water Temperature(°C)																											
		ELK-LKWT Elk River, lake				ELK-WT Elk River, creek				FRY-LKWT Fry Creek, lake				FRY-WT Fry Creek, creek				GRN-LKWT Greenstone Creek, lake				GRN-WT Greenstone Creek, creek				MLR-LKWT Miller Creek, lake			
		Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
2017	Mar	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.0	2.0	7.0	1.1
	Apr	-	-	-	-	-	-	-	-	7.6	5.0	11.1	1.6	7.6	5.0	11.1	1.6	-	-	-	-	-	-	-	-	8.2	5.0	12.1	1.8
	May	7.1	4.5	10.9	1.3	6.7	4.6	10.5	1.2	13.7	9.8	20.7	2.8	13.8	9.8	20.7	2.9	-	-	-	-	5.8	2.9	9.7	1.4	13.9	9.7	20.2	2.6
	Jun	9.7	6.5	14.9	1.9	9.0	6.6	14.1	1.6	18.5	16.0	22.8	1.6	18.5	16.1	22.8	1.5	-	-	-	-	9.9	6.6	14.8	2.0	17.0	14.2	21.3	1.6
	Jul	13.1	10.7	17.2	1.5	11.8	9.1	16.0	1.6	21.4	19.1	25.0	1.1	21.5	18.8	24.5	1.1	-	-	-	-	13.6	11.2	15.7	0.9	18.7	14.8	25.6	2.1
	Aug	14.2	11.4	18.3	1.6	13.6	10.7	17.1	1.5	21.3	19.8	23.7	0.7	21.5	18.2	25.0	1.5	-	-	-	-	14.6	12.4	16.7	0.9	21.4	18.6	25.3	1.0
	Sep	12.3	8.4	18.0	2.0	12.2	8.6	17.5	1.8	18.9	15.5	23.8	2.2	16.9	11.8	24.3	3.0	-	-	-	-	12.1	8.1	16.5	2.2	17.1	13.2	22.7	2.9
	Oct	8.2	5.5	12.3	1.1	8.0	6.2	12.0	1.0	12.3	9.3	16.4	2.1	10.8	8.6	14.7	1.0	-	-	-	-	7.0	5.1	9.7	0.9	9.7	5.3	14.3	1.8
	Nov	5.5	3.8	9.3	0.7	5.0	3.1	7.3	0.6	7.0	5.8	10.1	0.8	7.0	5.8	10.1	0.8	-	-	-	-	4.0	0.7	5.9	1.0	6.0	3.0	8.5	0.9
	Dec	3.8	1.8	5.0	0.7	3.4	0.9	5.1	0.8	4.6	2.9	6.5	1.0	4.6	2.9	6.5	1.0	-	-	-	-	2.2	0.0	4.6	1.1	3.2	0.7	6.0	1.1
2018	Jan	3.3	0.9	4.4	0.5	2.9	0.8	3.6	0.5	3.6	3.0	4.5	0.3	3.7	2.9	4.5	0.3	-	-	-	-	2.1	0.3	3.4	0.7	3.3	1.7	4.3	0.5
	Feb	3.2	1.7	4.5	0.5	2.6	0.8	4.1	0.7	3.8	2.4	4.9	0.5	3.8	2.5	4.9	0.5	-	-	-	-	1.5	0.0	3.1	0.9	3.4	1.8	4.5	0.6
	Mar	4.5	2.6	8.0	1.0	3.7	1.7	6.7	1.0	-	-	-	-	-	-	-	-	-	-	-	-	2.3	0.7	4.5	0.8	5.0	2.4	8.1	1.5
	Apr	5.5	3.4	9.4	1.2	5.2	3.0	8.8	1.1	-	-	-	-	-	-	-	-	-	-	-	-	3.8	1.7	6.6	0.9	9.3	5.8	15.8	2.2
	May	7.9	5.1	12.6	1.6	7.8	5.3	11.7	1.3	-	-	-	-	-	-	-	-	7.7	4.6	11.5	1.5	-	-	-	-	16.7	11.7	20.9	1.9
	Jun	9.7	6.5	14.6	1.9	9.5	6.7	14.3	1.6	-	-	-	-	-	-	-	-	11.0	6.7	18.7	2.6	-	-	-	-	15.7	11.5	22.2	2.2

"-" indicates not enough data was available to calculate these statistics

Blue and red shading represent minimum and maximum temperatures, respectively

Table 3. Continued.

3b)

Year	Month	Water Temperature(°C)																							
		MLR-WT Miller Creek, creek				PHL-LKWT Phillips Creek, lake				PHL-WT Phillips Creek, creek				WOL-LKWT Wolf Creek, lake				WOL-WT Wolf Creek, creek				RAL-WT Ralph River, creek			
		Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
2017	Mar	4.0	2.1	6.7	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.1	1.3	4.5	0.6
	Apr	8.2	5.0	12.1	1.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.4	3.1	5.7	0.5
	May	13.9	9.8	20.1	2.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.6	3.5	8.2	0.9
	Jun	16.9	14.1	21.8	1.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.3	5.1	10.6	1.2
	Jul	16.4	12.9	20.5	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.0	8.2	12.3	0.9
	Aug	15.6	12.5	19.3	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.0	10.2	13.7	0.7
	Sep	12.5	7.4	18.6	2.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10.8	7.8	13.7	1.5
	Oct	8.2	4.7	10.6	1.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.3	5.9	9.3	0.7
	Nov	6.1	3.3	8.5	0.8	5.1	3.1	6.8	0.6	5.0	3.2	6.9	0.5	4.8	1.8	7.1	0.7	4.7	2.6	6.7	0.7	4.6	2.3	6.6	0.7
	Dec	3.3	0.6	5.9	1.1	4.7	3.9	5.6	0.4	3.9	2.1	5.3	0.8	3.6	1.5	5.1	0.8	3.7	1.7	5.1	0.8	3.4	1.5	5.0	0.8
2018	Jan	3.3	2.0	4.1	0.4	4.2	3.9	4.6	0.2	3.7	2.3	4.2	0.4	3.3	0.7	4.2	0.5	3.3	0.6	4.2	0.5	3.2	1.8	3.9	0.4
	Feb	3.4	2.0	4.5	0.5	4.2	3.9	4.8	0.2	3.3	1.8	4.4	0.6	3.0	1.0	4.2	0.7	3.0	0.9	4.2	0.7	2.8	0.7	4.5	0.8
	Mar	-	-	-	-	3.9	3.0	4.5	0.3	3.5	2.6	4.7	0.5	3.9	2.1	6.6	0.7	3.7	2.1	5.6	0.6	3.5	2.3	5.0	0.6
	Apr	-	-	-	-	4.3	3.1	6.3	0.6	4.3	2.6	6.1	0.6	4.9	2.9	9.2	1.2	4.6	2.7	7.3	0.9	4.5	2.5	6.6	0.7
	May	-	-	-	-	6.0	4.2	8.3	0.8	5.8	4.2	7.9	0.8	6.7	4.4	9.9	1.1	6.5	4.3	9.5	1.1	6.7	4.8	9.2	1.0
	Jun	-	-	-	-	7.1	5.0	9.9	1.0	6.9	5.0	9.6	1.0	8.2	5.7	12.1	1.3	8.0	5.6	11.8	1.3	7.8	5.2	11.3	1.3

3.2. Incubation Period and Degree Days

For every operational year, incubation period for Cutthroat begins on February 1 and ends in the third week of June in the Lower Campbell Reservoir, while in the Upper Campbell Reservoir, incubation period for Rainbow Trout begins on June 1 and ends in the third week of August.

The longest incubation period in Year 5 was observed at Fry Creek, lake (FRY-LKWT) in 2017, with water temperatures greater than 7°C observed for 213 days. The shortest incubation period was observed at Wolf Creek, creek (WOL-WT) in 2018 (n=16 days). However, at many sites where the incubation period was comparatively short (e.g., Ralph River, creek, 2018; Phillips Creek, lake and creek, 2018) the number of days with valid data was also fewer than in waterways with longer incubation periods (**Table** 4). Thus, a lack of reliable data has influenced these results.

Table 4. Incubation period and cumulative degree days at monitoring stations in John Hart Reservoir, 2017 - 2018. Project phase was operational for all of these dates. Definition of degree days is provided in Table 1.

Site	Location	Year	Number of days with valid data	Growing Season Data Summary				
				Start Date	End Date	Length (days)	Gap (days)	Degree Days
ELK-LKWT	Elk River, lake	2017	241	14-May	03-Nov	174	0	1,913
		2018	186	05-May	09-Jul	65	1	569
ELK-WT	Elk River, creek	2017	241	19-May	02-Nov	168	0	1,779
		2018	189	05-May	12-Jul	68	1	590
FRY-LKWT	Fry Creek, lake	2017	283	12-Apr	09-Nov	212	0	3,480
		2018	67	-	-	-	-	-
FRY-WT	Fry Creek, creek	2017	282	12-Apr	10-Nov	213	1	3,393
		2018	67	-	-	-	-	-
GRN-LKWT	Greenstone Creek, lake	2017	-	-	-	-	-	-
		2018	62	12-May	12-Jul	61	1	597
GRN-WT	Greenstone Creek, creek	2017	241	24-May	14-Oct	144	0	1,698
		2018	126	-	-	-	-	-
MLR-LKWT	Miller Creek, lake	2017	304	09-Apr	05-Nov	211	0	3,219
		2018	182	02-Apr	12-Jul	101	1	1,393
MLR-WT	Miller Creek, creek	2017	304	09-Apr	13-Oct	188	0	2,599
		2018	70	-	-	-	-	-
PHL-LKWT	Phillips Creek, lake	2017	64	-	-	-	-	-
		2018	190	13-Jun	13-Jul	30	1	212
PHL-WT	Phillips Creek, creek	2017	64	-	-	-	-	-
		2018	190	13-Jun	13-Jul	30	1	208
WOL-LKWT	Wolf Creek, lake	2017	64	-	-	-	-	-
		2018	190	16-May	10-Jun	26	0	186
WOL-WT	Wolf Creek, creek	2017	64	-	-	-	-	-
		2018	190	17-May	01-Jun	16	0	113
RAL-WT	Ralph River, creek	2017	304	15-Jun	23-Oct	131	0	1,300
		2018	189	13-May	31-May	19	0	135

We defined the start of the growing season as the beginning of the first week that average stream temperatures exceeded and remained above 7°C for the season. The end of the growing season was defined as the last day of the first week that average stream temperatures dropped below 7°C (Coleman and Fausch 2007).

"-" indicates not enough data was available to calculate these statistics

PROJECT MAPS

JHTMON Campbell River Water Use Plan

JHTMON3 Physical Monitoring Station Locations

Legend

●	Water Temperature Monitoring Site
○	Strathcona Lodge
▨	Boat Launch
▨	First Nation Reserve
▭	Parks and Protected Areas

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 1 2 4 6 8 10 km

Scale: 1:200,000

NO.	DATE	REVISION	BY
1	03/01/2019	1230_JHTMON3_PhysicalMonStations_2019Jan03	CGA
2			
3			
4			
5			

Date Saved: 03/01/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_JHTMON3_PhysicalMonStations_2019Jan03.mxd

Appendix D. Drawdown Zone Representative Photographs

LIST OF FIGURES

2018 DRAWDOWN ZONE REPRESENTATIVE PHOTOGRAPHS

Lower Campbell Reservoir - 2018 (February 1 to April 30)

Figure 1. Looking at Greenstone River on February 6, 2018 at 09:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.613 m.

Figure 2. Looking at Greenstone River on April 22, 2018 at 10:00 with a min reservoir level during Cutthroat Trout Spawning season of 176.041 m.

Figure 3. Looking at Greenstone River on March 20, 2018 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.347 m.

Figure 4. Looking at Fry Creek on February 6, 2018 at 10:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.613 m

Figure 5. Looking at Fry Creek on April 22, 2018 at 10:00 with a min reservoir level during Cutthroat Trout Spawning season of 176.041 m.

Figure 6. Looking at Fry Creek on March 20, 2018 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.347 m.

Figure 7. Looking at Miller Creek on February 6, 2018 at 09:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.613 m.

Figure 8. Looking at Miller Creek on April 22, 2018 at 10:00 with a min reservoir level during Cutthroat Trout Spawning season of 176.041 m.

Figure 9. **Looking at Miller Creek on March 20, 2018 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.347 m.**

Upper Campbell Reservoir - 2018 (May 25 to July 31)

Figure 10. Looking at Elk River on June 25, 2018 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 217.471 m.

Figure 11. Looking at Elk River on June 7, 2018 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 216.81 m.

Figure 12. **Looking at Elk River on July 6, 2018. July 23, 2018 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 217.149 m[1].**

Figure 13. **Looking at Wolf River on June 25, 2018 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 217.471 m.**

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[1] Median reservoir level during Rainbow Trout Spawning season of 217.149 m was on July 23, 2018, canmera was pulled on July 6, 2018.

Figure 14. Looking at Wolf River on June 7, 2018 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 216.81 m.

Figure 15. Looking at Wolf River on July 23, 2018 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 217.149 m.

Figure 16. Looking at Ralph River on June 20, 2018 at 10:00[2].

Figure 17. Looking at Ralph River on June 7, 2018 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 216.81 m.

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[2] Max reservoir level during Rainbow Trout Spawning season of 217.471 m was on June 25, 2018, camera was pulled on June 20, 2018. Median reservoir level during Rainbow Trout Spawning season of 217.149 m on July 23, 2018.

Figure 18. Looking at Phillips Creek on June 25, 2018 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 217.471 m.

Figure 19. Looking at Phillips Creek on June 7, 2018 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 216.81 m.

Figure 20. Looking at Phillips Creek on July 23, 2018 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 217.149 m.

2017 DRAWDOWN ZONE REPRESENTATIVE PHOTOGRAPHS

Lower Campbell Reservoir - 2017 (February 1 to April 30)

Figure 21. Looking at Greenstone River on April 30, 2017 at 10:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.684 m.

Figure 22. Looking at Greenstone River on March 8, 2017 at 09:00 with a min reservoir level during Cutthroat Trout Spawning season of 177.105 m.

Figure 23. Looking at Greenstone River on April 3, 2017 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.586 m.

Figure 24. Looking at Fry Creek on April 30, 2017 at 10:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.684 m.

Figure 25. **Looking at Fry Creek on March 20, 2018 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.347 m.**

Figure 26. **Looking at Millar Creek on April 30, 2017 at 10:00 with a max reservoir level during Cutthroat Trout Spawning season of 177.684 m.**

Figure 27. **Looking at Millar Creek on March 8, 2017 at 10:00 with a min reservoir level during Cutthroat Trout Spawning season of 177.105 m.**

Figure 28. **Looking at Millar Creek on March 20, 2018 at 10:00 with a median reservoir level during Cutthroat Trout Spawning season of 177.347 m.**

Upper Campbell Reservoir - 2017 (May 21 to July 31)

Figure 29. Looking at Elk River on June 27, 2017 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 219.761 m.

Figure 30. Looking at Elk River on May 21, 2017 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 217.816 m.

Figure 31. Looking at Elk River on July 13, 2017 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 219.499 m.

Figure 32. Looking at Wolf River on June 27, 2017 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 219.761 m.

Figure 33. Looking at Wolf River on May 21, 2017 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 217.816 m.

Figure 34. Looking at Wolf River on July 13, 2017 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 219.499 m.

Figure 35. **Looking at Ralph River on June 27, 2017 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 219.761 m.**

Figure 36. **Looking at Ralph River on May 21, 2017 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 217.816 m.**

Figure 37. **Looking at Ralph River on July 13, 2017 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 219.499 m.**

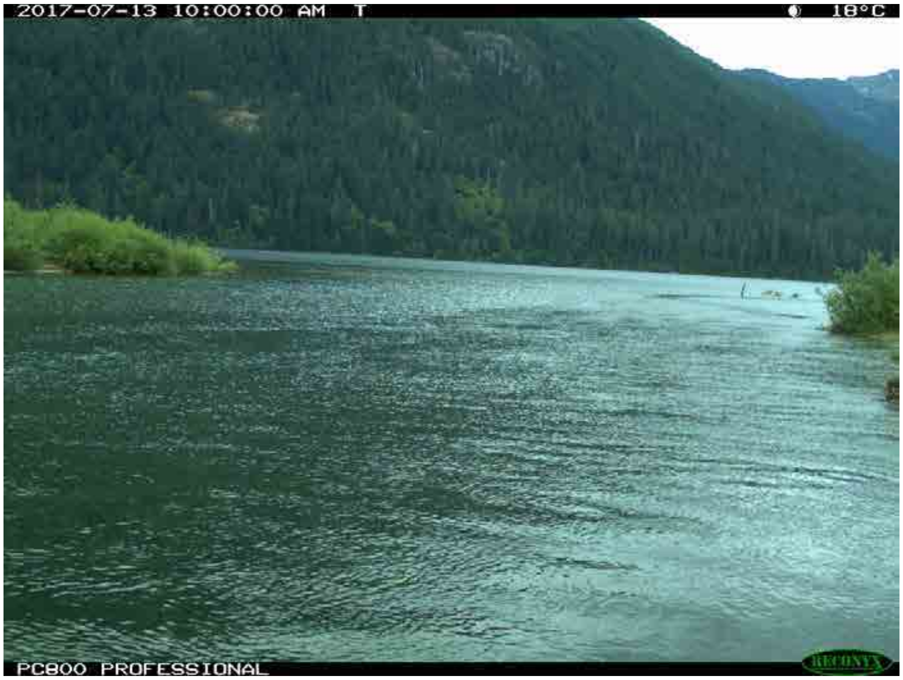

Figure 38. **Looking at Phillips Creek on June 27, 2017 at 10:00 with a max reservoir level during Rainbow Trout Spawning season of 219.761 m.**

Figure 39. Looking at Phillips Creek on May 21, 2017 at 10:00 with a min reservoir level during Rainbow Trout Spawning season of 217.816 m.

Figure 40. Looking at Phillips Creek on July 13, 2017 at 10:00 with a median reservoir level during Rainbow Trout Spawning season of 219.499 m.

Appendix E. Incubation Habitat and Seepage Conditions Memo

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MEMORANDUM

TO: **Jeff Walker, BC Hydro Water Licence Requirements**
FROM: **Rachel Day, M.Sc., P.Geo., David West, M.Sc., P.Eng., Nicole Wright, Ph.D., P.Geo., PWS, Ecofish Research Ltd.**
DATE: **February 21, 2019**
FILE: **1230-34**

RE: Methods and Results of the Incubation Habitat and Seepage Conditions Study, part of JHTMON-3, the Upper and Lower Campbell Lake Fish Spawning Success Assessment Year 5 Annual Monitoring Report – Draft V1

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1. INTRODUCTION

The *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3) is one of a number of effectiveness monitoring studies within the Campbell River Water Use Plan (BC Hydro 2012). The objective of JHTMON-3 is to test salmonid recruitment (trout and char) in the Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir to help resource managers better understand the potential biological effects of BC Hydro operations. Work was conducted in 2018 to assess the link between egg incubation success and groundwater upwelling by testing null impact hypothesis 4 from the JHTMON-3 terms of reference:

> $H_0$4: There is insufficient groundwater movement in areas of the drawdown zone suitable for trout spawning to replenish local oxygen supply and flush away metabolic waste.

Incubation tests were conducted to compare egg hatchability in inundated and non-inundated sites. Seepage tests were conducted at incubation test sites to measure groundwater input and water quality. This memorandum presents the detailed results of incubation habitat and seepage conditions. A summary of these results and their relation to the incubation tests conducted is presented in the JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment Year 5 Annual Monitoring Report (Buren *et al.* 2019).

2. METHODS

The methods used to measure the habitat variables at each site, including substrate composition, *in situ* water quality, and seepage (groundwater) flow hypothesized to influence salmonid incubation success are presented here. The selected study sites occur across a gradient of reservoir inundation (Table 1, Map 1 and Map 2).

Four key variables were measured to assess incubation habitat conditions: substrate composition (Section 2.1), seepage (groundwater) conditions (which included temperature variations and groundwater levels - see below for details of instrument installation), and dissolved oxygen (DO) and other water quality parameters (Section 2.3). Seepage conditions were in turn used to estimate seepage rates using the temperature tracer method and Darcy's equation and (Section 2.2). In addition, Upper Campbell Reservoir levels and stream flow were plotted with seepage rates to examine trends in groundwater movement in areas of the drawdown zone (Section 2.4).

Temperature Array Installation

To obtain continuous measurements of stream bed[1] temperature, four Onset Tidbit V2 temperature data loggers were installed in a vertical array at approximate depths of 0 cm (on the stream bed), 10 cm, 30 cm, and 50 cm. The stream bed sensor was fitted with a radiation shield with drilled holes to allow water to flow through. Temperature was continuously recorded at 2-minute intervals.

The temperature sensors were fastened to a steel stake at the appropriate spacing to create an array. Installation of the arrays consisted of either excavating and backfilling, or hammering a hollow sleeve into the stream bed that could be used to insert the array before removing the sleeve. The sleeve method was used in all locations where grain size allowed hammering in the sleeve. Substrate was set aside in an attempt to backfill the hole with the same substrate as that removed.

Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018). Some sites needed to be relocated slightly due to dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Additionally, sensors at a given depth for a site may also have been damaged or were found to be malfunctioning. In such cases, the sensor depths utilized (i.e., with viable data) are noted.

Piezometer Installation

Due to the greater water level depth at the third inundation sites (3 m below reservoir water level), piezometers were only installed at the above reservoir water level and 1 m depth below reservoir water level sites. At the above reservoir water level sites (RAL-WT04 and ELK-WT04B), piezometers were installed at three locations across a transect at approximately ¼, ½, and ¾ of the wetted width. Due to the large wetted width at the 1 m below reservoir water level sites (RAL-WT03B and ELK-WT03B), piezometers were installed at three locations across a sub-section of the wetted width.

Piezometers were custom made to be robust, reusable, and maintain tight contact between the bed material and the piezometer. The body of the piezometer was made of 1" S40 stainless steel with an inner diameter of 26 mm. A stainless-steel drive point tip was welded to the bottom of the body and a manual slide hammer was permanently attached to aid installation. The screen length of the

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[1] Note that the terms 'stream' and 'stream bed' have been used throughout for ease; however, the statements also apply to 'lake' and 'lake bed'.

piezometer was 10 cm. A ¾ inch PVC pipe fitted with a drive point was inserted into the piezometer during installation to prevent suspended sediment and small substrate from entering the screen.

The piezometers were driven vertically into the stream bed substrate to the desired depth and purged with a peristaltic pump at low flow rates. An equivalent of three piezometer volumes was pumped. The piezometers were left to equilibrate for a minimum of 15 minutes until the water level had stabilized[1]. Once water levels had stabilized, the water level tape and water quality probes were lowered into the standpipe piezometer to take measurements of depth to groundwater (Section 2.2), and DO, specific conductivity, pH, and water temperature (Section 2.3). Once the measurements were recorded, the tape/probes were removed and the piezometer was driven deeper or moved to another location within the same study site and allowed to equilibrate prior to completing another set of water quality and depth to groundwater measurements. Measurements were made at 0 cm, 30 cm and 50 cm depths, at three locations within each study site.

Measurements were taken at the study sites in areas representative of spawning habitat on June 19/20 and July 6/9, 2018 during incubator installation and removal, respectively. All sites and measurements were photo documented; representative photos are presented in Appendix A.

Piezometer transects were located within 20 m of the temperate array installed at each site.

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[1] The equilibration time was determined by undertaking measurements every 5 minutes for 30 minutes (more time was not required) at three sites, taking care to test equilibrium times at sites with different substrate conditions. Trends in water level, DO, and temperature were assessed over this duration and were used to confirm that sufficient equilibration time was allowed before each measurement during the study.

Table 1. Study site locations and instrument (temperature array and piezometer) installation/measurement dates during incubator installation (June 2018) and removal (July 2018).

Watercourse	Site[1]	Description	Temperature Array Installation Date	Piezometer In situ Sampling Dates
Elk River	ELK-WT04	above reservoir water level	15-Feb-2018	-
	ELK-WT04B		19-Jun-2018	19-Jun-2018 6-Jul-2018
	ELK-WT03B	1 m below reservoir water level	19-Jun-2018	19-Jun-2018 6-Jul-2018
	ELK-WT02B	3 m below reservoir water level	19-Jun-2018	-
Ralph River	RAL-WT04	above reservoir water level	15-Feb-2018	20-Jun-2018 9-Jul-2018
	RAL-WT03		14-Feb-2018	-
	RAL-WT03B	1 m below reservoir water level	15-Feb-2018	20-Jun-2018 9-Jul-2018
	RAL-WT02B	3 m below reservoir water level	20-Jun-2018	-

[1] Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018); however, some sites needed to be relocated slightly due to site dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Only sites for which viable data were obtained have been included.

2.1. Substrate Composition

Porosity, the portion of substrate volume occupied by pore spaces, was measured in the laboratory from sediment samples collected on June 19 and 20, 2018 (during piezometer installation) at each study site (Table 1, Map 1 and Map 2). Sediments were collected with a bucket and spade to a minimum depth of approximately 35 cm. A particle size analysis was conducted (as per Danielson and Sutherland 1986) and the average percent of fines (defined as particles < 2 mm) was reported. Porosity was used to compute the soil bulk density, the ratio of the mass of dry solids to the bulk volume of the substrate, assuming a sediment density of 2.65 g/cm^3 (Thien and Graveel 2002). Sediment thermal properties (i.e., thermal conductivity and sediment heat capacity) were calculated using dry bulk density values for use in the temperature tracer method (Lapham 1989). Dispersivity was assumed uniform for the entire project using typical values found in the literature (Bianchin *et al.* 2010, Birkel *et al.* 2016).

2.2. Seepage

2.2.1. Vertical Hydraulic Gradient

Water surface elevations were measured using an electronic interface measuring tape (Solinst Model 101; 1 mm accuracy). To reduce water level fluctuations outside of the piezometer, a stilling well was placed over the piezometer before measuring water surface elevation. Water level measurements were repeated a minimum of three times at each piezometer depth and location (e.g., river/transect right, mid-channel/transect, and river/transect left), until consecutive measurements were the same, to allow sufficient equilibrium time (i.e., water levels inside and outside of the piezometers remained consistent and stable) and to reduce the potential for human error in reading the measuring tape.

Water level measurements were used to determine an approximate vertical hydraulic gradient (VHG; $i = \frac{dh}{dl}$) where *i* is the VHG, *dh* is the difference in hydraulic head between the aquifer and river (positive indicates upwelling flow and negative indicates downwelling flow), and *dl* is the difference in distance between the stream bed and the midpoint of the piezometer perforations or screen at each piezometer location (Table 1, Map 1 and Map 2). An arbitrary datum of the river bed elevation at each location was used to determine hydraulic head. The VHG was used to estimate the extent of groundwater upwelling from or downwelling to the stream bed at a site.

2.2.2. Hydraulic Conductivity

Hydraulic conductivity (K) represents the ease with which a fluid can move through substrate, and is highly correlated to porosity. Hydraulic conductivity was estimated for selected sites using a temperature tracer method (Voytek *et al.* 2014; Koch *et al.* 2015) and slug (bail) tests (Kalbus *et al.* 2006).

2.2.2.1. Temperature Tracer Method

With a known *dh*, 1DTempPro can be used to numerically solve for an optimal K value that results in a similar modelled thermal gradient time series to that observed in the field (Voytek *et al.* 2014; Koch *et al.* 2015). 1DTempPro is a graphical user interface to the numerical model VS2DH (Healy and Ronan 1996). Running 1DTempPro requires a *dh* value at the same depth as the deepest thermistor (sensor). Hydraulic conductivity (K) values were estimated for the above reservoir water level and 1 m below reservoir water level sites at both Elk River and Ralph River for the incubation period (June – July 2018) (Table 1). The *dh* for each replicate (n=3) and sampling period (n=2) were averaged for each site. For sites with strong downwelling predictions, the range of modelled values that had root mean square error (RMSE) less than 0.2°C (the accuracy of Tidbits) were included. These estimates of K were compared to K calculated based on hydraulic response tests (see below).

2.2.2.2. Hydraulic Response Tests

Slug (bail) tests were conducted on July 6, 2018 at the above reservoir water level and 1 m below reservoir water level sites at Elk River and on July 9, 2018 at the same Ralph River sites (Table 1, Map **1** and Map 2), at a measured depth of 50 cm. Static water levels were measured prior to inserting equipment into the piezometers. A Solinist Levelogger was placed in each of the test piezometers and set to measure water levels every 60 seconds during the completion of the hydraulic response tests. Manual groundwater level measurements were also made during the test. A known volume of water was removed from each piezometer. The hydraulic response tests were complete when water levels reached stabilization. The data was run through AquiferTest 8.0 (software program) to determine hydraulic conductivity using the Bouwer and Rice (1976) method.

2.2.3. Seepage Rate

Approximate seepage rates were calculated using the temperature tracer method (Voytek *et al.* 2014; Koch *et al.* 2015) and Darcy's equation (Darcy 1856).

2.2.3.1. Temperature Tracer Method

Seepage rates were estimated at the study sites where temperature arrays were installed using temperature as a tracer method (Table 1, Map 1 and Map 2). The propagation of diurnal heat fluxes from a stream bed into a stream can be used to estimate groundwater recharge and discharge from the stream to the stream bed. Groundwater exchange rates were modelled using water temperature profiles and one-dimensional flow and heat-transport equations using 1DTempPro (Voytek *et al.* 2014; Koch *et al.* 2015). The 1DTempPro model has a function to estimate groundwater exchange rate using at least three thermistors, with one on the stream bed, and two at different depths in the stream bed. Four sensors were used where feasible (i.e., sensor function was maintained) to improve the accuracy of the estimates. The generalized premise of the model is that the phase lag and amplitude ratio between the sensors indicates the direction (amplitude ratio) and strength (amplitude ratio and phase lag) of groundwater exchange (Briggs *et al.* 2014).

Seepage rate was estimated at each site using subsets of the data collected from February 13, 2018 to July 9, 2018. 1DTempPro has an optimizer function that allows estimation of average seepage rate for a given period. The only field data required are the temperature array time series and porosity. Six periods were selected to estimate seepage rates given varying reservoir levels, stream flow rates, and seasons. The pre-incubation period included: minimum reservoir level and low flow (Period 1, March 30 – April 5, 2018), beginning of freshet (Period 2, April 8 – April 16, 2018), and the end of freshet (Period 3, May 15 – May 21, 2018). The incubation period included three periods to account for substantial variations in stream flow and modest variations in reservoir level (Period 4, June 20 – June 23, 2018; Period 5, June 24 – June 28, 2018; and Period 6, June 29 – July 6, 2018). Seepage rates over the entire incubation period were also averaged.

For each seepage rate estimate, an initial estimate had to be entered as a starting point for numerical optimization. To provide an initial estimate, a time series plot of the temperature array was reviewed and either 1 m/d of downwelling or upwelling were used depending on qualitative observation of the amplitude ratio. The optimization then consists of modelling the temperature pattern of the intermediate sensors associated with varying seepage rate estimates. The accuracy of the results is expressed in terms of RMSE (°C) between the observed and modelled temperature at the intermediate depths. The default 1DTempPro optimization involves minimizing the sum of the squared errors (SSE) by iteratively updating seepage rate and re-running the model until the difference between two SSE values is less than 0.01.

2.2.3.2. Darcy's Equation

Seepage rates were estimated at the study sites where piezometers were installed using Darcy's equation (Table 1, Map 1 and Map 2). Darcy's equation is $q = Ki$; where q is specific discharge or flow between the river and aquifer, K is hydraulic conductivity, and i is VHG. Hydraulic conductivity (K) determined using the temperature tracer method and hydraulic response tests were used in Darcy's equation. Where a range of K values was found, the more conservative (i.e., slower) estimate was used in Darcy's equation.

2.3. *In situ* Water Quality

DO, water temperature, pH and electrical conductivity were measured *in situ* at approximately 0 cm (substrate surface), 30 cm, and 50 cm substrate depths at the1 m below reservoir water level and above reservoir level sites in Elk River (Table 1 and Map 1), and Ralph River (Table 1 and Map 2). Site locations and sampling parameters are provided in Table 1 and Table 2, respectively. *In situ* meters were left in the piezometer until a steady reading was obtained (see Section 2 for description of the methodology).

Table 2. *In situ* water quality sampling parameters and meters.

Parameter	Units	Meter
pH	pH units	YSI Pro Plus
Specific Conductivity	µS/cm	YSI Pro Plus
Water Temperature	°C	YSI ProODO (Optical Dissolved Oxygen), YSI Pro Plus
Air Temperature	°C	Alcohol thermometer
Dissolved Oxygen	mg/L	YSI ProODO (Optical Dissolved Oxygen)
Dissolved Oxygen	% saturation	YSI ProODO (Optical Dissolved Oxygen)

2.3.1. QA/QC and Data Analysis

Water quality meters were maintained and field calibrated. Water quality sampling procedures followed the guidelines of the British Columbia Field Sampling Manual, Part E Water and Wastewater Sampling (Clark 2013).

All field data were entered into Ecofish's proprietary data management platform, EcoDAT. This data management platform has built-in rigorous QA/QC protocols. Hardcopy data from field forms were transcribed into EcoDAT and entries were visually compared by a second person to check for data entry errors.

Data were compared to typical ranges in BC watercourses (Table 3) and the applicable approved British Columbia Water Quality Guidelines (BC WQG; MOE 2018) for DO (Table 4) and pH. The BC pH criteria for the protection of aquatic life is 6.5-9.0. The instantaneous minimum BC WQG for the protection of buried embryo/alevin life stages for DO is 6 mg/L. Water temperature data were also compared to the provincial optimum water temperature ranges for Cutthroat Trout incubation period of 9.9-12.0 ºC (Oliver and Fidler 2001, MOE 2018), Rainbow Trout incubation period of 10.0-12.0 °C (Oliver and Fidler 2001), and Dolly Varden (equivalent temperature requirements as Bull Trout) incubation period of 2.0-6.0 ºC (MOE 2001).

Table 3. Typical range of specific conductivity, pH and dissolved oxygen in BC watercourses.

Parameter	Unit	Typical Range in BC	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, and lakes tend to have a pH ≥ 7.0. Coastal streams commonly have pH values of 5.5 to 6.5.	RISC (1998)
Dissolved Oxygen	mg/L	In BC surface waters are generally well aerated and have DO concentrations greater than 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)

Table 4. BC Water Quality Guidelines for the Protection of Aquatic Life for dissolved oxygen (mg/L).

	BC Guidelines for the Protection of Aquatic Life[1]		
	Life Stages Other Than Buried	**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).

2.4. Surface Hydrology

Upper Campbell Reservoir levels and stream flow were plotted with seepage rate directions[1] (i.e., upwelling or downwelling) and precipitation data to examine trends in groundwater movement in areas of the drawdown zone. Upper Campbell Reservoir levels were obtained from BC Hydro. Daily precipitation data were obtained for the BC Hydro climate station Elk River above Campbell Lake[2.] Elk River water level and discharge data were obtained from the Water Survey Canada (WSC) hydrometric station 'Elk River above Campbell Lake' (08HD018), located approximately 6 km upstream of ELK-WT04 (Map 1). The data provided by WSC were provisional at the time of reporting.

A hydrometric gauge was installed on Ralph River (RAL-LG01) on February 14, 2018, to collect continuous water level measurements (Map 2). The gauge consisted of a Solinst Model 3001 Levelogger and Barologger Edge. Four flow measurements were collected on Ralph River, upstream of RAL-WT04, to establish a stage-discharge relationship and to determine the flow on the day

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[1] Seepage rate directions were based on q values for sites above reservoir level and 1 m below reservoir level obtained using the Temperature Tracer Method.

[2] https://www.pacificclimate.org/data/bc-station-data

seepage measurements were collected. For the flow measurements, velocities at a transect were measured with a standard USGS magnetic head Pygmy current meter and water depths were taken with a 1.4 m top-set wading rod. The midsection method (a velocity-area method; RISC 2009, Rantz *et al.* 1982) was used to estimate discharge at each transect.

A number of physical factors are likely to influence incubation conditions, and measurements were taken to allow assessment of these during analysis. Water depth and water velocity were measured at each piezometer location on the day in which seepage and incubation habitat conditions were measured. Water depth was measured as surface level to stream bed using a meter stick. Water velocity was measured at the piezometer as the average water column velocity using a Swoffer meter, following RISC (2009) standards.

3. RESULTS

3.1. Substrate Composition

Substrate composition results for each site at Elk River and Ralph River are presented in Table 5. The substrate at all sites was dominantly comprised of gravel. Sites above the reservoir water level were located in mid-riffle and pool tailout geomorphic units at Elk and Ralph River, respectively. Sites 1 m and 3 m below the reservoir water level were located in pool tailout/run and lake bed/alluvial fan geomorphic units, respectively.

Porosity ranged from 0.14 (ELK-WT04B) to 0.28 (RAL-WT04 and RAL-WT02B). Percent fines (< 2 mm) ranged from 2.6% (ELK-WT03B) to 14.7% (RAL-WT03B). Elk River sites generally contained more sand and had a lower porosity compared to Ralph River sites. Sites containing sand generally had a higher percent of fines (< 2 mm) and lower porosity.

In Elk River, porosity above reservoir water level (ELK-WT04B) was lower (0.14) relative to 1 m below reservoir water level (ELK-WT03B, 0.24). Conversely, percent fines above reservoir water level (ELK-WT04B) were higher (10.9%) relative to 1 m below reservoir water level (ELK-WT03B, 2.6%).

In Ralph River, porosity was comparable above (RAL-WT04, 0.28) and 1 m below reservoir water level (RAL-WT03B, 0.27). Percent fines above reservoir water level (RAL-WT04) were lower (6.4%) relative to 1 m below reservoir water level (RAL-WT03B, 14.7%).

Values of thermal conductivity and sediment heat capacity were used in the temperature tracer method to determine seepage rates (see below) and are provided in Table 5.

Table 5. Substrate and thermal properties of seepage monitoring sites.

Watercourse	Site[1]	Description	Porosity[2] (-)	Thermal Conductivity[3] (J/(s•m•°C))	Sediment Heat Capacity[3] (J/(m^3•°C))	Dispersivity[4] (m)	Geomorphic Unit	Substrate class (dominant, subdominant)	% Fines (Average, < 2 mm)
Elk River	ELK-WT04 ELK WT04B	above reservoir water level	0.14	3.01	2.2 x 10^6	0.001	Mid-riffle	Gravel, sand	10.9
	ELK-WT03B	1 m below reservoir water level	0.24	2.43	2.3 x 10^6	0.001	Pool tailout	Gravel, NA	2.6
	ELK-WT02B	3 m below reservoir water level	0.24	2.43	2.3 x 10^6	0.001	Lake bed / alluvial fan	Gravel, sand	11.7
Ralph River	RAL-WT04	above reservoir water level	0.28	2.22	2.4 x 10^6	0.001	Pool tailout	Gravel, NA	6.4
	RAL-WT03 RAL-WT03B	1 m below reservoir water level	0.27	2.30	2.4 x 10^6	0.001	Pool / run	Gravel, NA	14.7
	RAL-WT02B	3 m below reservoir water level	0.28	2.22	2.4 x 10^6	0.001	Lake bed / alluvial fan	Gravel, trace sand	7.8

[1] Analyses were conducted for samples collected at sites where piezometers were installed (generally suffix "B"). Where two site locations are reported for a given site description (e.g., ELK-WT04 and ELK-WT04B), results were applied at both sites in the temperature tracer method.

[2] Porosity calculated by measuring volume of water that could be held in pore spaces of a sediment sample.

[3] Calculated using dry bulk density (derived from porosity and assumed 2.65 g/cm^3 grain density), and scaling from plot in Lapham (1989).

[4] Assumed uniform throughout all study sites, using the same value as Biacnchin *el al.* (2010) (transverse) and Birkel *et al.* (2016).

3.2. Seepage

Seepage results for each site at Elk River and Ralph River are presented in Table 6 to Table 9, inclusive, and Figure 1 and Figure 2. Details of these results are provided in the subsections below.

3.2.1. Vertical Hydraulic Gradient

Values of VHG ranged from positive, indicating upwelling, to negative, indicating downwelling conditions (Table 6 and Table 7, Figure 1 and Figure 2). Generally, at a given location the VHG at the 30 cm and 50 cm depths were similar in sign (positive or negative), providing confidence in the consistency of these results. The greater the magnitude in VHG, the stronger the up/downwelling at a given location.

In Elk River, the VHG was generally weakly positive (upwelling) at most locations with the exception of during incubator removal (July 2018) above the reservoir water level (ELK-WT04B). The VHG in Elk River above reservoir water level (ELK-WT04B) ranged from -0.128 to 0.106, with an average VHG of 0.016 and 0.003, during incubator installation (June 2018) and removal (July 2018), respectively. The VHG in Elk River 1 m below reservoir water level (ELK-WT03B) ranged from -0.014 to 0.071, with an average VHG of 0.031 and 0.035, during incubator installation (June 2018) and removal (July 2018), respectively. VHG values across piezometer transects in Elk River were generally consistent, with the exception of one location above reservoir water level (ELK-WT04a, approximately ¼ the wetted width), which was negative (downwelling) at both depths (30 cm and 50 cm) compared to otherwise positive (upwelling) VHG values.

In Ralph River, the VHG was generally negative (downwelling). Several VHG values of 0.0 were found at the Ralph River sites, indicating zero-flow points (neither up or downwelling). The VHG in Ralph River above reservoir water level (RAL-WT04) ranged from -0.130 to 0.100, with an average VHG of -0.015 and -0.024, during incubator installation (June 2018) and removal (July 2018), respectively. The VHG in Ralph River 1 m below reservoir water level (RAL-WT03B) ranged from -1.336 to 0.037, with an average VHG of 0.001 and -0.225, during incubator installation (June 2018) and removal (July 2018), respectively. The VHG of -1.336 at 50 cm depth is differs greatly compared to the VHG of 0.002 at the 30 cm for that location (RAL-WT03a). There was otherwise minor variability in VHG across piezometer transects in Ralph River, with the exception of one location above reservoir water level (RAL-WT04a), which was negative (downwelling) at both depths (30 cm and 50 cm) compared to otherwise positive (or weakly negative) VHG values.

3.2.2. Hydraulic Conductivity

Based on the temperature tracer method, K values in Elk River ranged from 0.04 m/d (1 m below reservoir level, ELK-WT03B) to 951 m/d (above reservoir level, ELK-WT04B). Values for K obtained for Elk River from the bail tests were deemed unreasonable for a sand and gravel aquifer and were not used to characterize the location.

Based on the temperature tracer method, K values in Ralph River ranged from 0.02 m/d (1 m below reservoir level, RAL-WT03B) to 1,427 m/d (above reservoir level, RAL-WT04). Based on bail test results, K values were 1.8 m/d (above the reservoir water level, RAL-WT04) and 6.7 m/d (1 m below reservoir level, RAL-WT03).

Hydraulic conductivities at sites above and 1 m below the reservoir water level are reasonable values for well sorted sand/gravel and silty sand aquifers, respectively (Freeze and Cherry 1979).

The AquiferTest hydraulic conductivity test summary sheets are presented in Appendix B.

3.2.3. Seepage Rate

3.2.3.1. Temperature Tracer Method

Seepage rates determined using the temperature tracer method during the pre-incubation and incubation periods are presented in Table 8 and Table 9, respectively.

Seepage rates in Elk River above reservoir water level (ELK-WT04B) ranged from -30.2 m/d to -12.9 m/d during the incubation period, with an average of -18.1 m/d (Table 9). In Elk River, seepage rates 1 m below the reservoir level (ELK-WT03B) were comparatively less and ranged from -8.7 m/d to -0.01 m/d, with an average of -2.2 m/d during the incubation period. Seepage rates 3 m below reservoir water level (ELK WT02B) ranged from 0.01 m/d to 0.05 m/d, with an average of 0.03 m/d. Seepage rates in Elk River were generally greater in Period 4 (June 20 to June 23, when incubators were installed) compared to Period 5 (June 24 to June 28) and Period 6 (June 29 to July 6, when incubators were removed).

In Ralph River, seepage rates above the reservoir water level (RAL-WT04) ranged from -41.8 m/d to -17.3 m/d, with an average of -34.3 m/d during the incubation period (Table 9). Seepage rates in Ralph River 1 m below reservoir level (RAL-WT03/B) were comparatively less and also indicative of weak upwelling, with an average of 0.09 m/d. Seepage rates 3 m below the reservoir level (RAL-WT02B) ranged from -12.6 m/d to -9.29 m/d, with an average of -11.0 m/d. Seepage rates in Ralph River were fairly consistent between different periods.

Prior to the incubation period, the average seepage rate in Elk River above reservoir water level (ELK-WT04) was less than it was during the incubation period (-2.04 m/d vs. -18.1 m/d) (Table 8 and Table **9**). In Ralph River, the average seepage rate was similar during the pre-incubation period compared to the incubation period (-42.1 m/d compared to -34.4 m/d at RAL-WT04).

3.2.3.2. Darcy's Equation

Specific discharge (q)/seepage rates calculated from K (determined using the temperature tracer method and hydraulic response tests) and VHGs using Darcy's equation are presented in Table 6 and Table 7.

Seepage rates in Elk River above reservoir water level (ELK-WT04B) ranged from -57.3 m/d to 14.3 m/d, with average seepage rates of 3.3 m/d and -11.4 m/d, during incubator installation

(June 2018) and removal (July 2018), respectively. Seepage rates in Elk River 1 m below reservoir water level (ELK-WT03B) ranged from -5.2 x 10^{-4} m/d to 1.9 x 10^{-3} m/s, with an average of 5.0 x 10^{-4} m/d and 1.2 x 10^{-3} m/s, during incubator installation (June 2018) and removal (July 2018), respectively.

Although seepage rates for Ralph River were calculated using K determined with both the temperature tracer method and hydraulic response tests, to allow for a direct comparison with Elk River seepage rates, Ralph River seepage rates determined using the temperature tracer K values are considered below. Seepage rates in Ralph River above reservoir water level (RAL-WT04) ranged from -18.3 m/d to 9.9 m/d, with average seepage rates of -3.9 m/d and -5.6 m/d, during incubator installation (June 2018) and removal (July 2018), respectively. Seepage rates in Ralph River 1 m below reservoir water level (RAL-WT03B) ranged from -1.3 x 10^{-4} m/d to 3.4 x 10^{-4} m/d, with an average of 2.5 x 10^{-5} m/d and -0.01 m/d, during incubator installation (June 2018) and removal (July 2018), respectively.

3.2.3.3. Uncertainty in Seepage Rate Calculations

Variation in VHG at different depths within the stream bed was also observed by Birkel *et al.* (2016), which suggests that vertical variations in K may be common. The variable head differential measurements at piezometer sites and across the transects is likely due to natural heterogeneity of interstitial flow at different points across the stream. Variance may be a function of several factors, including measurement error and piezometer water level not stabilizing. To obtain accurate water level measurements and ensure that flow within the piezometer had reached equilibrium (i.e., water levels inside and outside of the piezometers remained consistent and stable), water levels measurements were repeated a minimum of three times (and until equilibrium was reached) at each piezometer.

The primary sources of uncertainty associated with the temperature-based seepage modelling are related to sensor accuracy, installation depth accuracy, bed disturbance, and model limitations. Discussion of the influence of some of these sources of uncertainty are further below.

The results could be skewed if the sensor depths are not at the exact increments that are reported in the field. This source of uncertainty was mitigated by fastening the sensors to a fix rod before installing in the stream bed. The primary source of uncertainty would then be related to the entire rod being higher or lower than the reported depth series, which could happen if the stream bed elevation changes due to bedload transport during the monitoring period. However, as long as the buried sensors each stay buried, the estimated seepage rate should be similar if seepage rates vary minimally with depth. Each of the buried sensors were found to be still buried when during removal.

An additional installation related concern is that the stream bed could be disturbed when the sensor array is installed, causing a change in the local porosity. The expected result would be a reduction in fines that are mobilized during installation, resulting in overestimation of seepage rate. This effect would generally diminish as fines re-infill around the sensor array. This effect could explain the progressive reduction in seepage rate through the incubation period in Elk River (ELK-WT04B and ELK-WT03B) and in Ralph River (1 m below reservoir level, RAL-WT03B). These three arrays were installed immediately before the incubation period and were above the backwatering effect during the incubation period. This effect would also be more likely at sites where the stream bed was excavated rather than using the insertion tube.

The temperature tracer method performs somewhat poorly in conditions of strong downwelling. During strong downwelling conditions, the temperature at each depth in the array will be similar. Where temperature was identical at each depth, the model assumes an extreme and unrealistic downwelling rate. Since downwelling was expected to be strong at some of the sites, a confidence interval metric was developed to quantify this effect. Model runs consist of multiple iterations until improvements in RMSE are negligible. Therefore, seepage estimates were interpolated between each iteration, and the seepage rate corresponding to an RMSE 10% higher than the final value was extracted. The confidence interval estimate was then taken as the absolute value of 10% RMSE value subtract the final seepage rate estimate.

Table 6. Summary of seepage results at Elk River sites.

Watercourse	Site[1]	Description	Location	Depth measured (cm)	June (incubator installation)	July (incubator removal)	Temperature Tracer Method[3]	Hydraulic Response Test	June (incubator installation)		July (incubator removal)	
					VHG[2] (i = dh/dl)	**VHG[2] (i = dh/dl)**	**Hydraulic Conductivity (K) (m/d)**		**Seepage rate (q) Temp. Method[4] (m/d)**	**Seepage rate (q) Darcy's Eq.[5] (m/d)**	**Seepage rate (q) Temp. Method[4] (m/d)**	**Seepage rate (q) Darcy's Eq.[5] (m/d)**
Elk River	ELK-WT04 ELK WT04B	above reservoir water level	ELK-WT04a	30	0.017	-0.086						
				50	-0.005	-0.128			-2.1	-	-57.3	-
			ELK-WT04b	30	0.077	0.075						
				50	0.012	0.020			5.6	-	9.0	-
			ELK-WT04c	30	-0.017	0.106						
				50	0.014	0.032			6.3	-	14.3	-
			Average		**0.016**	**0.003**	**448 to 951**	Test did not complete	**3.3**	-	**-11.4**	-
	ELK-WT03B	1 m below reservoir water level	ELK-WT03a	30	0.022	0.056						
				50	0.023	0.052			8.3×10^{-4}	-	1.9×10^{-3}	-
			ELK-WT03b	30	0.071	0.007						
				50	0.033	0.005			1.2×10^{-3}	-	1.7×10^{-4}	-
			ELK-WT03c	30	0.050	0.050						
				50	-0.014	0.042			-5.2×10^{-4}	-	1.5×10^{-3}	-
			Average		**0.031**	**0.035**	**0.04**	Test did not complete	**5.0×10^{-4}**	-	**1.2×10^{-3}**	-
	ELK-WT02B	3 m below reservoir water level		-	-		-	- -	-	-	-	-

Table 7. Summary of seepage results at Ralph River sites.

Watercourse	Site[1]	Description	Location	Depth measured (cm)	June (incubator installation)	July (incubator removal)	Temperature Tracer Method[3]	Hydraulic Response Test	June (incubator installation)		July (incubator removal)	
					VHG[2] (i = dh/dl)	VHG[2] (i = dh/dl)	Hydraulic Conductivity (K) (m/d)		Seepage rate (q) Temp. Method[4] (m/d)	Seepage rate (q) Darcy's Eq.[5] (m/d)	Seepage rate (q) Temp. Method[4] (m/d)	Seepage rate (q) Darcy's Eq.[5] (m/d)
Ralph River	RAL-WT04	above reservoir water level	RAL-WT04a	30	0.000	-0.010						
				50	0.070	-0.044			9.9	0.47	-6.2	-0.30
			RAL-WT04b	30	0.100	-0.067						
				50	-0.024	-0.062			-3.4	-0.16	-8.7	-0.42
			RAL-WT04c	30	-0.103	0.050						
				50	-0.130	-0.013			-18.3	-0.87	-1.9	-0.09
			Average		**-0.015**	**-0.024**	**141 to 1,427**	**1.8**	**-3.9**	**-0.19**	**-5.6**	**-0.27**
	RAL-WT03 RAL-WT03B	1 m below reservoir water level	RAL-WT03a	30	0.000	0.002						
				50	-0.008	-1.336			-1.3×10^{-4}	-0.01	-0.02	-2.4
			RAL-WT03b	30	0.000	0.037						
				50	0.020	-0.064			3.4×10^{-4}	0.04	-1.1×10^{-3}	-0.11
			RAL-WT03c	30	0.000	0.017						
				50	-0.008	-0.005			-1.4×10^{-4}	-0.01	-7.9×10^{-5}	-0.01
			Average		**0.001**	**-0.225**	**0.02**	**6.7**	**2.5×10^{-5}**	**0.00**	**-0.01**	**-0.83**
	RAL-WT02B	3 m below reservoir water level		-	-		-	-	-		-	-

[1] All study sites are listed; however, data were only collected at sites in which piezometers were installed.

[2] Positive indicates upwelling flow; negative indicates downwelling flow

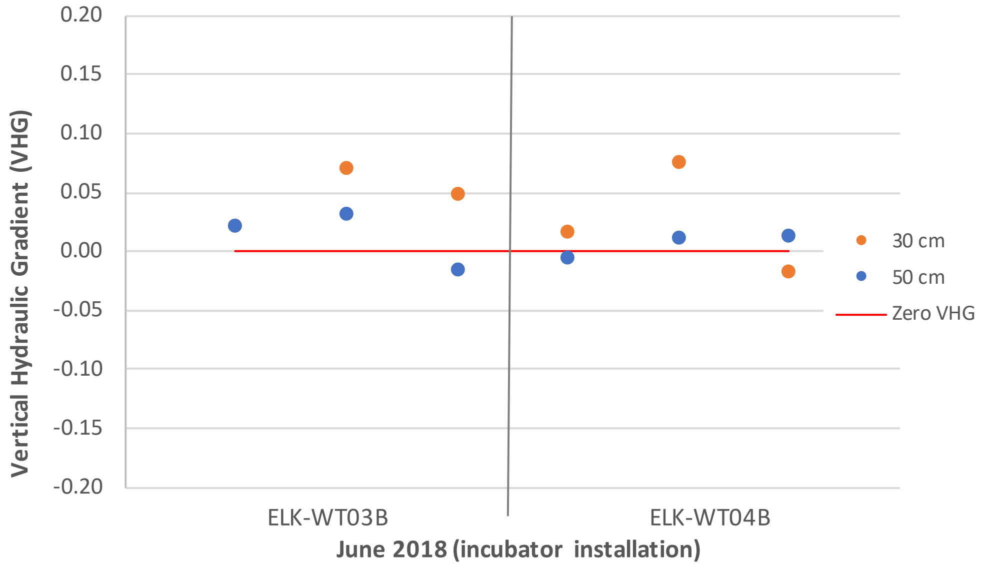
[3] Average dh of all piezometer locations at a site used in numerical model.

[4] Calculated using conservative (i.e., lower) K value obtained using the temperatrature tracer method. Only calculated at 50 cm depths to allow comparison to seepage rates obtained using Darcy's Equation.

[5] Darcy's Equation was applied to 50 cm depths only as hydraulic response tests at each site were conducted at a depth of 50 cm. Note that average VHG values include 30 cm and 50 cm depths.

Figure 1. Vertical hydraulic gradient at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator installation in June 2018.

a)



b)

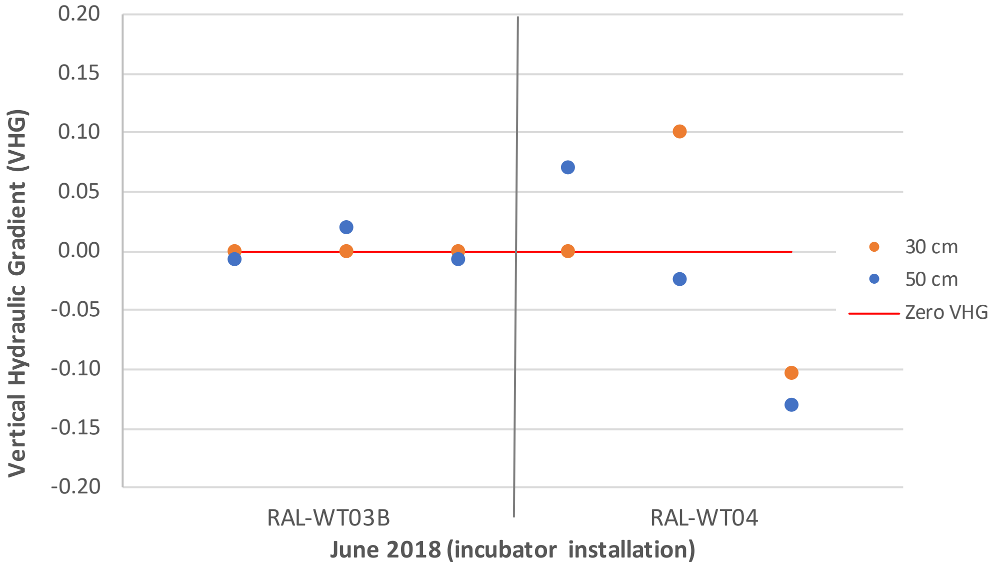
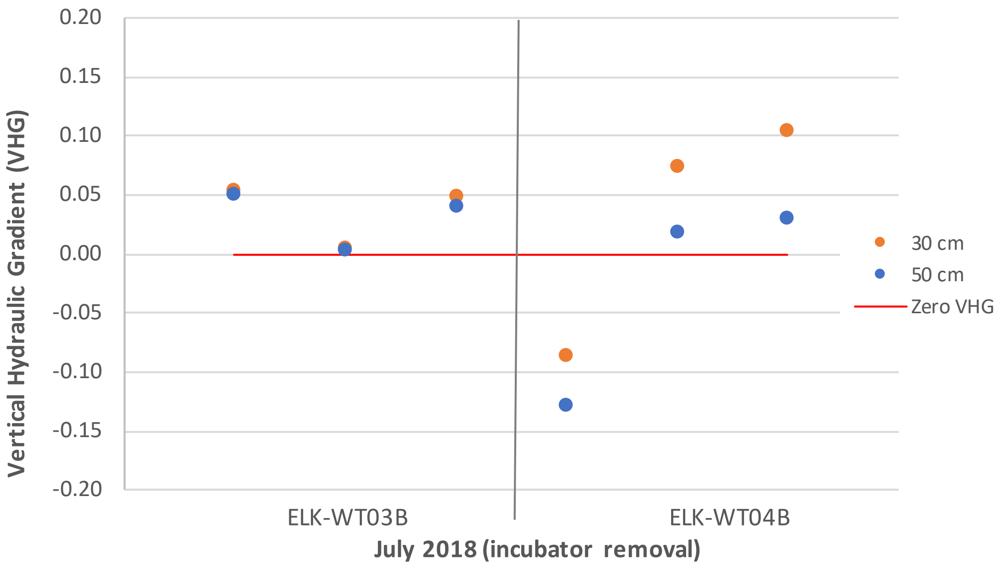


Figure 2. **Vertical hydraulic gradient at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator removal in July 2018 (note that a different scale was used).**

a)



b)

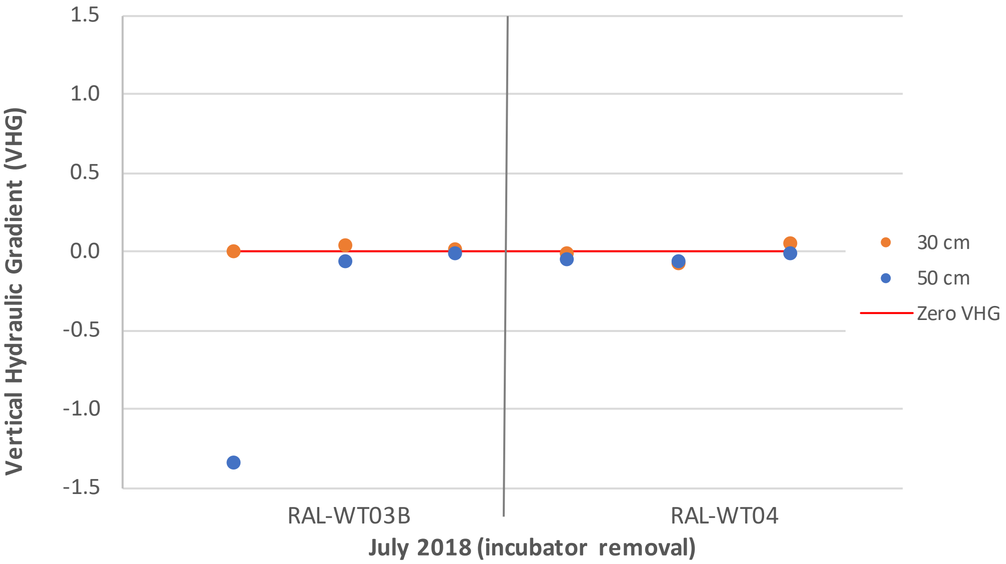


Table 8. Average seepage rates at Elk River and Ralph River study sites during the pre-incubation period, modelled using 1DTempPro.

Watercourse	Site[1]	Description	Sensor Depths (m)	Average of pre-incubation period runs	Period 1 (Mar 30 to Apr 5)			Period 2 (Apr 8 to Apr 16)			Period 3 (May 15 to May 21)[2]		
				q (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)
Elk River	ELK-WT04	above reservoir water level	All	-2.1	-2.04	0.17	0.42	-2.12	0.19	0.50	-	-	-
	ELK-WT04B		All	-	-	-	-	-	-	-	-	-	-
	ELK-WT03B	1 m below reservoir water level	0, 0.1, 0.3	-	-	-	-	-	-	-	-	-	-
			All	-	-	-	-	-	-	-	-	-	-
	ELK-WT02B	3 m below reservoir water level	All	-	-	-	-	-	-	-	-	-	-
Ralph River	RAL-WT04	above reservoir water level	All	-42.1	-25.9	0.12	20.4	-51.7	0.12	46.2	-47.3	0.12	36.9
	RAL-WT03		All	-12.4	-	-	-	-4.7	0.09	1.82	-20.2	0.05	7.35
	RAL-WT03B	1 m below reservoir water level	0.1, 0.3, 0.5	0.09	0.02	0.12	0.02	0.08	0.17	0.03	0.17	0.11	0.04
			All	-	-	-	-	-	-	-	-	-	-
	RAL-WT02B	3 m below reservoir water level	All	-	-	-	-	-	-	-	-	-	-

[1] Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018); however, some sites needed to be relocated slightly due to site dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Only sites for which viable data were obtained have been included.

[2] RAL-WT03B (0.1, 0.3, 0.5 m depths) started on May 17 at 00:00.

Table 9. Average seepage rates at Elk River and Ralph River study sites during the incubation period, modelled using 1DTempPro.

Watercourse	Site[1]	Description	Sensor Depths (m)	Incubation Period Average	Period 4 (June 20 to June 23)[2]			Period 5 (June 24 to June 28)			Period 6 (June 29 to July 6)[3]		
				q (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)	q (m/d)	RMSE (°C)	Confidence (m/d)
Elk River	ELK-WT04	above reservoir water level	All	-	-	-	-	-	-	-	-	-	-
	ELK-WT04B		All	-18.1	-30.2	0.04	11.5	-16.6	0.03	4.0	-12.9	0.04	1.91
	ELK-WT03B	1 m below reservoir water level	0, 0.1, 0.3	-2.2	-8.7	0.09	3.2	-0.52	0.25	NA[4]	-0.01	0.33	0.05
			All	-0.04	-0.04	0.69	0.08	-	-	-	-	-	-
	ELK-WT02B	3 m below reservoir water level	All	0.03	0.01	0.18	0.01	0.02	0.18	0.01	0.05	0.15	0.04
Ralph River	RAL-WT04	above reservoir water level	All	-34.3	-40.4	0.12	30.1	-17.3	0.12	12.45	-41.8	0.12	33.0
	RAL-WT03		All	-	-	-	-	-	-	-	-	-	-
	RAL-WT03B	1 m below reservoir water level	0.1, 0.3, 0.5	0.09	0.08	0.05	0.01	0.08	0.03	0.01	0.10	0.03	0.01
			All	0.13	-	-	-	-	-	-	0.13	0.13	0.02
	RAL-WT02B	3 m below reservoir water level	All	-11.0	-12.3	0.19	3.9	-12.6	0.14	3.42	-9.29	0.14	2.76

[1] Temperature array installation was originally done in February 2018 to obtain data prior to the incubation period (June-July 2018); however, some sites needed to be relocated slightly due to site dewatering or loss/damage of sensors from high flows. Relocated study sites were provided the suffix "B". Only sites for which viable data were obtained have been included.

[2] RAL-WT02B trial started on June 21 at 00:00

[3] RAL-WT03B (All depths) went from July 6 00:00 to July 9 00:00; ELK-WT04B ends on July 6 at 09:30; ELK-WT03B (0, 0.1, 0.3 m depths) ends on July 6 at 11:50.

[4] NA = Not applicable. Each interation resulted in an RMSE that was less than 1.1 times the final RMSE value, indicating the confidence algorithm did not complete. However, overall the accuracy of this measurement was considered strong because the RMSE was 0.25°C and there was substantial difference between the temperature series at each depth.

3.3. *In situ* Water Quality

Water quality results for DO (% saturation and mg/L), water temperature (°C), pH, and specific conductivity (µS/cm, corrected to 25°C) were collected at each piezometer site (Table 1) at the substrate surface and at each measured depth (0 cm, 30 cm, and 50 cm within the substrate). A summary of *in situ* water quality results for each site at Elk River and Ralph River are presented in Table 10 and Table 11, and Figure 3 to Figure 6, inclusive. Details of these results are provided in the subsections below.

3.3.1. Dissolved Oxygen

In Elk River, DO concentrations remained above the instantaneous minimum BC WQG (6 mg/L) at all locations and depths (Figure 3 and Figure 4). Compared to the 30-day minimum guideline (8 mg/L), DO concentrations in Elk River above reservoir water level (ELK-WT04B) remained above the guideline whereas concentrations 1 m below reservoir water level (ELK-WT03B) were generally close to or below the guideline, suggesting that if these concentrations were experienced over the long-term, adverse effects to buried life stages may occur (MOE 2017). To apply the long-term guidelines, however, samples are typically collected weekly over a 30-day period.

DO concentrations generally decreased with increasing depth in the substrate. DO concentrations in Elk River above reservoir water level (ELK-WT04B) ranged from 8.3 to 9.1 mg/L during both incubator installation (June 2018) and removal (July 2018). At locations 1 m below reservoir water level (ELK-WT03B), DO concentrations ranged from 6.8 to 8.9 mg/L and 6.3 to 8.1 mg/L during incubator installation (June 2018) and removal (July 2018), respectively.

In Ralph River, DO concentrations generally remained above the instantaneous minimum BC WQG (6 mg/L) (Figure 3 and Figure 4). Compared to the 30-day minimum guideline (8 mg/L), DO concentrations in Ralph River above reservoir water level (RAL-WT04) were above the guideline during incubator installation (June 2018); however, were generally below the guideline during incubator removal (July 2018). DO concentrations in Ralph River 1 m below reservoir water level (RAL-WT03B) were generally below the 30-day guideline (8 mg/L).

DO concentrations tended to show more variability with depth in the substrate in Ralph River compared to Elk River. DO concentrations in Ralph River above reservoir water level (RAL-WT04) ranged from 9.7 to 10.5 mg/L during incubator installation (June 2018) and from 7.4 to 8.3 mg/L during incubator removal (July 2018). At locations 1 m below reservoir water level (RAL-WT03B), DO concentrations ranged from 2.6 to 9.6 mg/L and 0.9 to 9.2 mg/L during incubator installation (June 2018) and removal (July 2018), respectively.

3.3.2. Temperature

In Elk River, subsurface water temperature was generally either above or below the provincial optimum water temperature ranges for Cutthroat and Rainbow Trout (Figure 5 and Figure 6). Water temperature generally decreased with depth in the substrate. Water temperatures at 30 cm and 50 cm depths, 1 m below reservoir water level (ELK-WT03B) were within the optimum water temperature ranges for Cutthroat and Rainbow Trout during incubator installation (June 2018). Water temperatures above the reservoir water level (ELK-WT04B) were within the optimum water temperature ranges for Cutthroat and Rainbow Trout during incubator removal (July 2018).

In Ralph River, subsurface water temperature was generally above the provincial optimum water temperature ranges for Cutthroat t and Rainbow Trout (Figure 5 and Figure 6). Water temperature with depth in the substrate was more variable in Ralph River compared to Elk River. Water temperatures above the reservoir level (RAL-WT04) were within the optimum temperate ranges for Cutthroat and Rainbow Trout during incubator removal (July 2018).

Water temperatures at all Elk and Ralph River locations were above the provincial optimum water temperature range for Dolly Varden (equivalent temperature requirements as Bull Trout)[1].

3.3.3. pH and Specific Conductivity

In situ pH and specific conductivity results are provided in Table 10 and Table 11. pH values at all Elk and Ralph River locations ranged from 6.4 to 8.0. Only one sample location (50 cm depth, RAL-WT03B in June 2018) was below BC WQG guidelines for the protection of aquatic life. All pH readings were otherwise within BC WQG and typical ranges in BC (Table 3).

Specific conductivity at all Elk and Ralph River locations ranged from 20.6 to 90.2 µS/cm. Generally, specific conductivity was low compared to the typical value of 100 µS/cm (Table 3), indicating a low concentration of dissolved ions were present in the water.

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[1] Note that incubation habitat and seepage conditions were not measured during the Dolly Varden spawning and incubation period.

Table 10. Summary of *in situ* water quality results at Elk River sites.

Watercourse	Site[1]	Description	Location	Depth measured (cm)	June[2]	July[3]	June[2]	July[3]	June[2]	July[3]	June[2]	July[3]	June[2]	July[3]
					Dissolved Oxygen (mg/L)		Dissolved Oxygen (%)		Water Temperature (°C)		pH		Specific Conductivity (µS/cm)	
Elk River	ELK-WT04 ELK WT04B	above reservoir water level	ELK-WT04a	Surface	11.5	11.2	104.6	99.4	11.1	10.3	6.5	6.6	27.3	32.6
				0	8.7	9.1	83.2	84.8	13.5	11.8	6.8	6.9	28.0	33.4
				30	9.0	8.9	86.0	82.2	13.7	11.7	6.8	7.1	28.0	33.5
				50	8.3	8.7	82.4	82.1	14.8	12.0	6.8	7.3	27.6	34.1
			ELK-WT04b	Surface	11.5	9.3	104.5	83.7	11.2	10.3	6.5	7.4	27.4	32.7
				0	8.9	8.3	86.5	77.3	14.0	11.9	6.8	7.3	27.6	33.0
				30	8.8	8.5	84.2	79.1	13.3	11.6	6.8	7.4	27.3	32.9
				50	8.9	8.1	85.5	76.2	13.8	12.0	6.8	7.4	27.8	33.5
			ELK-WT04c	Surface	11.0	9.2	103.5	81.7	12.5	10.4	6.6	7.4	26.5	32.7
				0	8.6	8.4	85.5	80.6	15.1	11.8	6.9	7.4	27.8	33.3
				30	9.1	8.4	91.4	79.2	15.3	11.7	6.8	7.3	27.7	33.0
				50	9.1	8.8	90.8	80.2	16.1	12.0	7.0	7.4	28.8	34.3
	ELK-WT03B	1 m below reservoir water level	ELK-WT03a	Surface	10.0	8.8	98.3	80.5	14.2	11.4	6.7	7.4	27.9	33.2
				0	8.2	7.4	83.6	71.4	15.9	12.6	6.8	7.4	28.7	36.4
				30	7.3	6.3	69.0	55.4	11.8	9.5	6.7	7.2	49.7	50.0
				50	7.7	6.5	72.3	58.4	12.0	9.3	6.7	7.4	47.8	50.8
			ELK-WT03b	Surface	10.3	8.7	101.2	79.7	13.9	11.6	6.7	7.4	27.9	32.9
				0	8.5	7.8	83.8	71.9	14.3	12.7	6.8	7.5	38.6	34.7
				30	6.8	6.8	63.7	61.0	11.1	9.6	6.8	7.2	54.6	52.6
				50	7.6	7.2	69.6	63.8	10.6	9.2	7.2	7.4	55.9	54.4
			ELK-WT03c	Surface	10.6	8.5	100.2	79.6	12.9	11.8	6.7	7.6	28.2	32.9
				0	8.9	8.1	88.4	72.3	14.3	12.8	6.9	7.6	28.8	36.1
				30	8.0	7.7	75.3	67.5	10.8	9.2	7.0	7.3	55.6	55.0
				50	8.2	7.8	74.7	67.1	10.5	8.2	7.1	7.4	56.8	55.7
	ELK-WT02B	3 m below reservoir water level		-	-	-	-	-	-	-	-	-	-	-

Table 11. Summary of *in situ* water quality results at Ralph River sites.

Watercourse	Site[1]	Description	Location	Depth measured (cm)	Dissolved Oxygen (mg/L)		Dissolved Oxygen (%)		Water Temperature (°C)		pH		Specific Conductivity (µS/cm)	
					June[2]	July[3]	June[2]	July[3]	June[2]	July[3]	June[2]	July[3]	June[2]	July[3]
Ralph River	RAL-WT04	above reservoir water level	RAL-WT04a	Surface	11.8	9.5	106.1	83.7	10.6	9.9	7.2	7.5	20.9	25.0
				0	10.0	7.8	-	73.0	12.0	12.0	7.0	7.4	21.5	25.2
				30	10.2	8.3	98.9	76.2	12.6	11.3	7.5	7.5	21.7	26.2
				50	10.5	7.7	99.9	71.4	12.2	11.5	7.3	7.5	21.7	26.3
			RAL-WT04b	Surface	11.8	9.1	106.1	80.6	10.6	10.1	6.9	7.5	20.9	25.1
				0	9.7	7.9	-	72.2	12.1	10.9	6.7	7.4	21.5	25.6
				30	10.5	7.4	100.4	67.9	12.6	11.6	7.1	7.4	24.8	25.2
				50	10.3	7.4	96.3	67.6	11.3	11.2	7.3	7.5	23.1	25.2
			RAL-WT04c	Surface	11.5	9.0	103.7	79.8	10.7	10.1	6.8	7.5	20.9	25.3
				0	9.8	7.6	91.7	70.3	12.2	11.4	7.0	7.5	21.5	25.2
				30	9.9	7.6	94.2	69.2	12.5	11.4	6.9	7.5	21.5	26.2
				50	9.0	7.4	85.6	67.3	12.7	11.4	6.8	7.5	22.3	26.4
	RAL-WT03		RAL-WT03a	Surface	9.1	8.0	95.5	72.3	17.5	12.8	7.0	7.6	54.7	36.6
	RAL-WT03B	1 m below reservoir water level		0	8.0	6.0	83.7	62.9	16.7	16.0	7.3	7.6	40.0	40.3
				30	6.5	1.5	69.5	75.5	16.7	13.2	7.0	6.9	64.4	56.6
				50	2.6	3.2	26.0	34.0	15.0	18.0	6.7	7.1	85.4	56.6
			RAL-WT03b	Surface	9.3	7.4	96.4	69.2	17.4	11.9	6.9	7.4	54.1	34.4
				0	7.5	7.1	81.2	69.0	18.5	14.2	7.0	7.5	55.0	37.2
				30	7.8	1.1	78.5	10.5	15.2	12.2	7.0	7.1	57.2	63.6
				50	7.9	5.2	79.2	52.4	13.6	15.6	6.4	7.3	90.2	50.6
			RAL-WT03c	Surface	10.3	10.5	107.9	96.1	16.9	11.4	6.8	8.0	54.5	33.9
				0	9.6	9.2	97.2	86.5	15.7	13.6	7.3	7.7	38.7	38.7
				30	8.0	3.3	79.7	30.7	14.1	12.9	7.0	7.0	44.2	52.4
				50	7.3	0.9	74.3	8.5	15.8	12.2	7.0	7.1	62.1	53.0
	RAL-WT02B	3 m below reservoir water level		-										

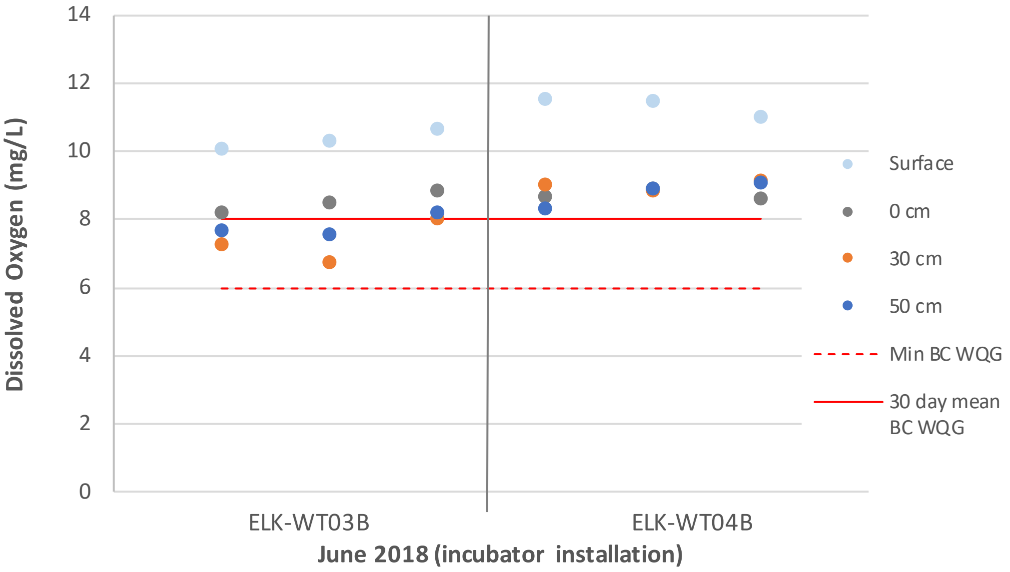
[1] All study sites are listed; however, data were only collected at sites in which piezometers were installed.

[2] Incubator installation.

[3] Incubator removal.

Figure 3. Dissolved oxygen (mg/L) at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator installation in June 2018.

a)



b)

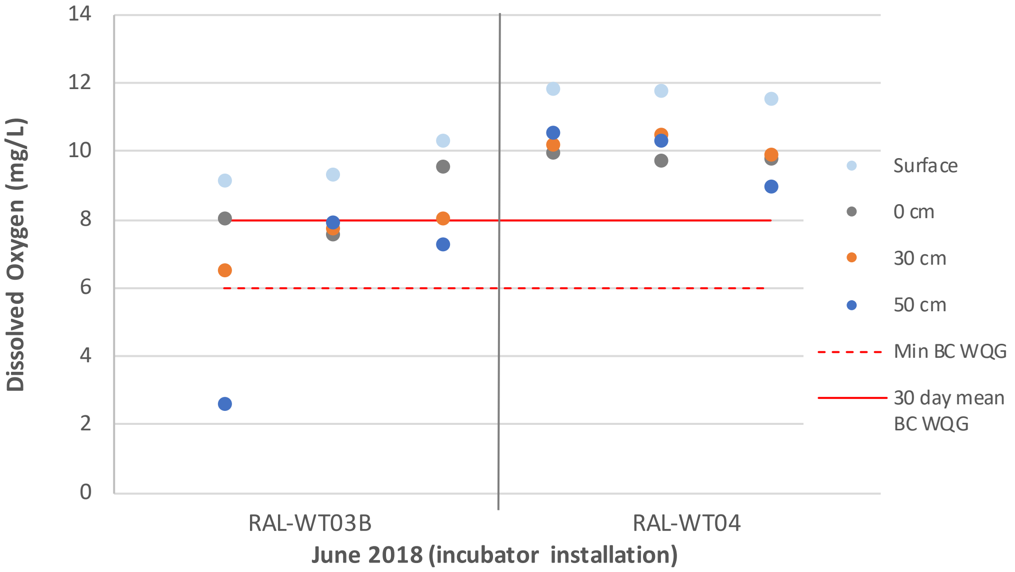
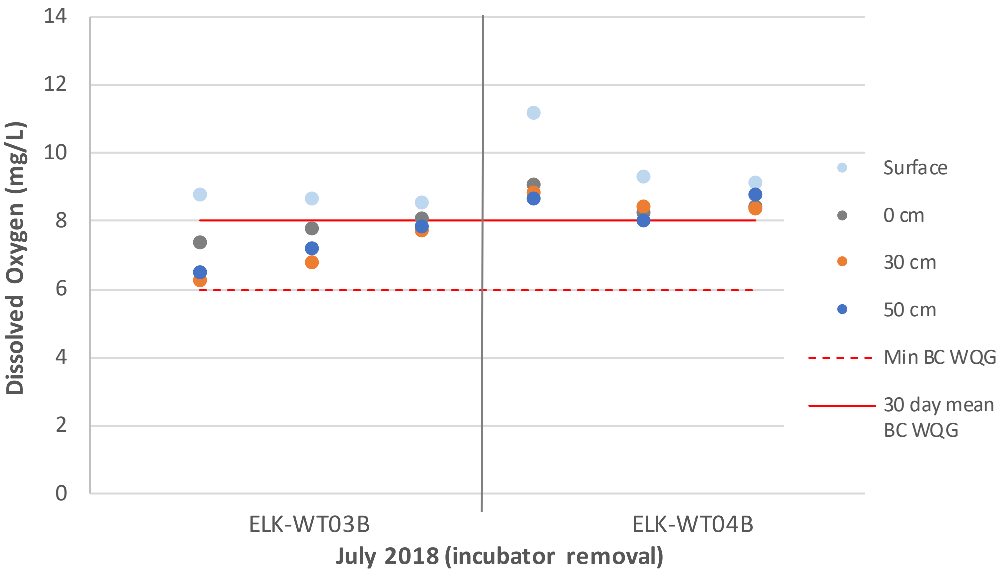


Figure 4. **Dissolved oxygen (mg/L) at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator removal in July 2018.**

a)



b)

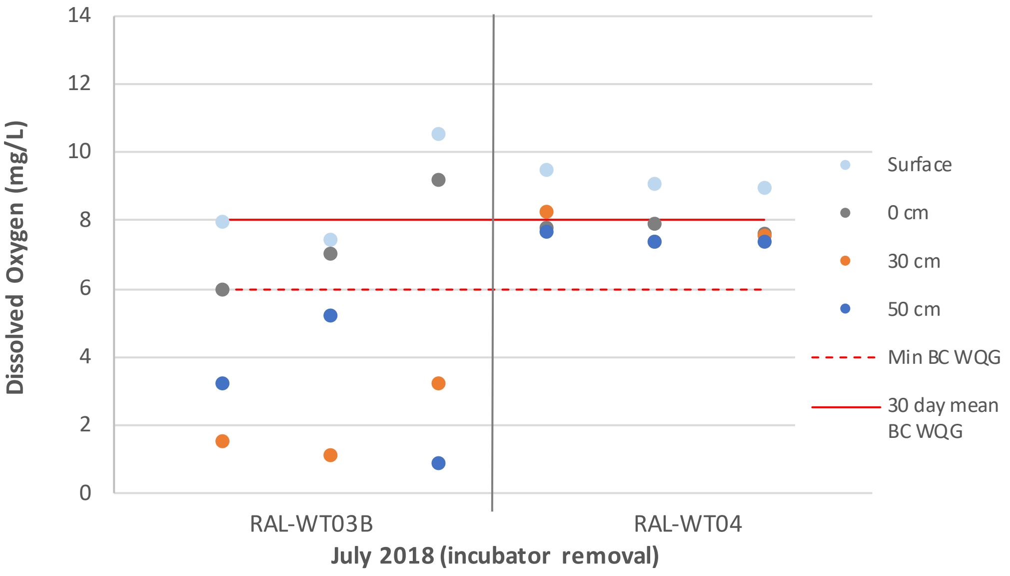
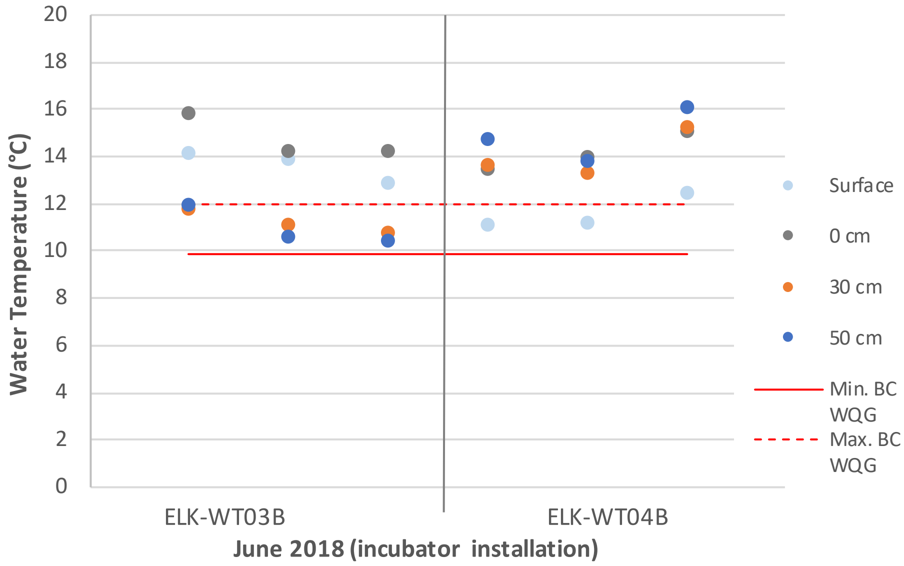


Figure 5. Water temperature (°C) at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator installation in June 2018. Optimum water temperature range for Cutthroat Trout incubation life stage is provided (Oliver and Fiddler 2001).

a)



b)

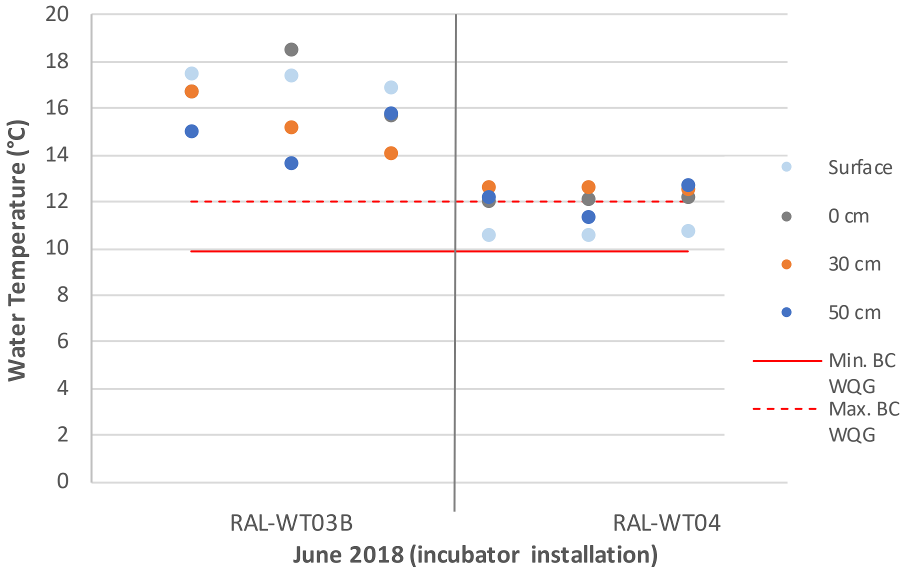
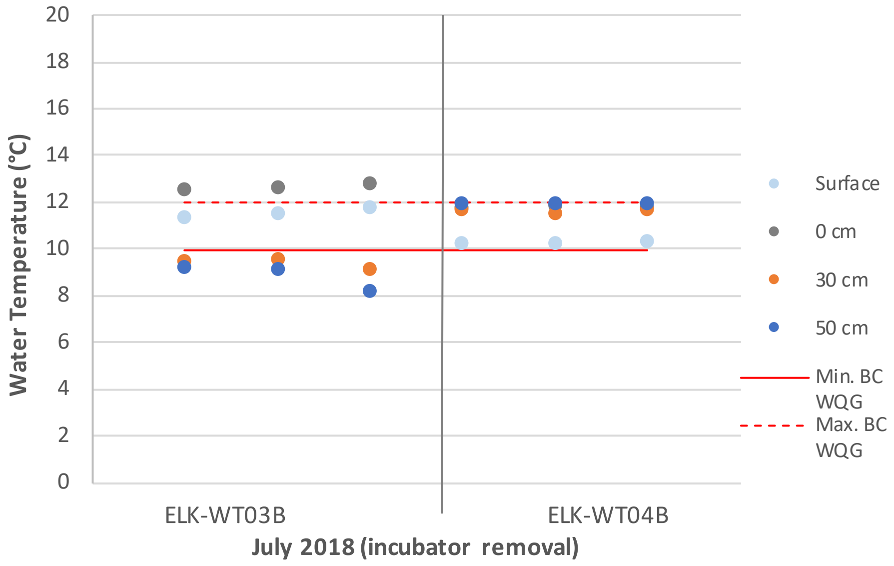
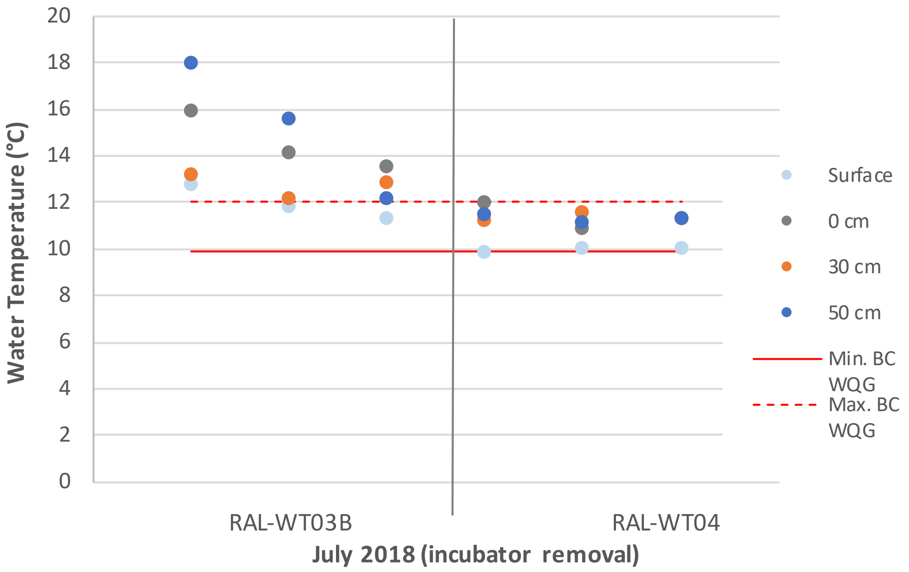


Figure 6. **Water temperature (°C) at depth in a) Elk River (ELK-WT03B – 1 m below reservoir water level, ELK-WT04B – above reservoir water level) and b) Ralph River (RAL-WT03B – 1 m below reservoir water level, RAL-WT04 – above reservoir water level) during incubator removal in July 2018. Optimum water temperature range for Cutthroat Trout incubation life stage is provided (Oliver and Fiddler 2001).**

a)



b)



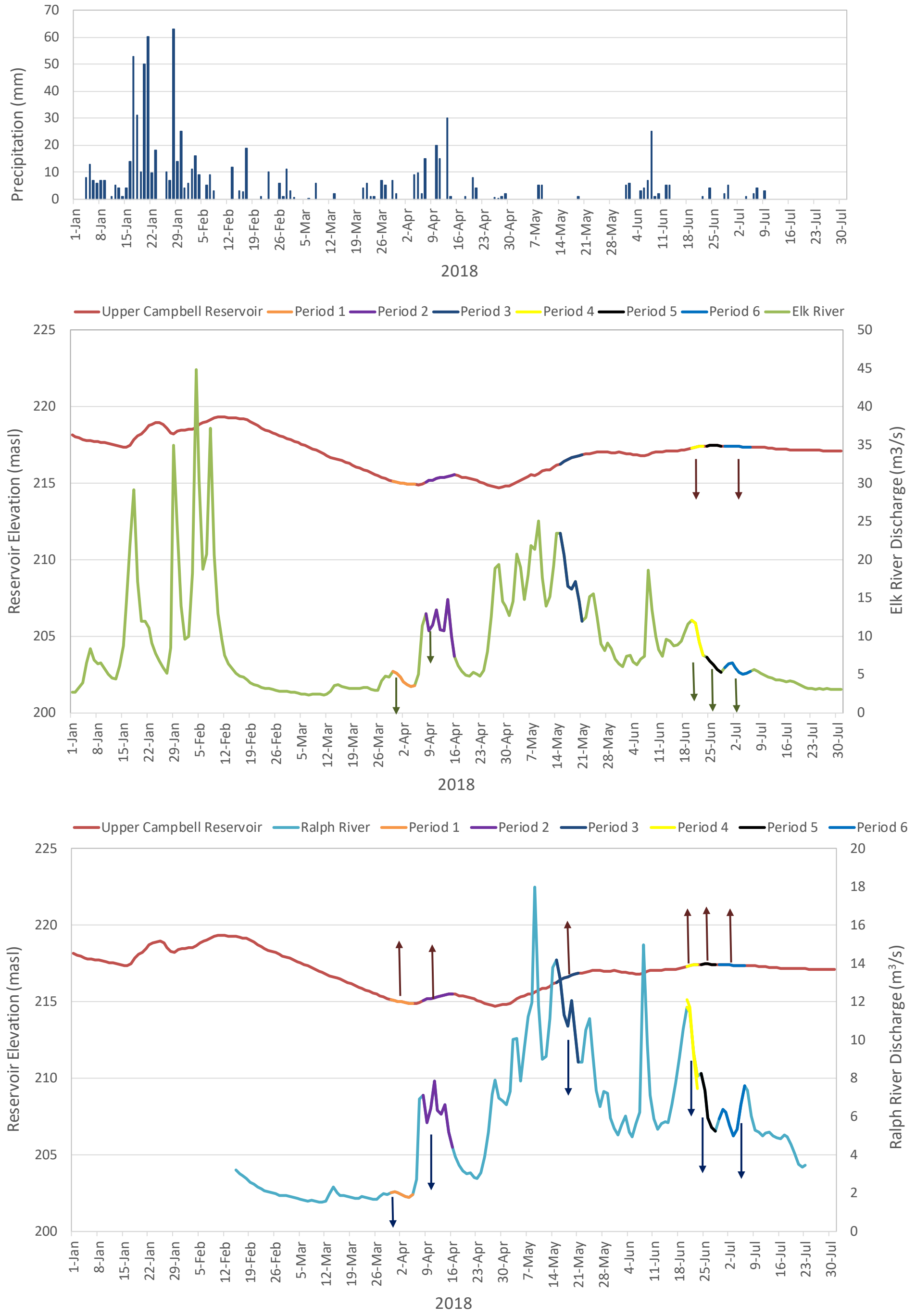
3.4. Surface Hydrology

Water depth and velocity measurements made at each piezometer location are provided in Appendix C. Water depth and velocity varied across the transects due to differences in stream bed topography. At the Elk River sites, water depths were highest at 1 m below reservoir water level (ELK-WT03B) during incubator installation (0.69 m) and removal (0.39 m), whereas water depths at Ralph River were lowest (0.29 m) at 1 m below reservoir water level (RAL-WT03B) during installation and highest (0.61 m) during incubator removal. Flow velocities were highest at sites above reservoir water level and ranged from an average of 0.64 m/s (during incubator installation) to 1.01 m/s (during incubation removal) at RAL-WT04 and 0.96 m/s (over the incubator installation and removal periods) at ELK-WT04B (Appendix C). Flow velocities were lower at the 1 m below reservoir level sites, with an average of 0.16 to 0.27 m/s at ELK-WT03B, and no flow recorded at RAL-WT03B during both incubation installation and removal periods.

Elk River and Ralph River flow are presented in Figure 7 with Upper Campbell Reservoir elevation and daily precipitation measured at the BC Hydro climate station Elk River above Campbell Lake for the six seepage analysis periods (see Section 3.2). Period 4 (June 20 – June 23, 2018) corresponds with incubator installation and Period 6 (June 29 – July 6, 2018) with incubator removal. Elk River flow (11.60 m^3/s) was similar to flow at Ralph River (11.74 m^3/s) during incubator installation, and less (5.38 m^3/s) than Ralph River flow (7.38 m^3/s) during incubator removal.

Based on the temperature tracer method, seepage rate directions in sites above reservoir water level and 1 m below reservoir water level were consistent in both Elk River and Ralph River across variable flow conditions (Figure 7). At sites above reservoir water level downwelling conditions were observed in both Elk River and Ralph River (ELK-WT04B and RAL-WT04). Downwelling conditions were observed in Elk River 1 m below the reservoir water (ELK-WT03B) level whereas upwelling conditions were observed in Ralph River 1 m below the reservoir level (RAL-WT03B).

Figure 7. **Precipitation (mm) (top plot), and reservoir elevation (masl) and Elk River discharge (middle plot) and Ralph River discharge (bottom plot). Seepage directions (upwelling/downwelling) are indicated with arrows. Above reservoir water level sites (WT04/B) depicted with river discharge data and 1 m below reservoir level sites (WT03B) depicted with reservoir data.**



4. SUMMARY

A summary of incubation habitat and seepage conditions in relation to the general condition of salmon redds is provided below. Further details with respect to the results of the incubation tests conducted as part of the study are discussed in the JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment Year 5 Annual Monitoring Report (Buren *et al.* 2019).

Calculated seepage rates and directions (i.e., upwelling or downwelling) in Elk River and Ralph River varied depending on the method used (temperature tracer method or Darcy's equation). Both of these methods provide point estimates of seepage that can vary with time (Kalbus *et al.* 2006). Seepage rates and direction were highly variable across the measurement transects in both the Elk River and Ralph River using Darcy's equation. Differences in substrate composition, size, and texture cause heterogeneity in the distribution of hydraulic properties (Freeze and Cherry 1979). Given these factors, the variability in seepage rates and directions observed in this study is not unexpected; however, general conclusions can still be drawn from the results.

The seepage rates and direction estimated from the temperature tracer method generally supported the results of the incubation study. A stronger groundwater exchange (-18.1 m/d on average) was observed at the Elk River above reservoir water level site (ELK-WT04B), where the majority of eggs/alevin survived, compared to the 1 m below reservoir water level site (ELK-WT03B, -2.2 m/d on average), where approximately 86% of the eggs/alevin survived. In further contrast, there was relatively no groundwater exchange at the 3 m below reservoir water level site (ELK-WT02B, 0.03 m/d on average), where the egg/alevin survival rate was nil.

In Ralph River, there was strong groundwater exchange at the above reservoir water level site (RAL-WT04, -34.3 m/d on average) and 3 m below reservoir water level site (RAL-WT02B, -11 m/d on average), and a weak upwelling (0.09 m/d on average) at the 1 m below reservoir water level site (RAL-WT03B). Egg/alevin survival was 100% at all Ralph River sites, despite the weak upwelling at the 1 m below reservoir water level site (RAL-WT03B). The location of the temperature sensors at this latter site was likely influenced by cold water currents from Ralph River. This may have helped circulate oxygen around the incubators despite relatively weaker groundwater exchange, thus improving egg/alevin survival. It is interesting to note that the two sites with upwelling conditions (Ralph River 1 m below reservoir water level, RAL-WT03B, and Elk River 3 m below reservoir water level, ELK-WT02B) were also the sites with the greatest % of fines (14.7% and 11.7%, respectively).

The exchange of oxygenated water with the riverbed (downwelling and upwelling), and the ability of the riverbed substrate to transport water, are critical to determining the level of DO available to eggs (Greig *et al.* 2007). In Elk River and Ralph River, DO concentrations in the subsurface generally remained above the instantaneous minimum BC WQG (6 mg/L) at all locations and depths with the following exception. During incubator removal, DO concentrations at 1 m below reservoir water level (RAL-WT03B; at depths below 0 cm) were below the instantaneous minimum BC WQG guideline. The lower DO at this site may be associated with the higher % of fines (14.7% at RAL-WT03B) relative to the other sites (ranged between 2.6% and 10.9%). A lack of water movement (zero-flow) and/or downwelling conditions (as calculated using Darcy's Equation), may have also contributed to the low DO observed. It is also worth noting that DO is likely to decrease with increasing depth in the stream bed assuming reduced gas exchange with the surface water or infiltration of groundwater (MOE 1997b).

Water temperature can influence DO saturation and concentration (DO saturation is inversely related to water temperature). Cooler water temperatures are able to hold more soluble gases, i.e., a greater amount of DO (Greig *et al.* 2007). Conversely, warmer water thus holds less DO. Therefore, water temperature within the substrate also influences the rate of salmonid embryonic incubation and development, with warmer water temperature equating to faster development and metabolism, and consequently, greater O_2 consumption rates (Greig *et al.* 2007). Here, water temperature was occasionally above the optimal water temperature for incubation for Cutthroat and Rainbow Trout, which would have resulted in lower DO in the water, although this does not necessarily equate to egg mortality.

Suitable DO levels and incubation habitat within the egg pocket are created as the female salmonid alters the hydraulic conductivity during redd construction (Tonina and Buffington 2009). This localized altered hydraulic conductivity is the primary factor for enhancing seepage rates and DO content within the egg pocket habitat of salmon redds (Tonina and Buffington 2009). Redd construction significantly enhances the seepage rate and oxygen concentration, that otherwise would not occur, increasing the potential for embryo survival. Thus, the very localized incubation habitat conditions within the egg pocket may be a better indicator of egg survival compared to the general (and variable) conditions observed at point measurements across the stream bed environment.

Our results suggest that there may be insufficient groundwater movement in some areas of the Elk River drawdown zone to replenish local oxygen supply and flush away metabolic waste for trout spawning. Localized incubation habitat conditions and surface water flow conditions may; however, be favourable to promote egg/alevin survival in areas where groundwater movement is otherwise insufficient.

Yours truly,

Ecofish Research Ltd.

Prepared by:	Reviewed by:
Signed	*Signed*
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Water Resource Engineer

Disclaimer:

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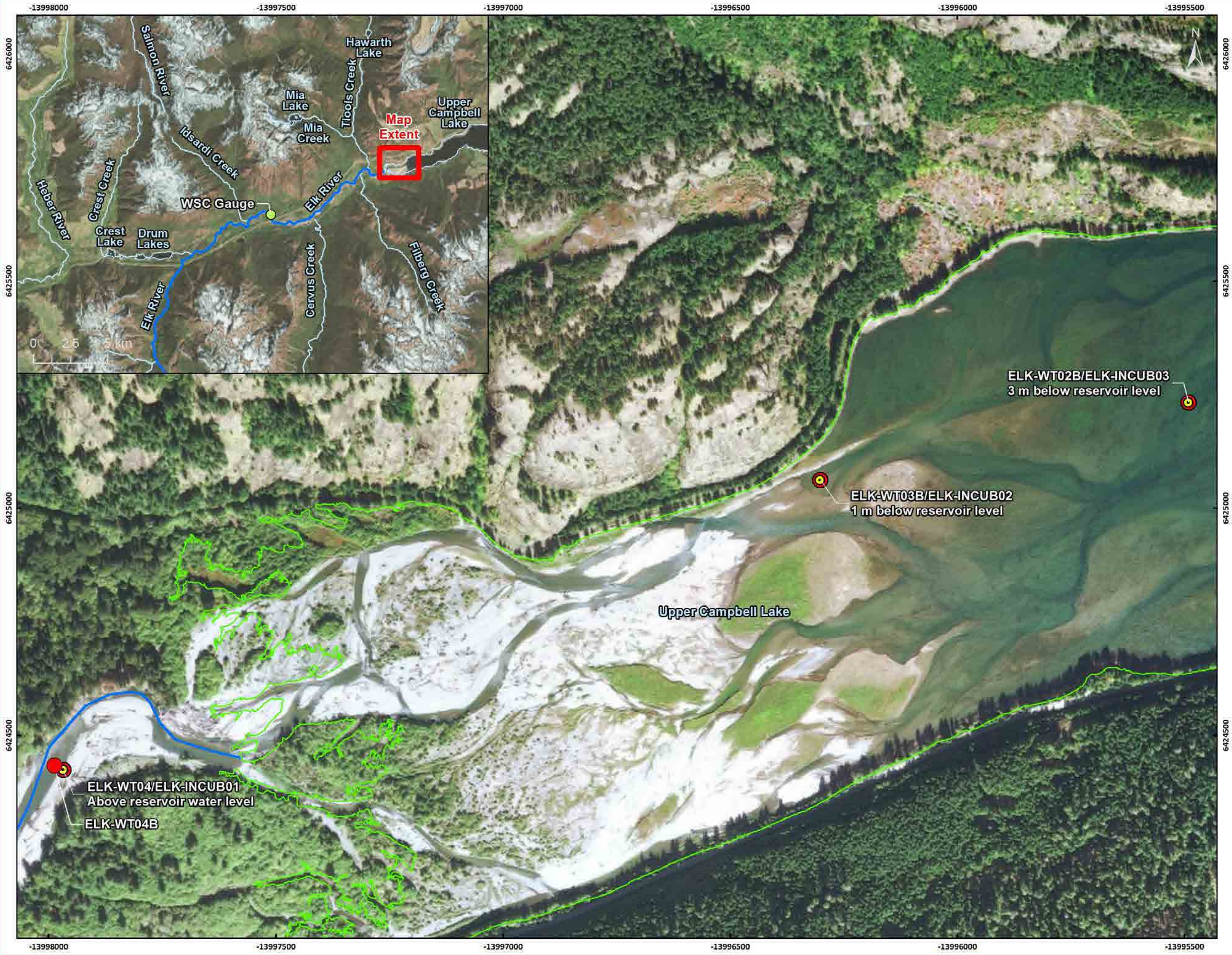
PROJECT MAPS



JHTMON CAMPBELL RIVER WATER USE PLAN

Elk River Incubation Test Sites and Seepage Measurements

Legend

- ● Incubation Test Site
- ● Seepage Measurement
- ● Hydrometric Gauge
- Drawdown Zone (220.5 m)
- Elk River

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 40 80 160 240 320 400 m

Scale: 1:8,000

NO.	DATE	REVISION	BY
1	17/01/2019	1230.34.06.04 Yr 5, Seepage Measurements_2950_2018Nov28b	CGA
2			
3			
4			
5			

Date Saved 17/01/2019
Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

ECOFISH RESEARCH

Map 1

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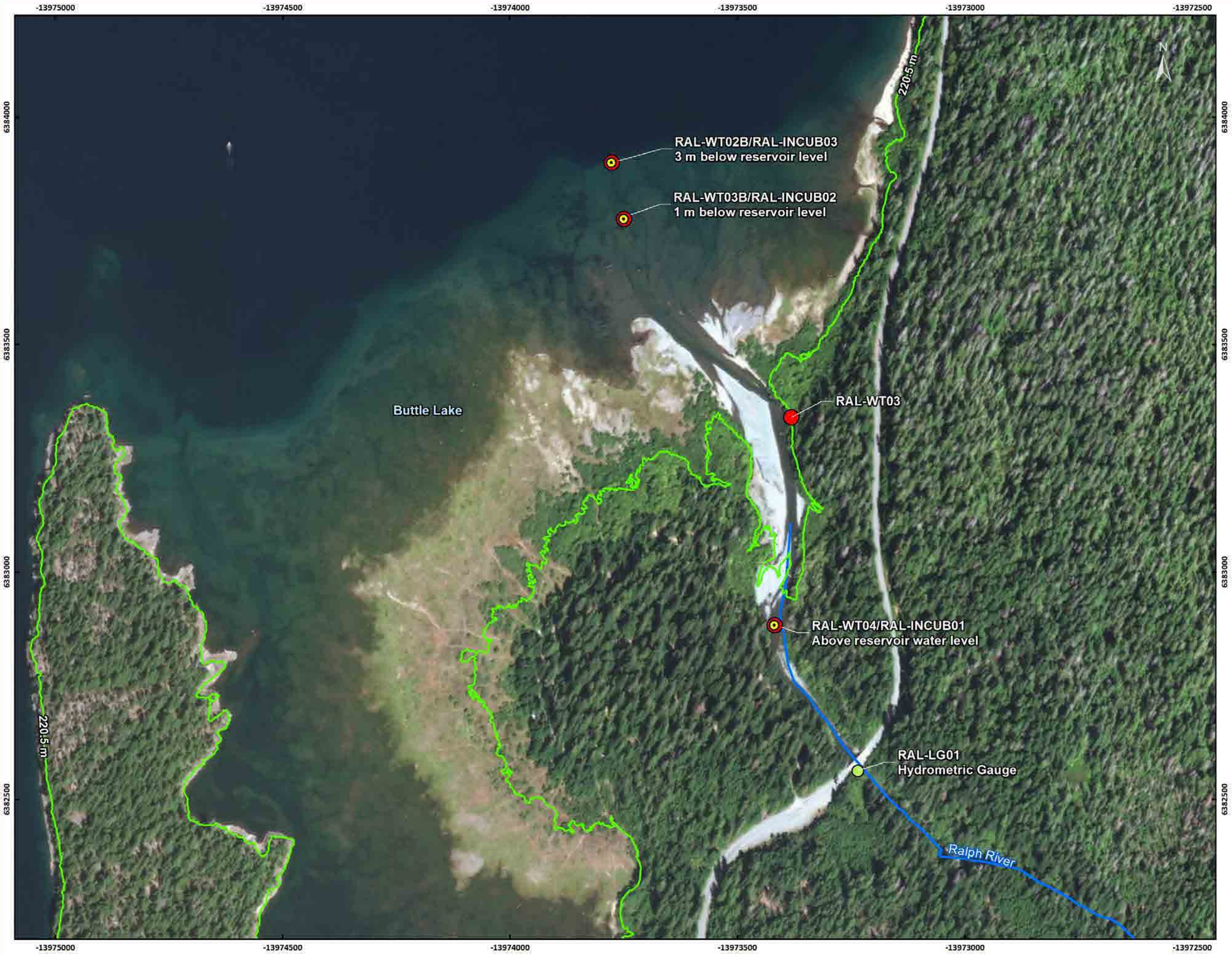

JHTMON CAMPBELL RIVER WATER USE PLAN

Ralph River Incubation Test Sites and Seepage Measurements

Legend

- ⊙ Incubation Test Site
- ● Seepage Measurement
- ● Hydrometric Gauge
- — Drawdown Zone (220.5 m)
- — Ralph River

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 40 80 160 240 320 400 m

Scale: 1:8,000

NO.	DATE	REVISION	BY
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2			
3			
4			
5			

Date Saved 17/01/2019
Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

ECOFISH RESEARCH

Map 2

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APPENDICES

Appendix A. **Groundwater Seepage Representative Site Photographs for Elk River and Ralph River**

Appendix B. **AquiferTest Summary Sheets**

Appendix C. **Surface Hydrology Results**

Appendix A. Groundwater Seepage Representative Site Photographs for Elk River and Ralph River

LIST OF FIGURES

Figure 1. Looking upstream at ELK-WT03B on June 19, 2018.

Figure 2. Looking downstream at ELK-WT03B on June 19, 2018.

Figure 3. Looking upstream at ELK-WT03B on July 06, 2018.

Figure 4. Looking downstream at ELK-WT03B on July 06, 2018.

Figure 5. Looking upstream at ELK-WT04B on June 19, 2018.

Figure 6. Looking downstream at ELK-WT04B on June 19, 2018.

Figure 7. Looking upstream at ELK-WT04B on July 06, 2018.

Figure 8. Looking downstream at ELK-WT04B on July 06, 2018.

Figure 9. Looking upstream at RAL-WT03B on June 20, 2018

Figure 10. Looking downstream toward Buttle Lake at RAL-WT03B on June 20, 2018

Figure 11. Looking upstream at RAL-WT03B on July 09, 2018

Figure 12. Looking downstream toward Buttle Lake at RAL-WT03B on July 09, 2018

Figure 13. Looking river right to river left at RAL-WT04 on June 20, 2018.

Figure 14. Looking downstream at RAL-WT04 on June 20, 2018.

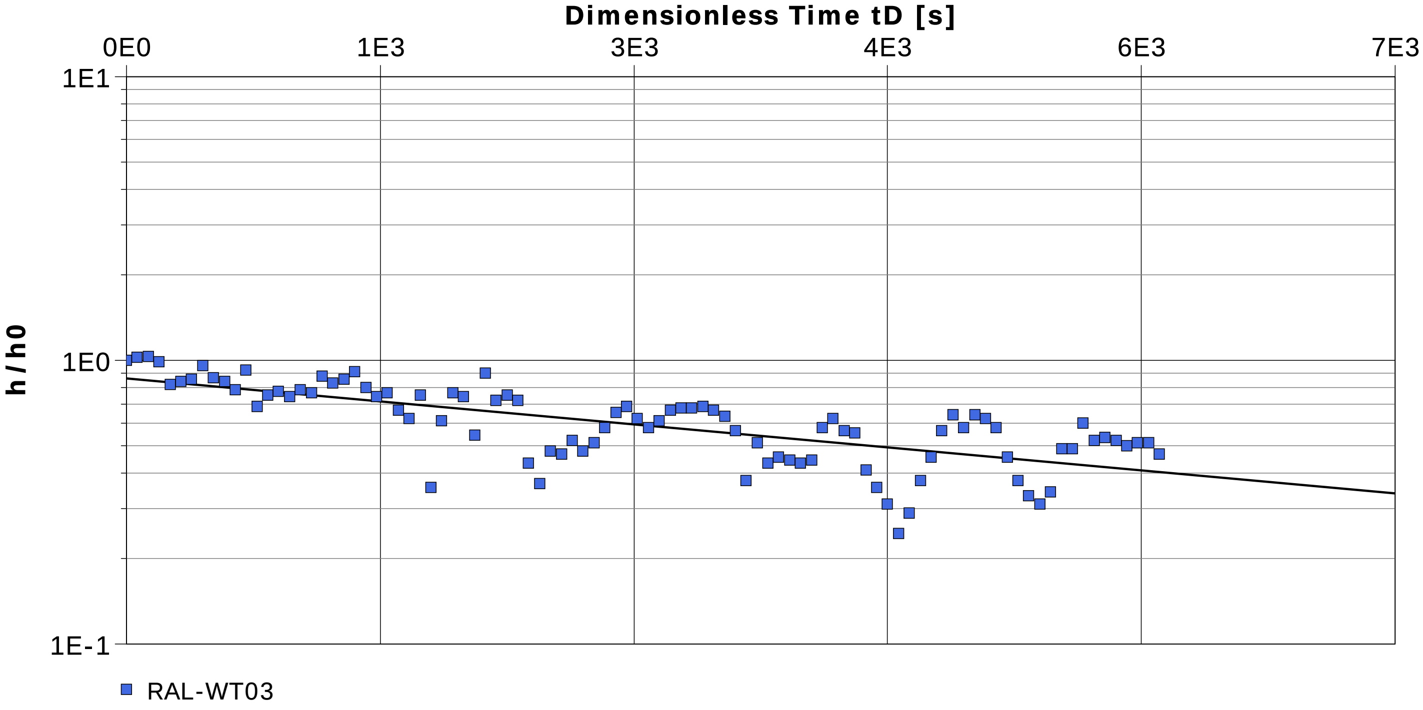
Figure 15. Looking river right to river left at RAL-WT04 on July 09, 2018.

Figure 16. Looking downstream at RAL-WT04 on July 09, 2018.

Appendix B. AquiferTest Summary Sheets

Ecofish Research	**Slug Test Analysis Report**
	Project: JHTMON3 - 2018 Seepage Study
	Number: 1230-34
	Client: BC Hydro

Location: Ralph River	Slug Test: Slug Test RAL-WT03	Test Well: RAL-WT03
Test Conducted by: NW/LH		Test Date: 7/9/2018
Analysis Performed by: RMD	Bouwer-Rice	Analysis Date: 11/21/2018
Aquifer Thickness: 9.00 m		
File path::		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/s]	
RAL-WT03	2.04×10^{-5}	

Ecofish Research

Slug Test - Analyses Report

Project: JHTMON3 - 2018 Seepage Study

Number: 1230-34

Client: BC Hydro

Location: Ralph River	Slug Test: Slug Test RAL-WT03	Test Well: RAL-WT03
Test Conducted by: NW/LH		Test Date: 7/9/2018
Aquifer Thickness: 9.00 m		
File path::		

	Analysis Name	Analysis Performe	Analysis Date	Method name	Well	T [m²/s]	K [m/s]	S
1	Bouwer-Rice	RMD	11/21/2018	Bouwer & Rice	RAL-WT03		2.04×10^{-5}	

Ecofish Research

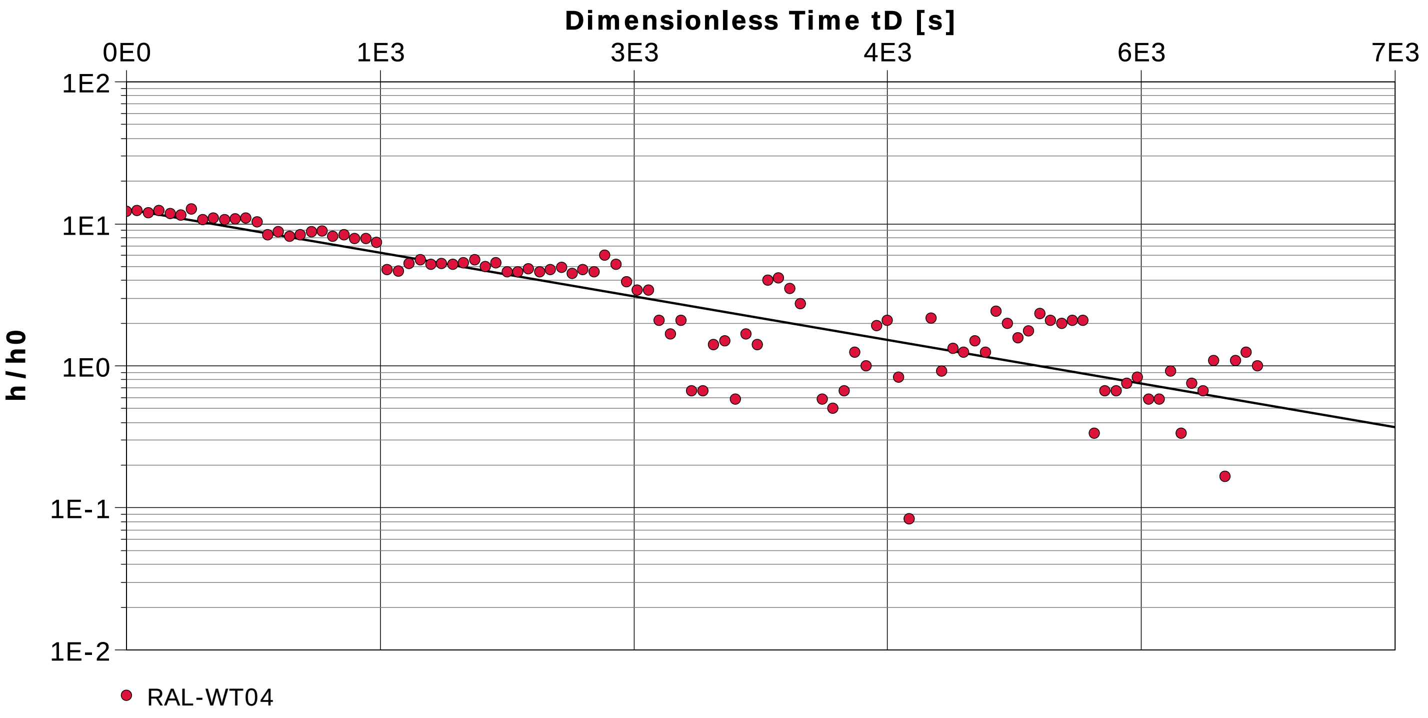
Slug Test Analysis Report

Project: JHTMON3 - 2018 Seepage Study

Number: 1230-34

Client: BC Hydro

Location: Ralph River	Slug Test: Slug Test 2 RAL-WT04	Test Well: RAL-WT04
Test Conducted by: NW/LCH		Test Date: 11/19/2018
Analysis Performed by: RMD	Bouwer & Rice	Analysis Date: 11/21/2018
Aquifer Thickness: 9.00 m		
File path::		



Calculation using Bouwer & Rice

Observation Well	Hydraulic Conductivity [m/s]	
RAL-WT04	7.77×10^{-5}	

Ecofish Research	**Slug Test - Analyses Report**
	Project: JHTMON3 - 2018 Seepage Study
	Number: 1230-34
	Client: BC Hydro

Location: Ralph River
Slug Test: Slug Test 2 RAL-WT04
Test Well: RAL-WT04
Test Conducted by: NW/LCH
Test Date: 11/19/2018
Aquifer Thickness: 9.00 m
File path::

	Analysis Name	Analysis Performec	Analysis Date	Method name	Well	T [m²/s]	K [m/s]	S
1	Bouwer & Rice	RMD	11/21/2018	Bouwer & Rice	RAL-WT04		7.77×10^{-5}	

Appendix C. Surface Hydrology Results

Table 1. Water depth and velocity measurements at Elk River and Ralph River piezometer locations.

Watercourse	Site[1]	Description	Location	June 2018 (incubator installation)	July 2018 (incubator removal)	June 2018 (incubator installation)	July 2018 (incubator removal)
				Water Depth (m)[2]		Flow Velocity (m/s)[3]	
	ELK-WT04 ELK WT04B	above reservoir water level	ELK-WT04a	0.49	0.28	0.99	0.90
			ELK-WT04b	0.37	0.20	0.90	0.99
			ELK-WT04c	0.35	0.15	1.05	0.92
			Average	**0.40**	**0.21**	**0.98**	**0.94**
	ELK-WT03B	1 m below reservoir water level	ELK-WT03a	0.52	0.35	0.11	0.23
			ELK-WT03b	0.74	0.31	0.16	0.17
			ELK-WT03c	0.80	0.50	0.55	0.08
			Average	**0.69**	**0.39**	**0.27**	**0.16**
	ELK-WT02B	3 m below reservoir water level		-	-	-	-
Ralph River	RAL-WT04	above reservoir water level	RAL-WT04a	0.52	0.27	0.89	0.45
			RAL-WT04b	0.49	0.28	1.22	0.70
			RAL-WT04c	0.43	0.29	0.93	0.77
			Average	**0.48**	**0.28**	**1.01**	**0.64**
	RAL-WT03 RAL-WT03B	1 m below reservoir	RAL-WT03a	0.31	0.48	0.00	0.00
			RAL-WT03b	0.27	0.58	0.00	0.00
			RAL-WT03c	0.29	0.78	0.00	0.00
			Average	**0.29**	**0.61**	**0.00**	**0.00**
	RAL-WT02B	3 m below reservoir water level		-	-	-	-

[1] All study sites are listed; however, data were only collected at sites in which piezometers were installed.

[2] Water depth measured using a wading rod.

[3] Flow velocity measured as average water column velocity using a Swoffer meter.

Appendix F. Gill Net Capture Data and Representative Photographs

LIST OF TABLES

LIST OF FIGURES

Table 1. Individual net set and capture data for Upper Campbell Lake gill netting.

Waterbody	Site	Set Number	Net Type	Net Position [1]	Net Length (m)	Water Temp °C	Turbidity [2]	Estimated Visibility	Time In	Time Out	Catch [3]					Soak Time
											CT	RB	CC	CT/ RB	UNK	
Upper Campbell Reservoir	UCR-LKGN08	1	RISC	SK	91.2	21.4	C	8	14:03:00	09:10:00	11	11		1		19.12
	UCR-LKGN08	2	RISC	FL	91.2	21.4	C	8	14:23:00	09:22:00	3	13	1			18.98
	UCR-LKGN07	1	RISC	SK	91.2	21.6	C	8	13:08:00	08:02:00	7	27				18.9
	UCR-LKGN07	2	RISC	FL	91.2	21.6	C	8	13:20:00	08:28:00		10				19.13
	UCR-LKGN07	3	RISC	SK	13	21.6	C	8	13:30:00	08:42:00		1	3			19.2
	UCR-LKGN06	1	RISC	SK	91.2	22	C	8	13:30:00	08:51:00	6	16		3	1	19.35
	UCR-LKGN06	2	RISC	FL	91.2	22	C	8	13:41:00	09:05:00		3				19.4
	UCR-LKGN04	1	RISC	SK	91.2	21.6	C	8	12:27:00	08:12:00	4	4				19.75
	UCR-LKGN04	2	RISC	FL	91.2	21.6	C	8	12:43:00	08:23:00		5		2		19.67
	UCR-LKGN04	3	RISC	SK	13	21.6	C	8	12:51:00	08:36:00		5				19.75
	UCR-LKGN02	1	RISC	SK	91.2	20.9	C	8	12:56:00	09:15:00	3	11	2			20.32
	UCR-LKGN02	2	RISC	FL	91.2	20.9	C	8	13:16:00	09:26:00		8				20.17
	UCR-LKGN01	1	RISC	FL	91.2	20.2	C	8	12:12:00	08:39:00	2	1				20.45
	UCR-LKGN01	2	RISC	SK	91.2	20.2	C	8	12:23:00	08:52:00	1	12		1		20.48

[1] SK - Sinking, FL - Floating

[2] C - Clear

[3] CT - Cutthroat Trout, RB - Rainbow Trout, CC - Sculpin Species, CT/RB - Cutthroat Trout/Rainbow Trout, UNK - unknown

Table 2. Raw fish data from gill net sampling.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	4	RB	258	198	1.15	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	4	RB	255	192	1.16	M	UNK	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	4	RB	225	125	1.10	F	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	4	RB	197	101	1.32	F	I	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	6	RB/CT	340	348	0.89	M	M	SC	05	FC	05	OT	05	FC	05
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	313	269	0.88	F	M	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	312	275	0.91	F	M	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	277	256	1.20	M	M	SC	08	FC	08	OT	08		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	269	183	0.94	F	M	SC	09	FC	09	OT	09		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	267	200	1.05	M	I	SC	10	FC	10	OT	10		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	262	222	1.23	F	M	SC	11	FC	11	OT	11		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	RB	293	240	0.95	F	M	SC	12	FC	12	OT	12		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	3	CT	312	301	0.99	M	M	SC	13	FC	13	OT	13		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	1	1	RB	104	17	1.51		I	SC	14	FC	14	OT	14		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	1	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	4	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	6	CT	316	313	0.99	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	3	CT	368	418	0.84	M	M			FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN01	8/20/2018	SK	2	3	RB	260	166	0.94	F	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	1	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	6	RB	285	277	1.20	M	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	6	RB	322	323	0.97	F	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	6	RB	269	238	1.22	M	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	4	RB	185	81	1.28	F	I	SC	04	FC	04	OT	04		

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, FL

Table 2. Continued.

Water Body	Year	Site Name	Date	Capture Method	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	2	4	RB	171	57	1.14	M	I	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	2	4	RB	203	106	1.27	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	2	3	RB	287	226	0.96	F	M	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	2	3	RB	276	237	1.13	M	M	SC	08	FC	08	OT	08		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	3	CT	295			F	M			FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	6	RB	286	272	1.16	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	6	RB	278	254	1.18	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	6	CT	364	522	1.08	M	M	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	2	CT	389	606	1.03	M	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	148	41	1.26	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	163	67	1.55	M	I	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	228	151	1.27	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	159	56	1.39	M	I	SC	09	FC	09	OT	09		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	168	58	1.22		I	SC	10	FC	10	OT	10		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	RB	168												
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	CC	131												
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	4	CC	122	20	1.10										
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	1	RB	111	21	1.54		I	SC	14	FC	14				
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	1	RB	98	18	1.91										
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	Gill Net	1	1	RB	128	26	1.24										
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	3	RB	292	299	1.20	M	M	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	6	CT	302	271	0.98	M	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	6	CT	348	428	1.02	M	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	6	CT	389	612	1.04	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	4	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	3	CT	286	223	0.95	F	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	1	RB	123	23	1.24	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	1	RB	123	21	1.13	M	I	SC	07	FC	07				
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	1	1	RB	134												
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	Gill Net	2	2	NFC													

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[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	4	RB	171	57	1.14	M	I	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	4	RB	203	106	1.27	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	3	RB	287	226	0.96	F	M	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	2	3	RB	276	237	1.13	M	M	SC	08	FC	08	OT	08		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	3	CT	295			F	M			FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	6	RB	286	272	1.16	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	6	RB	278	254	1.18	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	6	CT	364	522	1.08	M	M	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	2	CT	389	606	1.03	M	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	4	RB	148	41	1.26	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	FL	1	4	RB	163	67	1.55	M	I	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	RB	228	151	1.27	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	RB	159	56	1.39	M	I	SC	09	FC	09	OT	09		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	RB	168	58	1.22		I	SC	10	FC	10	OT	10		
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	RB	168												
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	CC	131												
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	4	CC	122	20	1.10										
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	1	RB	111	21	1.54		I	SC	14	FC	14				
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	1	RB	98	18	1.91										
Upper Campbell Reservoir	2018	UCR-LKGN02	8/20/2018	SK	1	1	RB	128	26	1.24										
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	3	RB	292	299	1.20	M	M	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	6	CT	302	271	0.98	M	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	6	CT	348	428	1.02	M	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	6	CT	389	612	1.04	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	4	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	3	CT	286	223	0.95	F	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	1	RB	123	23	1.24	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	1	RB	123	21	1.13	M	I	SC	07	FC	07				
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	1	1	RB	134												
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	2	NFC													

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, SK

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	6	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	3	RB/CT	330	345	0.96	M	M	SC	01	FC	01	OT	01	FC	01
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	3	RB	312	297	0.98	F	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	3	RB	299	254	0.95	F	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	3	RB/CT	284	262	1.14	M	M	SC	04	FC	04	OT	04	FC	04
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	3	RB	326	260	0.75	M	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	4	RB	249	172	1.11	M	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	2	1	RB	147	39	1.23		I	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	3	1	RB	100	13	1.30		I	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	3	2	RB	135			F	I	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	3	2	RB	89	9.4	1.28		I	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	SK	3	3	RB	124	24	1.26	M	I	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN04	8/21/2018	FL	3	4	RB	276	222	1.06	M	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	6	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	4	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	1	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	3	RB	291	219	0.89	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	3	RB	275	214	1.03	M	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	2	3	RB	281	233	1.05	F	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	4	RB	250	185	1.18	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	4	RB	253	200	1.24	M	I	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	4	RB	253	177	1.09	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	4	RB	221	134	1.24	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	4	RB	212	118	1.24	F	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	5	UNK	306												
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	5	RB	288	236	0.99	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	5	RB	205	113	1.31	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	5	RB	241	176	1.26	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	RB	221	127	1.18	M	I								

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	RB	180	75	1.29	M	I	SC	11	FC	11	OT	11		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	RB	164	60	1.36	M	I	SC	12	FC	12	OT	12		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	RB/CT	264	201	1.09	M	M	SC	13	FC	13	OT	13	FC	13
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	RB/CT	247	186	1.23	M	M	SC	14	FC	14	OT	14	FC	14
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	5	CT	398	693	1.10	M	M	SC	15	FC	15	OT	15		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	FL	1	3	RB	293	262	1.04	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	CT	330	373	1.04	F	M	SC	17	FC	17	OT	17		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	RB	212	124	1.30	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	RB	227	154	1.32	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	RB	231	141	1.14	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	CT	276	248	1.18	F	M	SC	21	FC	21	OT	21		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	3	CT	326	388	1.12	F	M	SC	22	FC	22	OT	22		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	2	CT	371	477	0.93	M	M	SC	23	FC	23	OT	23		
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	6	CT													
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	6	RB/CT	327	344	0.98	F	M	SC	25	FC	25	OT	25	FC	25
Upper Campbell Reservoir	2018	UCR-LKGN06	8/21/2018	SK	1	1	RB	140	34	1.24		I	SC	26	FC	26	OT	26		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	RB	286	263	1.12	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	RB	267	252	1.32	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	RB	282	246	1.10	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	CT	299	287	1.07	M	I	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	CT	312	336	1.11	M	M	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	CT	350	377	0.88	F	M	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	6	CT	314	329	1.06	F	M	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	270												
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	CT	215	110	1.11	M	I	SC	09	FC	09	OT	09		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	174	77	1.46	M	I	SC	10	FC	10	OT	10		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	169	66	1.37	F	I	SC	11	FC	11	OT	11		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	172	69	1.36	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	214	122	1.24	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	188	84	1.26	F	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	217	121	1.18	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	226	134	1.16										

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	223	133	1.20	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	225	150	1.32	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	232	154	1.23	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	4	RB	228	148	1.25	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	2	CT	354	496	1.12	F	M	SC	21	FC	21	OT	21		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	2	CT	352	477	1.09	F	M	SC	22	FC	22	OT	22		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	1	RB	99	15	1.55		I	SC	23	FC	23	OT	23		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	1	RB	150	51	1.51		I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	1	RB	121	25	1.41		I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	1	1	RB	104	18	1.60		I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	302	286	1.04	M	M	SC	27	FC	27	OT	27		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	232	156	1.25										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	224	133	1.18										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	249	184	1.19										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	267	225	1.18										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	234	142	1.11										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	204	107	1.26										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	3	RB	294	277	1.09										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	1	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	3	RB	254	201	1.23	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	2	3	RB	281	231	1.04	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	2	3	RB	305	319	1.12	M	M	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	2	4	RB	172	74	1.45	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	2	4	RB	191	92	1.32	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	2	4	RB	169	68	1.41	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	1	RB	127	26	1.27		I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	1	RB	127	24	1.17	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	1	RB	102	15	1.41		I								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	1	RB	94	13	1.57		I	SC	10	FC	10	OT			
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	2	6	NFC													

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	3	1	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	3	2	RB	166	61	1.33	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	FL	3	3	CC	141	37	1.32										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	3	3	CC	55	2	1.20										
Upper Campbell Reservoir	2018	UCR-LKGN07	8/22/2018	SK	3	4	CC	124	19	1.00										
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	1	CT	400	727	1.14	F	M	SC	01	FC	01	OT	01		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	2	CT	439	929	1.10	M	M	SC	02	FC	02	OT	02		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	213	113	1.17	F	I	SC	03	FC	03	OT	03		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	254	182	1.11	F	M	SC	04	FC	04	OT	04		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	240	170	1.23	M	I	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	278	212	0.99	F	M	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	246	160	1.07	M	I	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	275	195	0.94	F	M	SC	08	FC	08	OT	08		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	3	RB	285	212	0.92	F	M	SC	09	FC	09	OT	09		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	306	322	1.12	F	M	SC	10	FC	10	OT	10		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	330	393	1.09	M	M	SC	11	FC	11	OT	11		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	289	268	1.11	M	I	SC	12	FC	12	OT	12		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	388	677	1.16	M	M	SC	13	FC	13	OT	13		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	367	565	1.14	M	M	SC	14	FC	14	OT	14		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	352	451	1.03	F	M	SC	15	FC	15	OT	15		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	367	550	1.11	F	M	SC	16	FC	16	OT	16		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	CT	244	138	0.95	M	I	SC	17	FC	17	OT	17		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	6	RB	265	178	0.96	M	I	SC	18	FC	18	OT	18		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	4	RB	268	185	0.96	F	M	SC	19	FC	19	OT	19		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	4	CT	200	82	1.03	F	I	SC	20	FC	20	OT	20		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	4	RB	204	90	1.06	M	I	SC	21	FC	21	OT	21		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	5	RB	246	170	1.14	F	M	SC	22	FC	22	OT	22		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	1	5	RB/CT	231	129	1.05	F	I	SC	23	FC	23	OT	23	FC	23
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	2	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	5	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	6	NFC													
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	3	RB	282	219	0.98	F	M								

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Table 2. Continued.

Water Body	Year	Site Name	Date	Net Type	Set #	Panel #	Species[1]	Measured Length (mm)	Weight (g)	K	Sex	Sexual Maturity (I, M, UNK)	Age Sample (Type 1)	Age Sample Number 1	Age Sample (Type 2)	Age Sample Number 2	Age Sample (Type 3)	Age Sample Number 3	DNA Sample Type	DNA Sample Number
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	3	RB	276	235	1.12	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	3	RB	266	198	1.05	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	SK	2	3	RB	258	183	1.07	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	3	CT	228	147	1.24	M	I	SC	05	FC	05	OT	05		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	1	CT	255	162	0.98	F	I	SC	06	FC	06	OT	06		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	1	CT	142	30	1.05	M	I	SC	07	FC	07	OT	07		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	1	RB	142	33	1.15		I	SC	08	FC	08	OT	08		
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	1	RB	145	41	1.34		I								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	1	CC	105	42	3.63										
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018	FL	2	4	RB	251	198	1.25	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	231	153	1.24	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	236	144	1.10	F	I								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	238	166	1.23	F	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	274	222	1.08	M	M								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	242	155	1.09	M	I								
Upper Campbell Reservoir	2018	UCR-LKGN08	8/22/2018		2	4	RB	262	187	1.04	F	I								

[1] NCF - No fish caught, RB - Rainbow Trout, CT - Cutthroat Trout, CT/RB - Cutthroat Trout/Rainbow Trout, CC - Sculpin

Figure 1. Gill net gear deployed at each site during 2018 gill net surveys.

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Figure 2. Example of typical gill net gear deployment location (UCR-LKGN01) during 2018 gill net surveys.

Figure 3. 258 mm Rainvow Trout captured at UCR-LKGN01 on August 20, 2018.

Figure 4. 272 mm Cutthroat Trout captured at UCR-LKGN01 on August 21, 2017.

Figure 5. 187 mm Rainbow Trout captured at UCR-LKGN01 on August 21, 2017.

Figure 6. 316 mm Cutthroat Trout captured at UCR-LKGN01 on August 20, 2018.

Figure 7. 278 mm Rainbow Trout captured at UCR-LKGN02 on August 20, 2018.

Figure 8. 389 mm Cutthroat Trout captured at UCR-LKGN02 on August 20, 2018.

Figure 9. 122 mm sculpin captured at UCR-LKGN02 on August 20, 2018.

Figure 10. 389 mm Cutthroat Trout captured at UCR-LKGN04 on August 21, 2018.

Figure 11. 89 mm Rainbow Trout captured at UCR-LKGN04 on August 21, 2018.

Figure 12. 330 mm Rainbow Trout/Cutthroat Trout captured at UCR-LKGN04 on August 21, 2018.

Figure 13. 291 mm Rainbow Trout captured at UCR-LKGN06 on August 21, 2018.

Figure 14. 398 mm Cutthroat Trout captured at UCO-LKGN06 on August 21, 2018.

Figure 15. Stomach contents of a 299 m Cutthroat Trout captured at UCR-LKGN07 on August 22, 2018.

Figure 16. 141 mm Sculpin captured at UCR-LKGN07 on August 22, 2018.

Figure 17. 400 mm Cutthroat Trout captured at UCR-LKGN08 on August 22, 2018.

Figure 18. 213 mm Rainbow Trout captured at UCR-LKGN08 on August 22, 2018.

Appendix G. Snorkel Survey Representative Photographs

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Figure 1. **Looking downstream at Greenstone River snorkel section start on April 16, 2018.**

Figure 2. **Looking downstream at Greenstone River snorkel section end on April 16, 2018.**

Figure 3. Looking upstream at Miller Creek snorkel section start on March 9, 2018.

Figure 4. Looking upstream at Fry Creek snorkel section start on March 9, 2018.

Figure 5. Looking downstream at Fry Creek snorkel section start on March 9, 2018.

Figure 6. Looking downstream at Ralph River snorkel section start on June 4, 2018.

Figure 7. Looking downstream at Ralph River middle snorkel section on June 4, 2018.

Figure 8. Looking at drawdown zone area at Ralph River on June 4, 2018.

Figure 9. Looking upstream at Henshaw Creek on June 4, 2018.

Figure 10. Looking downstream at Henshaw Creek on June 4, 2018.

Figure 11. Looking upstream at Wolf River on June 5, 2018.

Figure 12. Looking downstream at Wolf River on June 5, 2018.

Figure 13. Looking at fish during snorkel survey in Wolf River on June 5, 2018.

Figure 14. Looking upstream at Phillips Creek on June 5, 2018.

Figure 15. **Looking downstream at Phillips Creek on June 5, 2018.**

Figure 16. **Looking downstream at Elk River snorkel section on June 6, 2018.**

Figure 17. Looking downstream at Elk River on June 6, 2018.

Figure 18. Looking at fish egg during snorkel survey in Elk River on June 6, 2018.

Figure 19. Looking downstream at Elk River on June 6, 2018.

Figure 20. Looking downstream at Elk River on June 6, 2018.

Figure 21. Looking upstream at Thelwood Creek on June 7, 2018.

Figure 22. Looking downstream at Thelwood Creek on June 7, 2018.

Figure 23. Looking at fish during snorkel survey in Thelwood Creek showing on June 7, 2018.

Appendix H. Redd Survey Comparative Figures and Maps (2017 and 2018)

LIST OF FIGURES

LIST OF MAPS

Figure 1. 2017 and 2018 Greenstone Creek Drawdown Zone Redds.

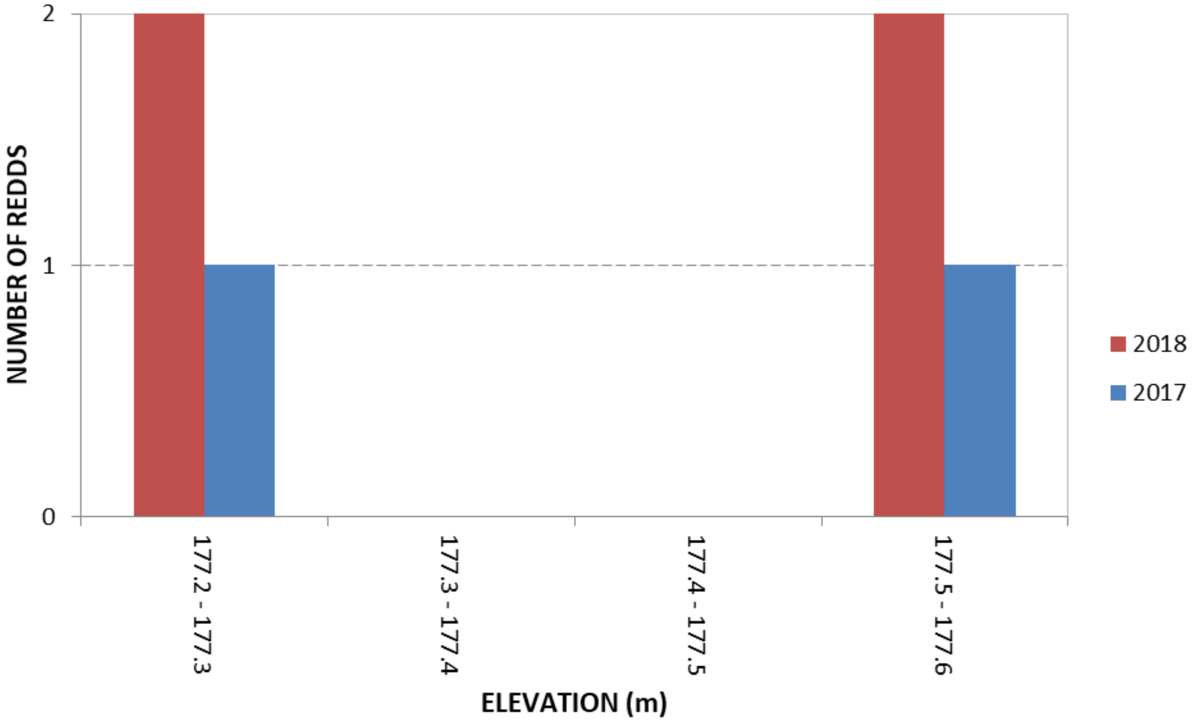


Figure 2. 2017 and 2018 Elk River Drawdown Zone Redds.

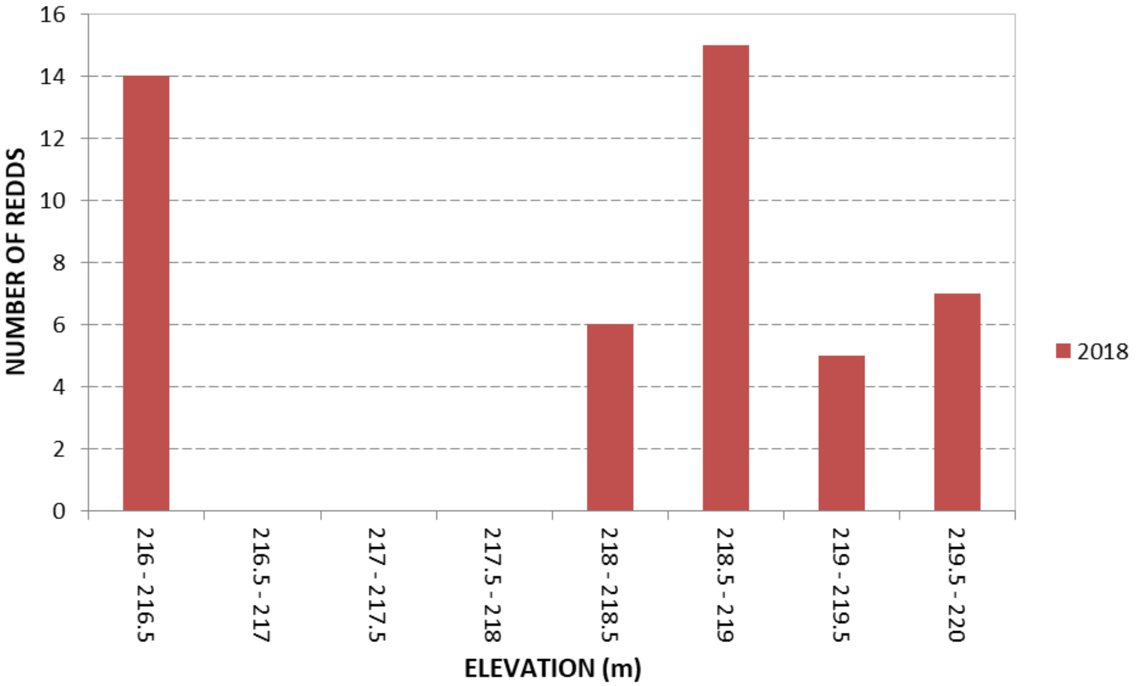


Figure 3. 2017 and 2018 Wolf River Drawdown Zone Redds.

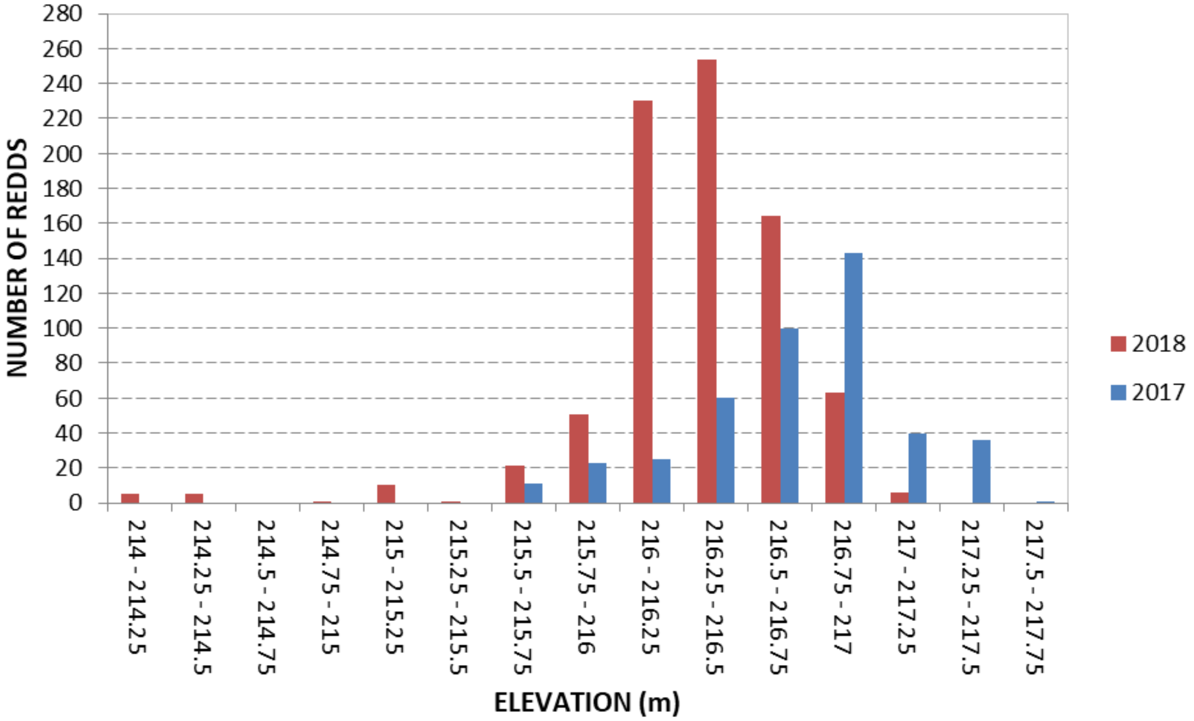


Figure 4. 2017 and 2018 Philips Creek Drawdown Zone Redds.

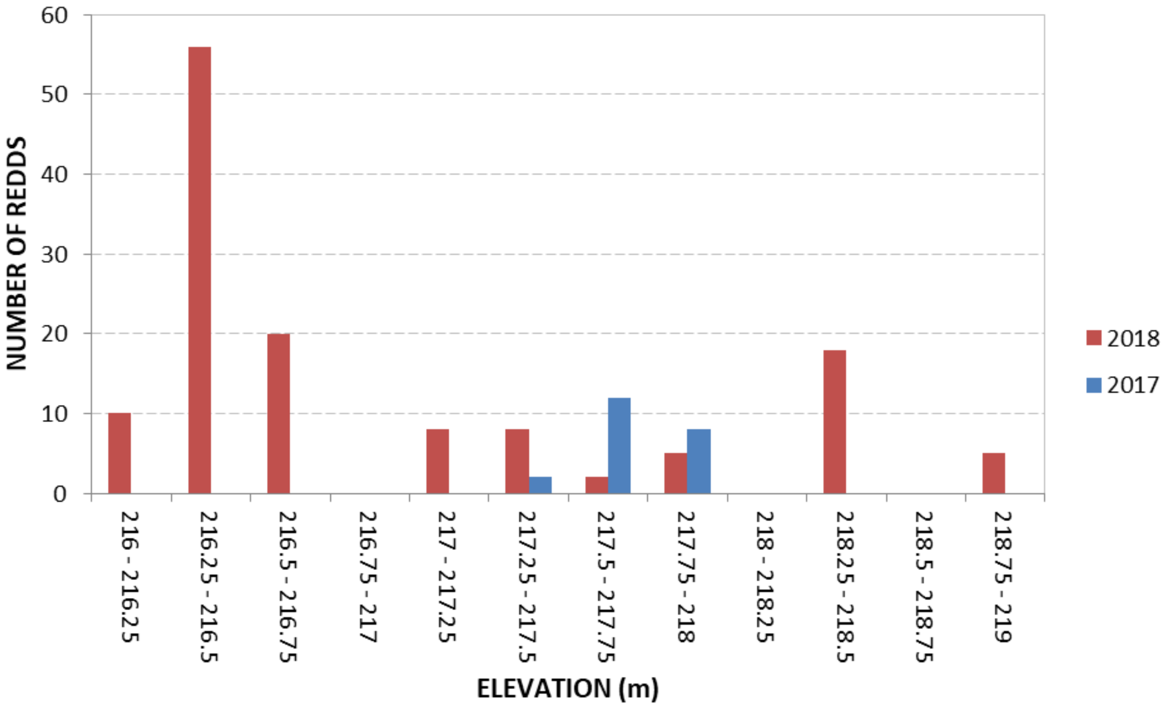
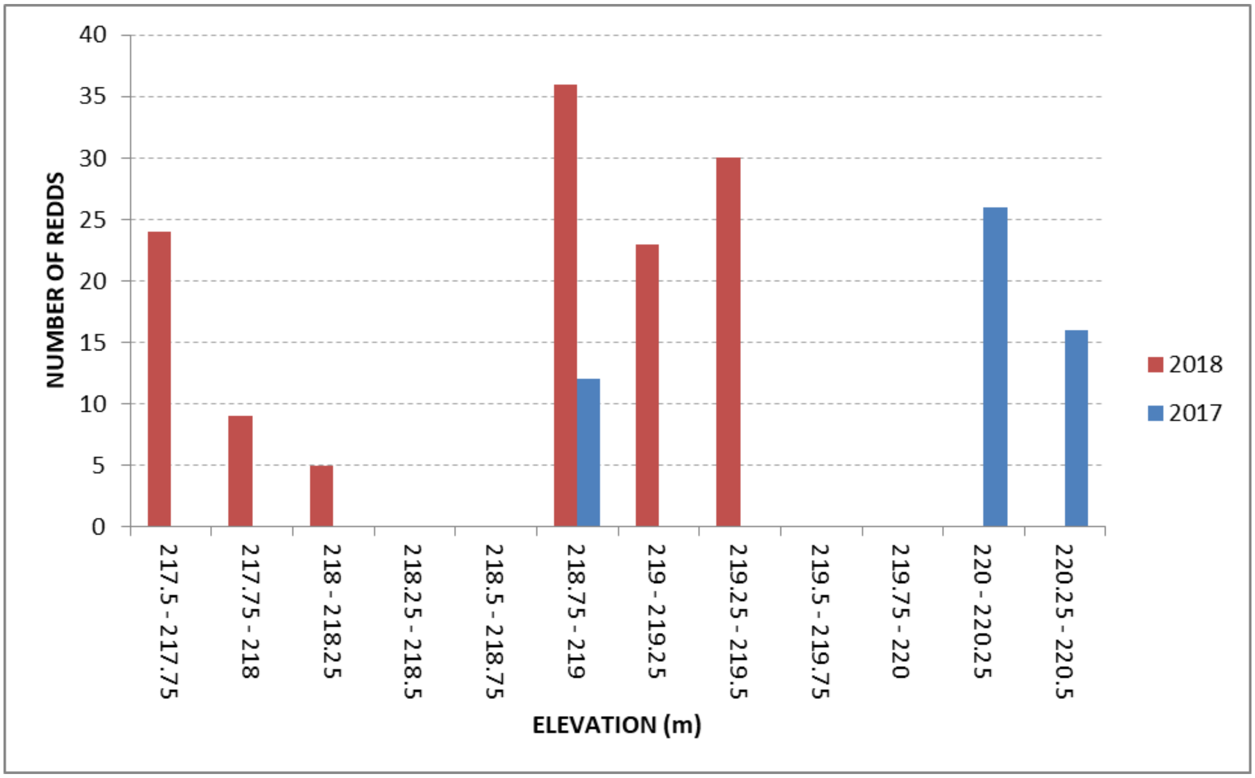
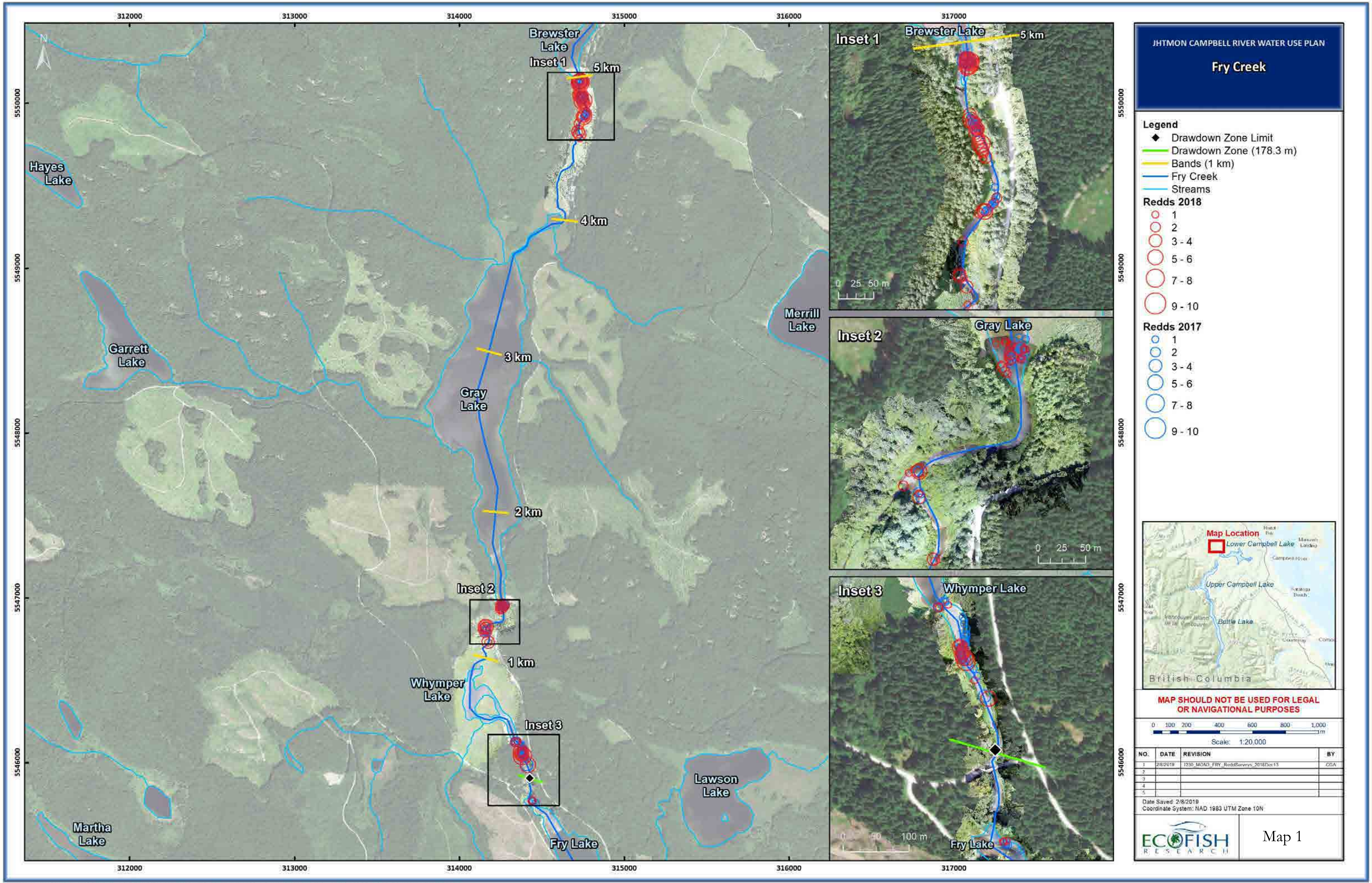


Figure 5. 2017 and 2018 Ralph River Drawdown Zone Redds.





JHTMON CAMPBELL RIVER WATER USE PLAN

Fry Creek

Legend

◆ Drawdown Zone Limit
Drawdown Zone (178.3 m)
Bands (1 km)
Fry Creek
Streams

Redds 2018

○ 1
○ 2
○ 3 - 4
○ 5 - 6
○ 7 - 8
○ 9 - 10

Redds 2017

○ 1
○ 2
○ 3 - 4
○ 5 - 6
○ 7 - 8
○ 9 - 10

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 100 200 400 600 800 1,000 m

Scale: 1:20,000

NO.	DATE	REVISION	BY
1	2/8/2019	1230_MON3_FRY_ReddSurveys_2018Dec13	CGA
2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

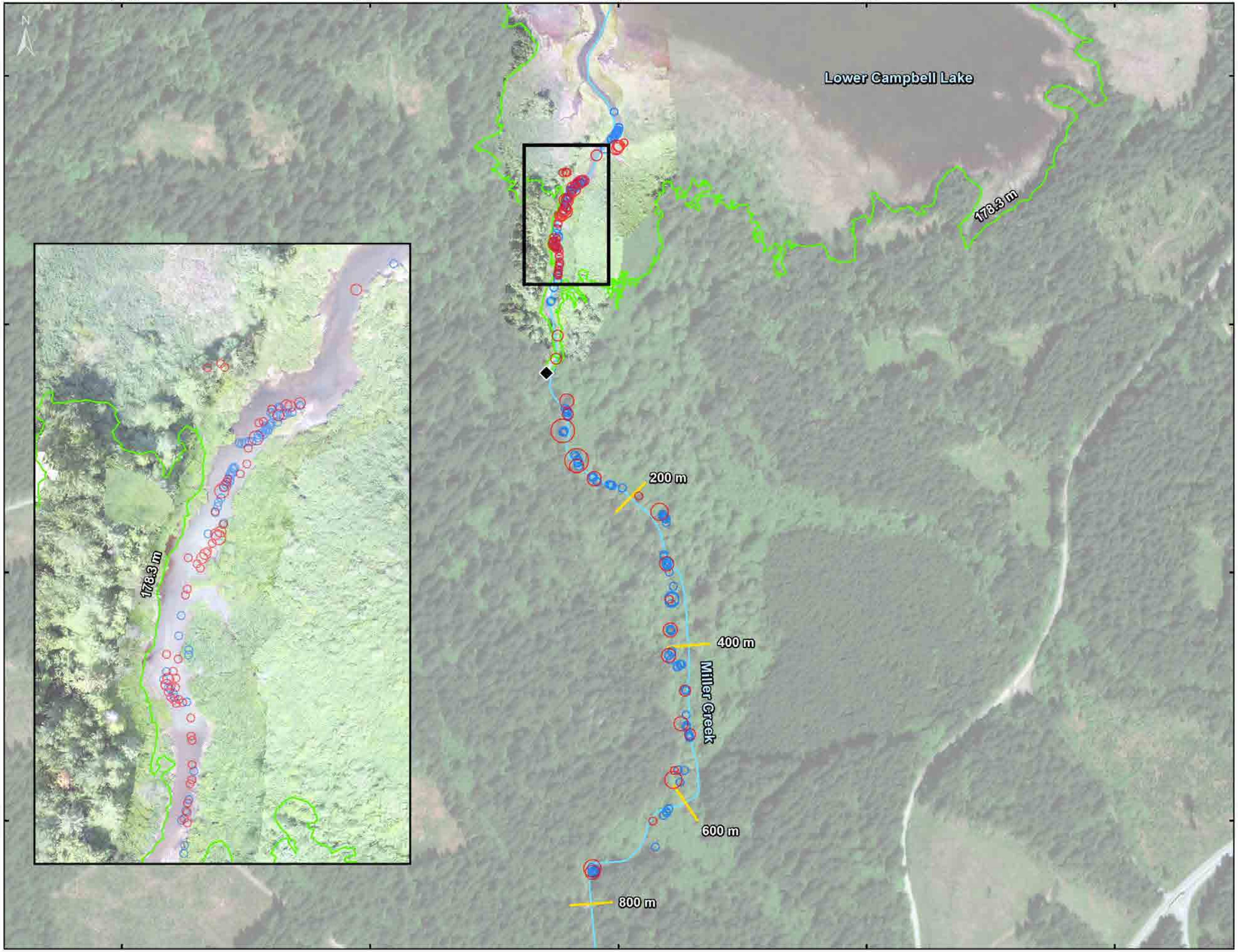
ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_FRY_ReddSurveys_2018Dec13.mxd

JHTMON CAMPBELL RIVER WATER USE PLAN

Miller Creek



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

Scale: 1:4,500

NO.	DATE	REVISION	BY
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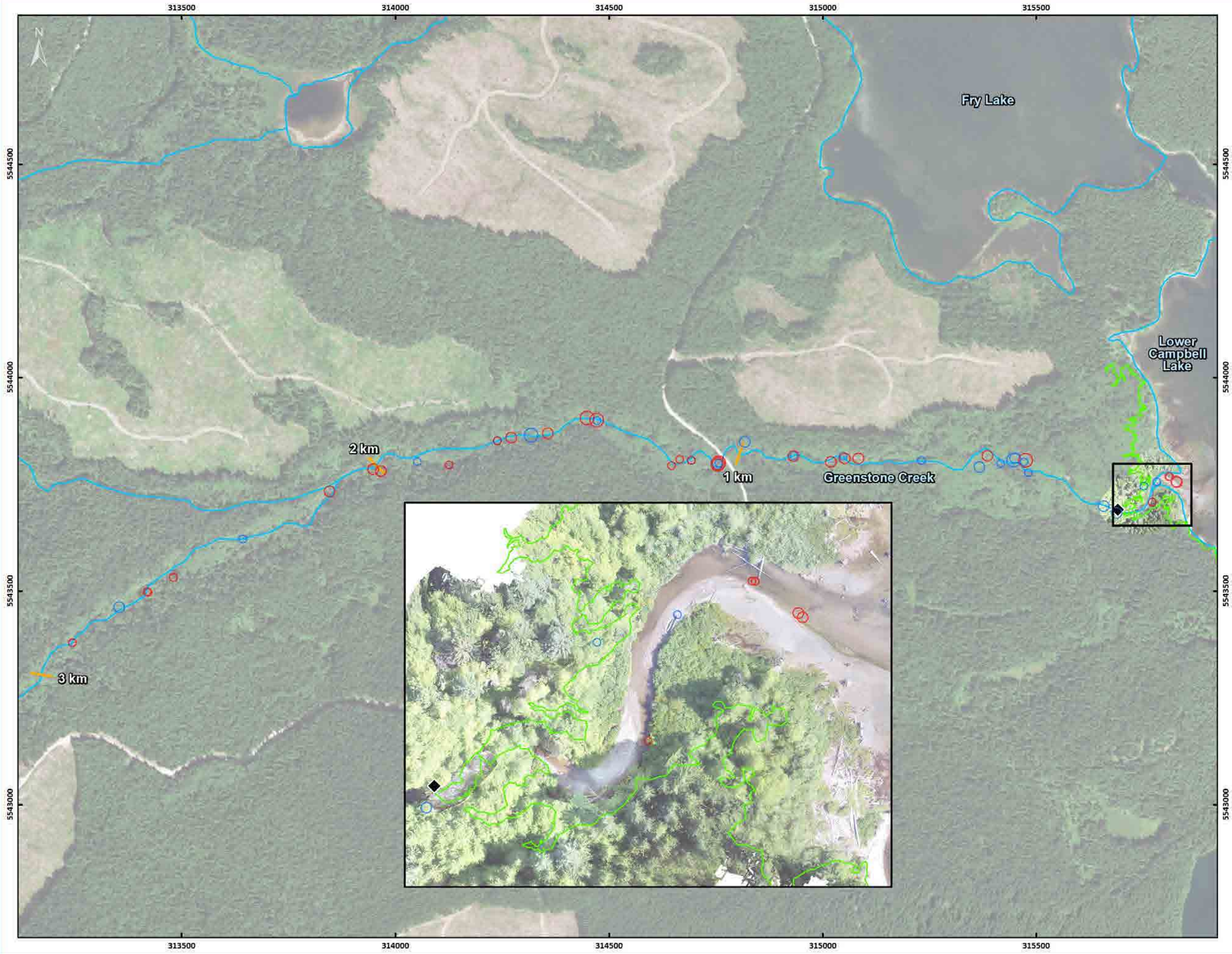
2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_MLR_ReddSurveys_2018Nov26.mxd



JHTMON CAMPBELL RIVER WATER USE PLAN

Greenstone Creek

Legend
- ◆ Drawdown Zone Limit
- Drawdown Zone (178.3 m)
- Bands (1 km)
- Streams

Redds 2018
- ○ 1
- ○ 2
- ○ 3 - 4

Redds 2017
- ○ 1
- ○ 2
- ○ 3 - 4

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 40 80 160 240 320 400 m

Scale: 1:8,500

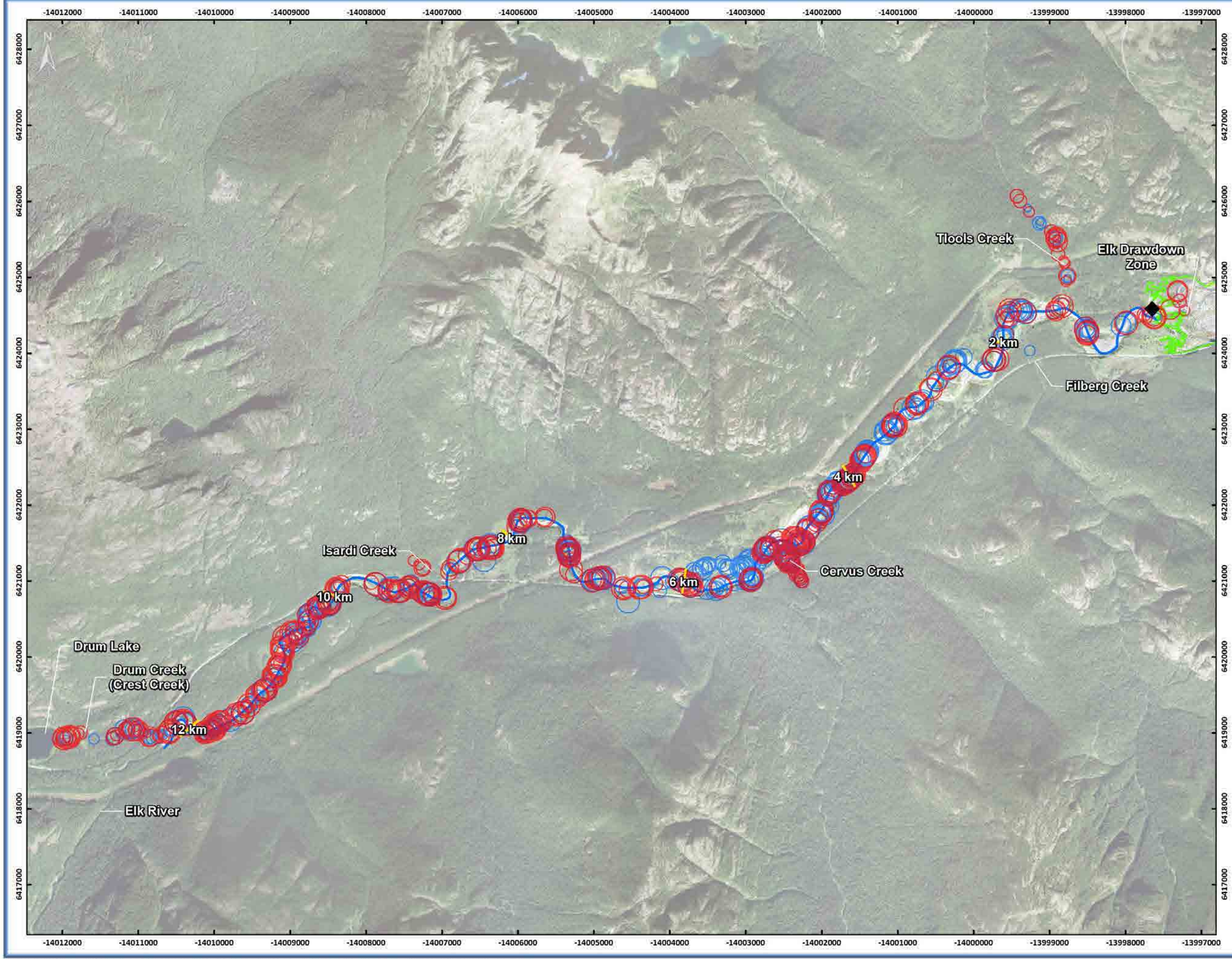
NO.	DATE	REVISION	BY
1	2/8/2019	1230_MON3_GRN_ReddSurveys_2018Nov26	CGA
2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 3

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_GRN_ReddSurveys_2018Nov26.mxd



JHTMON CAMPBELL RIVER WATER USE PLAN

Elk River (Upstream)

Legend

◆ Drawdown Zone Limit

Drawdown Zone (220.5 m)

Bands (2 km)

Elk River

Redds 2018

reddCount

○ 1
○ 2
○ 3 - 4
○ 5 - 6
○ 7 - 8
○ 9 - 10

Redds 2017

reddCount

○ 1
○ 2
○ 3 - 4
○ 5 - 6
○ 7 - 8
○ 9 - 10

0 260 520 1,040 1,560 2,080 2,600 m

Scale: 1:47,416

NO.	DATE	REVISION	BY
1	2/8/2019	1230_MON3_ELKUPPER_ReddSurveys_2018Nov26	CGA
2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere

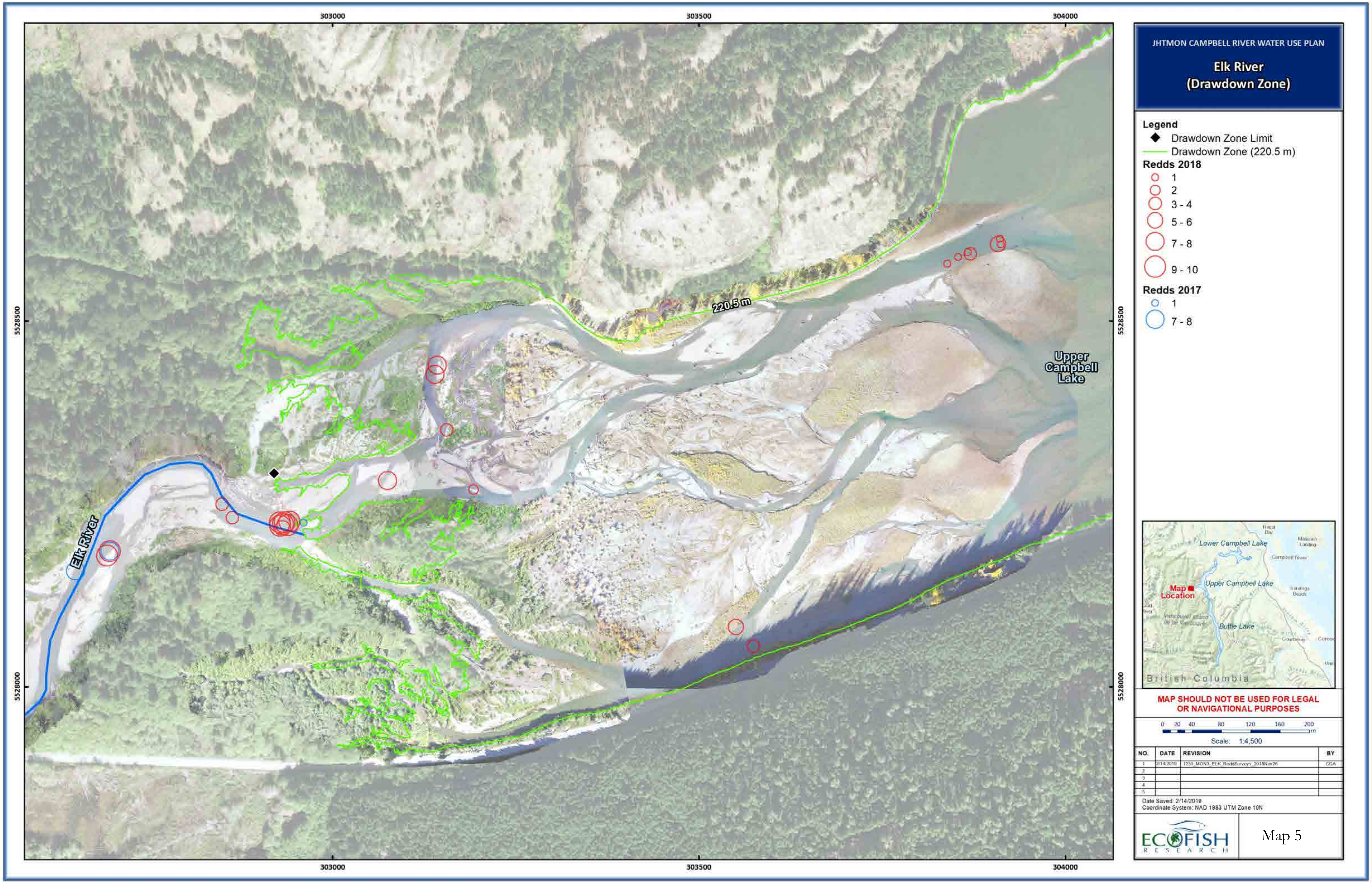
ECOFISH RESEARCH

Map 4

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_ELKUPPER_ReddSurveys_2018Nov26.mxd

JHTMON CAMPBELL RIVER WATER USE PLAN

Elk River
(Drawdown Zone)



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

Scale: 1:4,500

NO.	DATE	REVISION	BY
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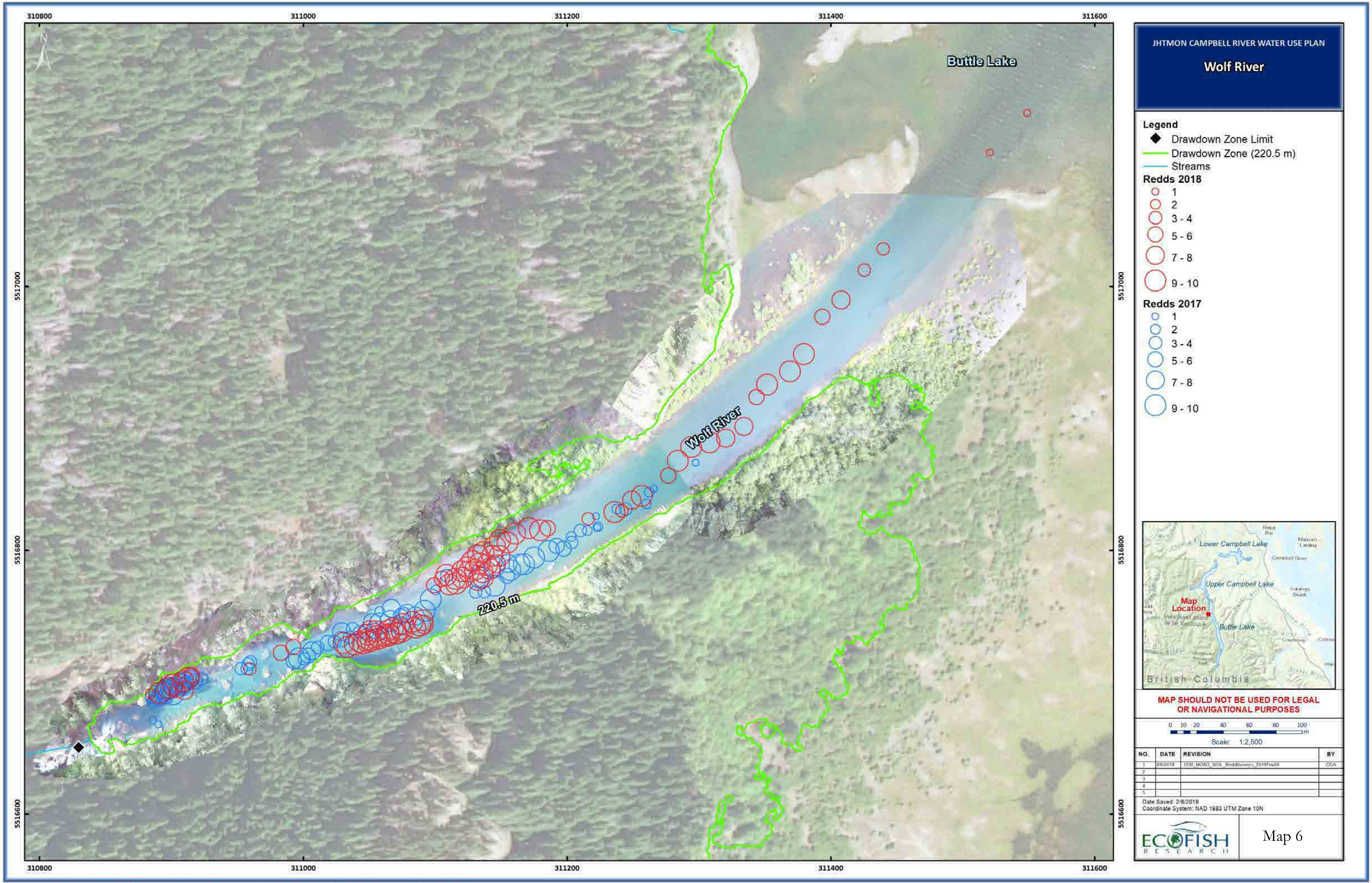
2			
3			
4			
5			

Date Saved: 2/14/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 5

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_ELK_ReddSurveys_2018Nov26.mxd



JHTMON CAMPBELL RIVER WATER USE PLAN

Wolf River

Legend

- ◆ Drawdown Zone Limit
- Drawdown Zone (220.5 m)
- Streams

Redds 2018

- ○ 1
- ○ 2
- ○ 3 - 4
- ○ 5 - 6
- ○ 7 - 8
- ○ 9 - 10

Redds 2017

- ○ 1
- ○ 2
- ○ 3 - 4
- ○ 5 - 6
- ○ 7 - 8
- ○ 9 - 10

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

Scale: 1:2,500

NO.	DATE	REVISION	BY
1	2/8/2019	1230_MON3_WOL_ReddSurveys_2019Fev05	CGA
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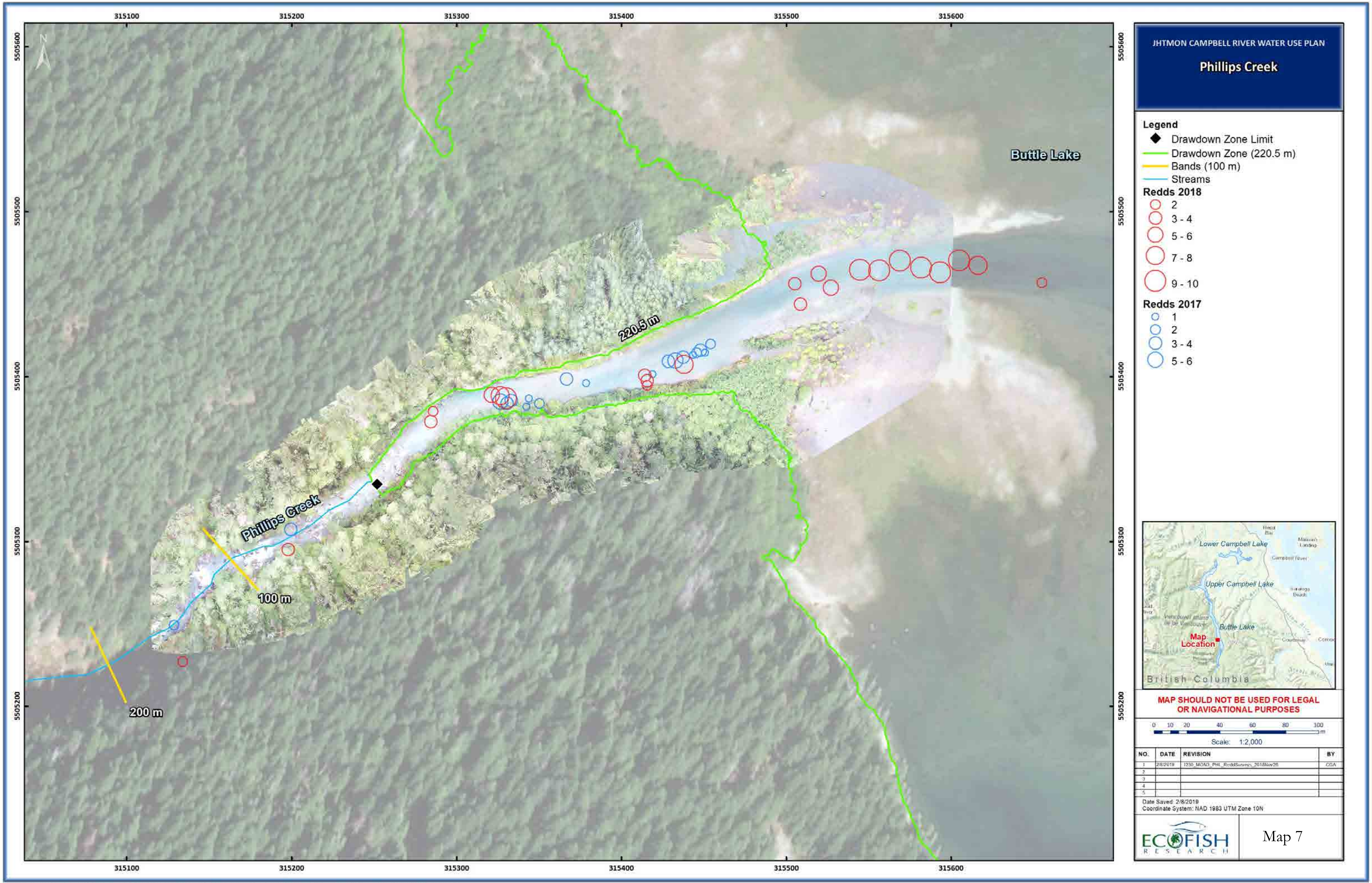
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 6

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_WOL_ReddSurveys_2019Fev05.mxd



JHTMON CAMPBELL RIVER WATER USE PLAN

Phillips Creek

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

Scale: 1:2,000

NO.	DATE	REVISION	BY
1	2/8/2019	1230_MON3_PHL_ReddSurveys_2018Nov26	CGA
2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

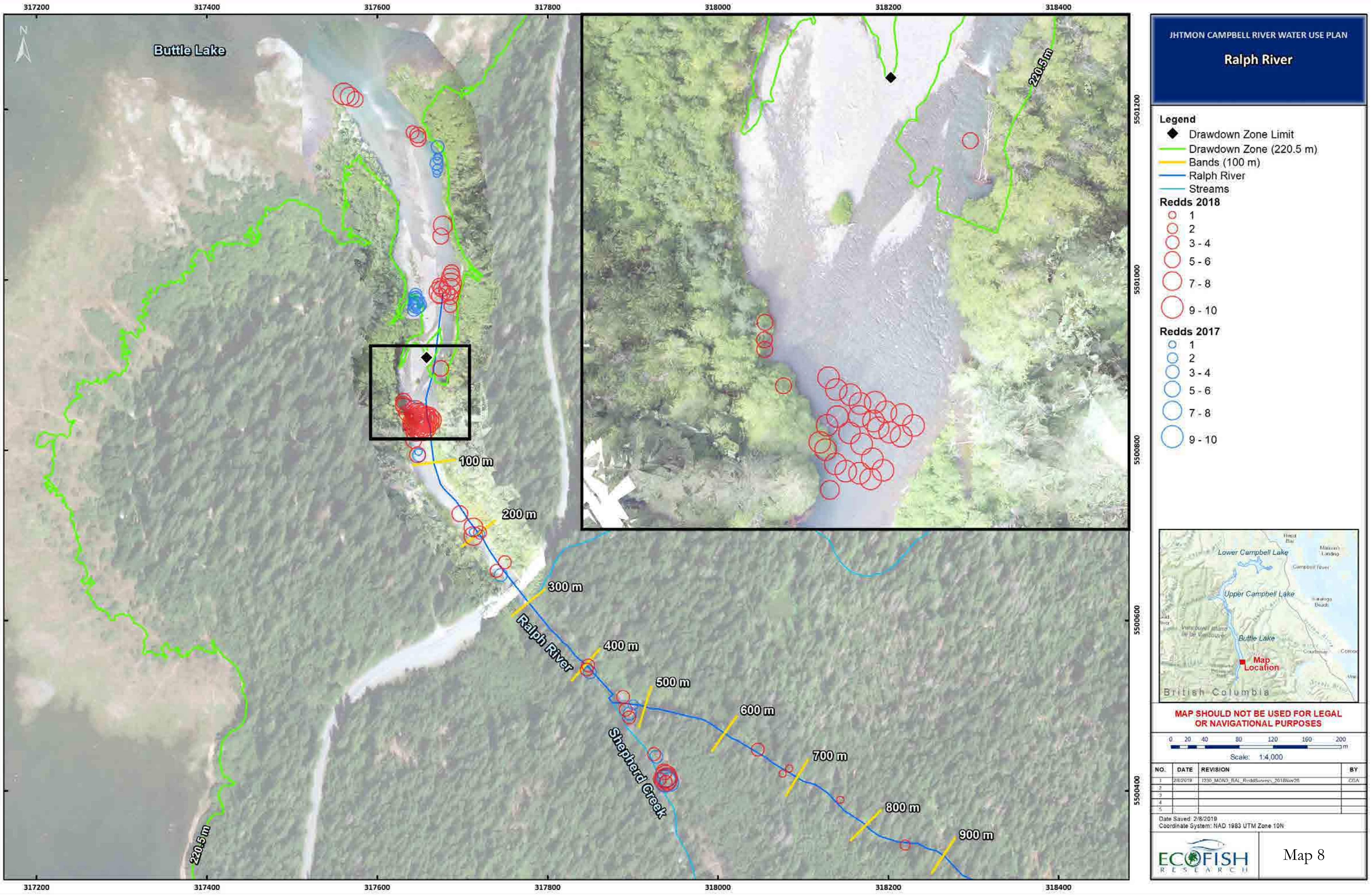
ECOFISH RESEARCH

Map 7

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_PHL_ReddSurveys_2018Nov26.mxd

JHTMON CAMPBELL RIVER WATER USE PLAN

Ralph River



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

Scale: 1:4,000

NO.	DATE	REVISION	BY
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2			
3			
4			
5			

Date Saved: 2/8/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 8

Path: M:\Projects-Active\1230_JHTMON\MXD\Fisheries\ReddSurveys2018\1230_MON3_RAL_ReddSurveys_2018Nov26.mxd