Aberfeldie Project Water Use Plan

Effectiveness Monitoring of Fish Habitat Works

Implementation Year 1-5

Reference: ABFMON 5 Task 2B

Project ABFMON 5 Task 2B: Fish and Fish Habitat

Study Period: 2008-2013

VAST Resource Solutions
4500 Mennie Rd
Cranbrook, BC
V1C0B4

21 July 2014

Aberfeldie Project Water Use Plan
Effectiveness Monitoring of Fish Habitat Works

(Year 1-5)

Project ABFMON 5 Task 2B: Fish and Fish Habitat (Contract Q9-9260)

FINAL Report

Prepared For:

British Columbia Hydro and Power Authority
Water Licence Requirements
6911 Southpoint Drive
Burnaby BC
V3N 4X8

Prepared By:

Ben Meunier, MSc, and Misun Kang, PhD, RPBio
VAST Resource Solutions Inc.

July 2014

Acknowledgements

VAST Resource Solutions Inc. would like to thank the following BC Hydro and Power Authority personnel for their contributions to this project during the past 5 years. Their assistance in project management and technical support during implementation was beneficial to the project and greatly appreciated.

Guy Martel	BC Hydro - Natural Resource Specialist, Burnaby
Michael McArthur	BC Hydro - Natural Resource Specialist, Burnaby
Ryan Hill	BC Hydro - Natural Resource Specialist, Castlegar
Jeff Berdusco	BC Hydro - Natural Resource Specialist, Cranbrook

Field/technical support was also provided by the following VAST Resource Solutions Inc. staff:

Kimball Nogier	Environmental Technician
Tanya Foster	Environmental Technician
Jodi Schneider	Environmental Technician
Aden Stewart	Environmental Technician

Suggested Citation

VAST Resource Solutions Inc. 2014. Aberfeldie Project Water Use Plan. Effectiveness Monitoring of Fish Habitat Works Task 2b, Fish and Fish Habitat Monitoring (Year 1-5). Prepared for British Columbia Hydro and Power Authority, Burnaby, BC. Prepared by VAST Resource Solutions Inc., Cranbrook, BC.

Cover Photo

Top: Female Kokanee on spawning platform. Bottom left: aerial view of side channel outlet. Bottom right: Fisheries crew during summer juvenile use assessment.

Executive Summary

The Aberfeldie side channel was constructed in the fall of 2008 to compensate for fish habitat and productivity losses predicted to result from the redevelopment of the Aberfeldie Generating Station and associated alterations to the flow regime over the dam and through the diversion reach of the Bull River.

The monitoring program ABFMON-5 Effectiveness Monitoring Fish Habitat Works was designed to characterize the effectiveness of the constructed channel to achieve the objectives of its design. The goal of this program was to address management questions presented in Table 1.

This report summarises results from the study, ABFMON-5 Task 2B, which monitored fish and fish habitat in the side channel during the first five years of operation. The objectives of this study were to: 1) characterize fish community and fish habitat in the constructed channel; 2) assess water quantity and quality; 3) monitor structural stability; and 4) describe habitat use by target species including spring spawning, summer rearing, fall spawning, and overwintering.

The Aberfeldie side channel measures 586 m and is comprised of 4 large pools, 12 glides, 5 riffles, and 4 cascades. It is fed by groundwater and does not have any surface input from the Bull River mainstem. Spawning platforms were constructed at the tail-out of glides to support spawning of target species. A total of 5,290 m^2 of aquatic habitat was created through the construction of the channel.

While large woody debris were found to provide adequate cover for rearing fish, substrate in the side channel is inadequate to support spawning of target species. Spawning gravel is larger than the gravel size prescribed during the design of the channel and fine sediments are present throughout the constructed habitat.

Water quality conditions in the Aberfeldie side channel are below optimal levels for the support of aquatic life. Particularly, dissolved oxygen rarely meets the requirements for rearing and reproduction of fish species as set in BC MoE guidelines (BC MoE, 2006). Dissolved oxygen is particularly poor during winter and restricts the overwintering potential of the side channel for target species.

The side channel intercepts enough groundwater to maintain surface flow throughout the side channel during all seasons. However, the side channel does not meet the flow velocity objectives of 0.3 to 0.5 m/s to support spawning and egg development at spawning platforms.

There was no spring spawning activity observed in the side channel during the first five years of operation. However, large numbers of Kokanee utilize the side channel in the fall for spawning. A low abundance of juvenile fish were found in the constructed habitat during summer, including Kokanee, Rainbow Trout, Westslope Cutthroat Trout, and Torrent Sculpin.

Active bank erosion is present throughout the side channel, likely caused by the steep slope of the banks. Eroded material affects fish habitat availability through the settling of fines in spawning gravel and the reduction of the channel effective width.

In conclusion, the construction of the side channel successfully created additional primary and secondary productive capacity. However, the effectiveness of the constructed system in providing suitable habitat to fish is limited, mainly due to water quality, water quantity, and physical habitat

issues. The long term sustainability of the constructed habitat is also threatened by active bank erosion and decreasing connectivity with the Bull River mainstem.

Table 1 Management Questions and their status after implementation Year 5

#	Management Questions (MQ)	Studies Addressing MQ	Status after implementation Year 5
1	What is the net effect of the post redevelopment flow regime on the community composition, diversity, abundance, and peak biomass of periphyton in the diversion reach of the Bull River.	ABFMON#2	**ADDRESSED**: • The implementation of the post upgrade 2 $m^3 \cdot s^{-1}$ minimum summer flow release does not change the peak biomass of periphyton in the diversion reach of the Bull River from pre-upgrade conditions. • The implementation of the post upgrade 2 $m^3 \cdot s^{-1}$ minimum summer flow release does not change the diversity of periphyton in the diversion reach of the Bull River from pre-upgrade conditions.
2	What is the net effect of the post redevelopment flow regime on the community composition, diversity, and abundance of benthic invertebrates in the diversion reach of Bull River?	ABFMON#2	**ADDRESSED**: • The implementation of the post upgrade 2 m3·s-1 minimum summer flow release does not negatively impact the abundance, biomass and diversity of total benthic invertebrates in the diversion reach of the Bull River from pre-upgrade conditions. The density of the assemblage of mayflies, stoneflies, and caddisflies significantly increased with implementation of minimum flow in the diversion reach.
3	If changes in the benthic community associated with post-redevelopment facility operations are detected, does the prescribed flow regime of 2 m^3/s summer minimum flow combined with the productive capacity realized from the constructed compensation habitat achieve the Aberfeldie Redevelopment project goal of no net loss of productive capacity?	ABFMON#5-2a ABFMON#5-2b ABFMON#5-2c	**ADDRESSED:** • There was a 19% decline in abundance of benthic invertebrate caused by loss of wetted area in the diversion reach but the productivity achieved through the constructed side channel was sufficient to offset this loss (Task 2A; Perrin and Bennett 2013b). • The construction of the side channel successfully created additional primary and secondary productive capacity. However, the effectiveness of the constructed system in providing suitable habitat to fish is poor due to water quality and quantity issues (Task 2B). The long term sustainability of the constructed habitat is also threatened by active bank erosion and decreasing connectivity with the Bull River mainstem (Task 2B and 2C).
4	Is there a lower summer minimum flow discharge that, in combination with the productive capacity of the compensation habitat, could achieve the Aberfeldie Redevelopment project compensation goal of no-net-loss of productive capacity?	ABFMON#5-2a ABFMON#5-2b	**ADDRESSED**: • Further reduction of summertime flows in the diversion reach should not be implemented unless effective improvements are made to the side channel for utilization by target fish species (Task 2A and 2B).

TABLE OF CONTENT

1 Introduction

The Aberfeldie Generating Station is a run-of-the river hydroelectric facility located on the Bull River, approximately 12 km upstream from the confluence of the Bull and Kootenay Rivers, and about 35 kilometres east of Cranbrook, BC (Figure 1). The facility was recently redeveloped to replace outdated equipment and to create additional energy and capacity. The facility layout includes a concrete dam at the upper end of a canyon stretch of the Bull River, a gravity penstock that directs water around the canyon (diversion reach) through a surge tower, and the powerhouse (Figure 2). The water is then directed back to the mainstem of the Bull River at the tailrace pool.

To meet capacity objectives, the Water Use Plan for the redevelopment required a reduction in the amount of spill over the dam and annual flows through the canyon (diversion reach) to the powerhouse, resulting in annual dewatering of instream glide, riffle, pool and channel margin habitat (Cope 2006, BC Hydro 2006). In particular, during the biological productive season, median flow in the diversion reach declined from 6 $m^3.s^{-1}$ before the upgrade to 2 $m^3.s^{-1}$ after the upgrade (Perrin and Bennett 2013a). The diversion reach flow reduction was estimated to result in an annual dewatering of 2,991 m^2 of the channel and result in a commensurate decline in fish habitat through primary and secondary productivity losses (DFO 2006). An additional 170 m^2 of habitat associated with the temporary installation of the tailrace cofferdam was also to be impacted.

In order to carry out the redevelopment, an authorization was obtained through Fisheries and Oceans Canada (DFO) for the harmful alteration, disruption and destruction (HADD) of aquatic habitat (DFO 2006). As a condition of the HADD Authorization (No. 05-HPAC-PA7-000-000188), BC Hydro was required to compensate for fish habitat and productivity losses through the construction of approximately 3,000 m^2 of off-channel habitat in a permanent side channel. The objective of this compensation strategy was to achieve a no net loss of productive capacity of the Bull River after redevelopment.

1.1 Mainstem Aquatic Values Prior to Redevelopment

A detailed habitat assessment was conducted prior to redevelopment to characterize baseline conditions within the diversion reach and enable the comparison of the Bull River mainstem productive capacity before and after redevelopment (Cope, 2006). This assessment included the characterization of fish habitat availability and the quantification of primary and secondary productive capacity (i.e., periphyton and benthic invertebrates).

The diversion reach, located between the tailrace pool and the dam, includes an upper and a lower habitat section. These sections are separated by a natural bedrock fall approximately 800 m downstream of the dam, which forms a barrier that restricts upstream fish access between the two sections. The main habitat of concern for productivity losses is a pool-riffle sequence with a mid-channel bar that connects the generating station tailrace and pool with the deep bedrock pool at the base of the upstream fish barrier. Streambed in this section of the Bull River is dominated by large cobbles, boulder, rubble, and bedrock. It provides low abundances of Kokanee (*Oncorhynchus nerka*) spawning habitat and potential spawning and summer rearing habitat for Westslope Cutthroat Trout (*Oncorhynchus clarki lewisi*), Mountain Whitefish (*Prosopium williamsoni*), Longnose Dace (*Rhinichthys cataractae*), Largescale Sucker (*Catostomus macrocheilus*), Torrent Sculpin (*Cottus rhotheus*), Slimy Sculpin (*Catostomus cognatus*), and possibly Bull Trout (*Salvelinus confluentus*). In the upstream section (canyon), habitat provides connectivity to over-wintering pools for isolated Westslope Cutthroat Trout and Mountain Whitefish entrained over the dam (Cope 2006).

As a whole, fish habitat in the diversion reach was not considered high quality (Cope 2006). Therefore, the offsetting of lost primary and secondary production was considered the main priority for the compensation efforts.

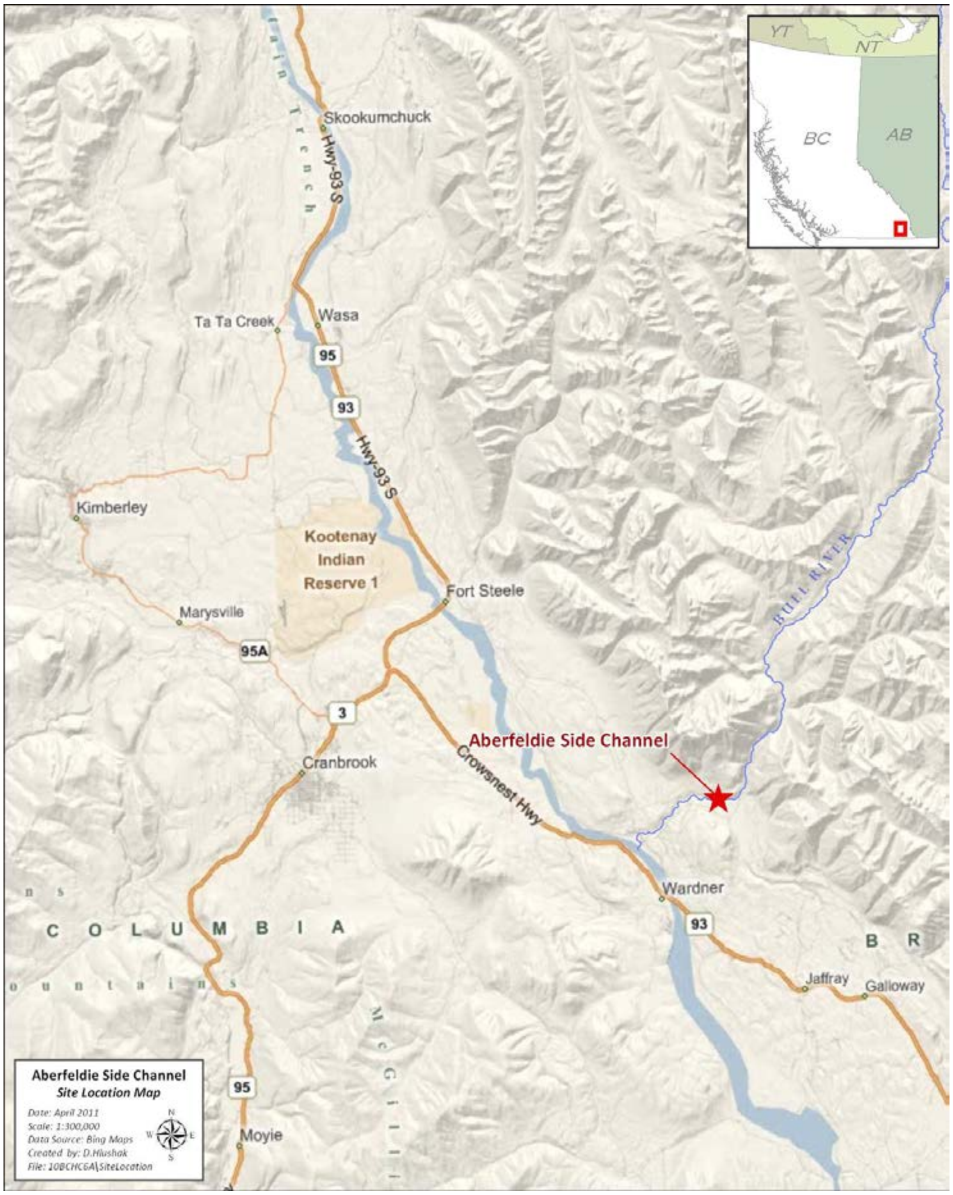

Figure 1 Location of the BC Hydro Aberfeldie side channel.

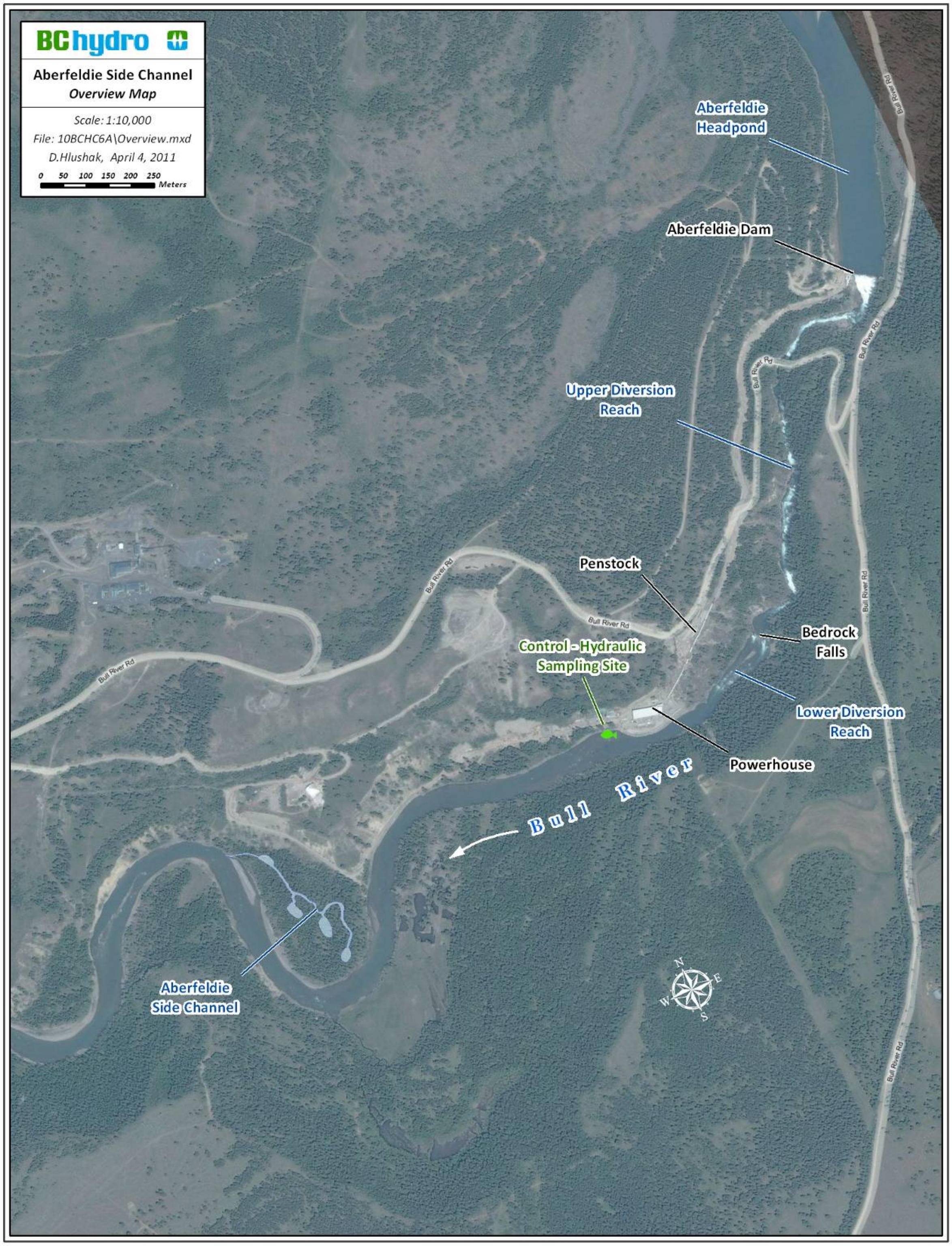

Figure 2 Layout of the Aberfeldie hydroelectric generating facility, diversion reach and side channel compensation habitat.

1.2 Side Channel Design

The side channel was built in the fall of 2008 and is located on the right downstream bank of the Bull River, approximately 500 m downstream of the tailrace. This area is a floodplain segment of the Bull River bounded by the valley wall to the north and the river on all other aspects. The channel was designed to intercept shallow groundwater flow from the river and groundwater flow from the upslope area to the north (Reid et al. 2008). The site was selected because of its proximity to the impacted area, its potentially low maintenance requirements, and the potential to retrofit a surface water intake in future years, if required (Reid et al. 2008).

The groundwater channel was intended, primarily, to compensate for primary and secondary productivity losses in the diversion reach (as per the 2011 Fish Authorization) and, secondarily, to provide enhance fish habitat (as per the ToR). In terms of fish habitat enhancement, the side channel was designed to provide a variety of hydraulic conditions required to support various life history stages, including the spawning and rearing of Westslope Cutthroat Trout (WCT), Kokanee (KO; non-native to the area), and possibly Bull Trout, as well as the rearing requirements for Mountain Whitefish (Table 1). It was also recognized that the channel might also be used by non-native Rainbow Trout (RT; *O. mykiss*) and Eastern Brook Trout (*S. fontinalis*). A detailed map showing the layout of the constructed side channel is presented in Figure 3.

Table 2 Potential habitat use of the Aberfeldie side channel by fish species (Reid et al. 2008).

Species	Scientific Name	Life History Stage	Duration
Westslope Cutthroat Trout	*Oncorhynchus clarkii lewisi*	spawning, fry, juvenile and adult	year-round
Kokanee [a]	*Oncorhynchus nerka*	spawning and fry	2 months post swim-up
Bull Trout	*Salvelinus malma*	spawning, fry, and juvenile	year-round until >300 mm fork length
Mountain Whitefish	*Prosopium williamsoni*	juvenile and adult	year-round, but primarily juvenile
Rainbow Trout [a]	*Oncorhynchus mykiss*	spawning, fry, juvenile and adult	year-round, but primarily juvenile
Eastern Brook Trout [a]	*Salvelinus fontinalis*	spawning, fry, juvenile and adult	year-round

[a] non-native species that may utilize the side channel

On May 21, 2009, a Fish Habitat Assessment Procedure (FHAP) was completed for the entire side channel (McPherson and Robinson 2010). Given that the FHAP was completed during the first year of the operation of the side channel and prior to spring freshet events, it is considered an as-built survey of the area. The FHAP determined the channel to be 586 m long with a wetted area of 5,290 m^2. Flows estimated from a permanent gauging station (weir; Figure 3) ranged from 0.01 to 0.04 m^3/s during 2009-2010 (McPherson and Robinson 2010).

The side channel has three reaches (Figure 3). Reach 1 comprises the main length of the channel (478 m), while Reach 2 (54 m) and Reach 3 (53 m) are each made up of a short glide and large alcove pool extending off from the main reach. The side channel has four large pools (totalling 3,726 m^2), 12 glides (totalling 1m436 m^2), 5 riffles (totalling 94 m^2), and 4 cascades (34.8 m^2).

The following is an overview of each habitat type as described by McPherson and Robinson (2010; unless otherwise cited):

Pools made up 70% of the total area of the channel and were constructed to provide refuge, rearing, and adult holding habitat for fish, as well as low velocity and deep water areas for other aquatic organisms (e.g., algae, invertebrates, etc.) (Reid *et al.* 2008). The side channel design prescribed at least 25% cover provided by large woody debris (LWD) and a residual maximum pool depth of 1.5 to 2.0 m. The FHAP assessment found that between 50 and 75% of the pool area was covered LWD and that the mean maximum depth of the four pools (two inline and two alcove) was 1.4 m (± 0.4).

Glides comprised 27% of the total area in the side channel. Glides were intended to support the majority of benthic production and fish rearing in the channel, as well as isolated spawning in areas where suitable hydraulics and bed materials exist (Reid *et al.* 2008). The side channel design prescribed an average glide depth of 0.3 m and a density of one LWD piece for every 5m of channel length to provide cover and vary hydraulic conditions. The FHAP assessment found that LWD was the main type of habitat cover in glides, covering approximately 40% of the area. Glides had low gradients ranging from 1% to 2% and consequently produced low water velocities (range 0.10 to 0.01 m/s).

Seven of the 12 glides had spawning platforms constructed at their most downstream end, where the glide transitioned to a riffle or cascade. Pebble surveys completed on 3 of the spawning platforms indicated mean pebble diameter to be 48.3 (± 34.1 SD) mm. The median size of substrates (D_{50}) was 45 mm, a pebble diameter larger than that required by smaller salmonids of the Bull River. Based on known body lengths, the appropriate D_{50} for Kokanee was estimated to be 20 mm, and the D_{50} for Westslope Cutthroat Trout was estimated to range from 15 to 35 mm. As-built spawning platform details differed from the design specifications (Reid *et al.* 2008), which prescribed velocities of 0.3 to 0.5 m/s over 25 mm washed gravel, necessary for Westslope Cutthroat Trout and Kokanee spawning.

Riffle and cascade habitat combined made up 2.5% of the total area of the side channel. These habitats were intended to provide aeration, connectivity, benthic production, fish rearing areas, and grade/water level control (Reid *et al.* 2008). The side channel design prescribed a 6.5% gradient for riffle habitat. Mean riffle gradients measured during the FHAP assessment were 3.4 (± 1.1 SD) %, and mean cascade gradients were 15.5 (± 6.6 SD) %.

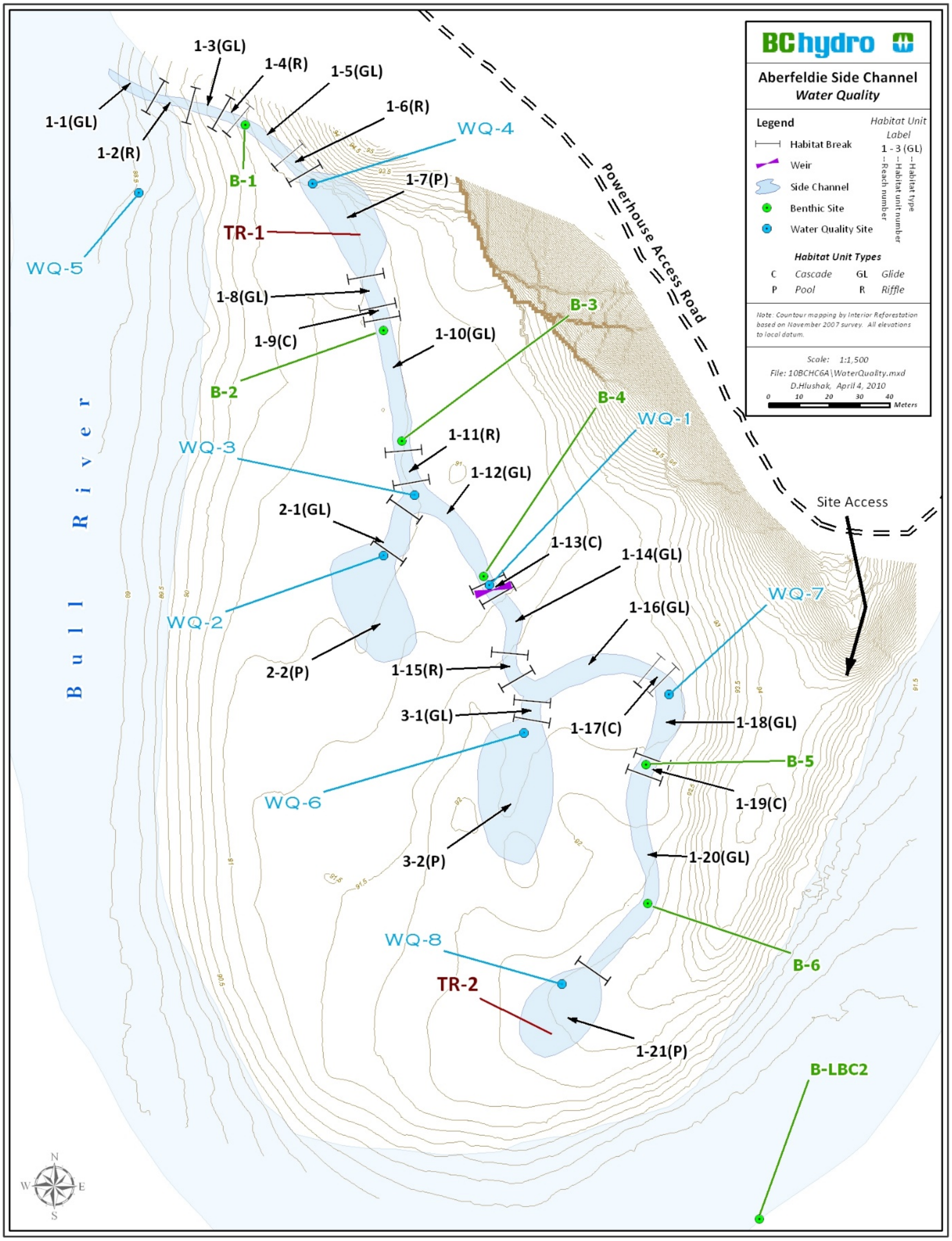

Figure 3 Map showing layout of Aberfeldie side channel and location of habitat units (HU), water quality sampling sites (WQ), and benthic sampling sites (B).

1.3 Scope

BC Hydro and Power Authority (BC Hydro) retained the services of VAST Resource Solutions Inc. (VAST; formerly Interior Reforestation Co. Ltd.) in 2009 to develop and implement a 5-year (2009-2013) fish habitat works effectiveness monitoring program for the Aberfeldie side channel. The program, entitled ABFMON-5 Task 2B, was to assess the status of the newly constructed side channel in providing suitable fish habitat and to provide recommendations on improvements to achieve its design objectives.

This study was one of five effectiveness monitoring components undertaken to determine the effectiveness of the Aberfeldie redevelopment compensation works in meeting the federal fisheries goal of no-net-loss. The other environmental components assessed include:

- Baseline productivity monitoring (ABFMON-1. Cope 2006)
- Primary and secondary productivity monitoring (ABFMON-2 and ABFMON-5 Task 2A. Perrin and Bennett, 2013a and 2013b)
- Riparian vegetation monitoring (ABFMON-5 Task 2C. Przeczek and Isaac 2013)
- Habitat impact monitoring (ABFMON-3. Perrin and Canning, 2010)
- Winter flow effectiveness monitoring (ABFMON-4; McArthur et al., 2010)

The results of these combined effectiveness monitoring studies will be used to answer the management questions presented in Table 2. Management questions were developped by the WUP consultative committee and the fisheries technical community (BC Hydro 2008a and 2008b).

Table 3 Management Questions and their status after implementation Year 5

#	Management Questions (MQ)	Studies Addressing MQ	Status after implementation Year 5
1	What is the net effect of the post redevelopment flow regime on the community composition, diversity, abundance, and peak biomass of periphyton in the diversion reach of the Bull River.	ABFMON#2	**ADDRESSED**: • The implementation of the post upgrade 2 $m^3 \cdot s^{-1}$ minimum summer flow release <u>does not change the peak biomass of periphyton</u> in the diversion reach of the Bull River from pre-upgrade conditions. • The implementation of the post upgrade 2 $m^3 \cdot s^{-1}$ minimum summer flow release <u>does not change the diversity of periphyton</u> in the diversion reach of the Bull River from pre-upgrade conditions.
2	What is the net effect of the post redevelopment flow regime on the community composition, diversity, and abundance of benthic invertebrates in the diversion reach of Bull River?	ABFMON#2	**ADDRESSED**: • The implementation of the post upgrade 2 m3·s-1 minimum summer flow release <u>does not negatively impact</u> the abundance, biomass and diversity of total benthic invertebrates in the diversion reach of the Bull River from pre-upgrade conditions. The density of the assemblage of mayflies, stoneflies, and caddisflies significantly increased with implementation of minimum flow in the diversion reach.
3	If changes in the benthic community associated with post-redevelopment facility operations are detected, does the prescribed flow regime of 2 m^3/s summer minimum flow combined with the productive capacity realized from the constructed compensation habitat achieve the Aberfeldie Redevelopment project goal of no net loss of productive capacity?	ABFMON#5-2a ABFMON#5-2b ABFMON#5-2c	**ADDRESSED:** • There was a 19% decline in abundance of benthic invertebrate caused by loss of wetted area in the diversion reach but the productivity achieved through the constructed side channel was sufficient to offset this loss (Task 2A; Perrin and Bennett 2013b). • The construction of the side channel successfully created additional primary and secondary productive capacity. However, the effectiveness of the constructed system in providing suitable habitat to fish is poor due to water quality and quantity issues (Task 2B). The long term sustainability of the constructed habitat is also threatened by active bank erosion and decreasing connectivity with the Bull River mainstem (Task 2B and 2C).
4	Is there a lower summer minimum flow discharge that, in combination with the productive capacity of the compensation habitat, could achieve the Aberfeldie Redevelopment project compensation goal of no-net-loss of productive capacity?	ABFMON#5-2a ABFMON#5-2b	**ADDRESSED**: • Further reduction of summertime flows in the diversion reach should not be implemented unless effective improvements are made to the side channel for utilization by target fish species (Task 2A and 2B).

1.4 ABFMON-5 Task 2B Objectives

The objectives of this study were to qualitatively and quantitatively describe the fish community and fish habitat in the side channel and to monitor the structural integrity of the compensation habitat. Seven main components were developed to achieve the objectives of the study:

Fish and Fish Habitat Assessment Procedure (FHAP; Year 1): The FHAP is a detailed description of habitat types (and habitat units) and their locations to provide a baseline of habitat features. Details from the FHAP can be used to perform spatial analyses of fish and fish habitat and to document changes in fish-habitat associations and habitat quality over time. The FHAP data were used to relate fish species and life-history stage to types of habitat and to evaluate fish habitat conditions in the side channel for target fish species.

Water Quality and Water Level Data (Years 1 – 5): Water quality data were collected once per season at benchmark sites established throughout the side channel. Water level measurements were also collected during each site visit to determine whether the channel flows met fish habitat requirements. In Year 4 and 5, intra-gravel dissolved oxygen was monitored in the side channel and on the mainstem of the Bull River to evaluate conditions for egg incubation of target fish species.

Structural Stability Survey (Years 1 - 5). The structural integrity of the constructed side channel was monitored to determine if: 1) the constructed outlet protection groyne was effectively protecting the channel's downstream reach and preventing infilling of sediment at the outlet; 2) the berm on the right downstream boundary was effectively protecting the side channel from the tributary gully and ravelling slope; 3) the berm on the left downstream boundary was effectively protecting the side channel from Bull River floods; and 4) the Bull River bank at the upstream end of the channel remained stable. The presence of cattle, beaver, and any other impacts on stability were also monitored.

Spring Spawning Survey (Years 1, 2, 4 and 5): The purpose of this survey was to qualitatively describe the fish community and characterize habitat use by spawning fish during spring by documenting the number of spawning fish (i.e., Western Cutthroat Trout and Rainbow Trout) and redds observed.

Summer Habitat Use (Years 1, 2, 4 and 5): The purpose of this survey was to quantitatively describe the fish community and characterize habitat use by juvenile fish during summer

Fall Spawning Survey (Years 1, 3 and 4): This survey characterized fall spawning activity in the side channel through repeated enumerations of spawning Kokanee and Bull Trout and the estimation of the annual total number of spawners utilizing the side channel habitat.

Overwintering assessment (Years 1, 3 and 4): Physico-chemical parameters were recorded during winter to determine the suitability of the side channel habitat to provide overwintering habitat for target species.

This report presents the results from monitoring year 5. Results from the years 1 to 4 are also synthesised to draw the overall conclusions and findings of the monitoring program.

2 Methods

2.1 Water Quality and Quantity Measurements

Water Quality

Water quality data were collected seasonally from eight sites including one mainstem location (run habitat) and seven locations within the constructed side channel (Figure 3). The water quality parameters recorded included temperature (°Celsius), specific conductivity (µS/cm), salinity (ppt), pH, dissolved oxygen (DO; mg/L), and percent DO. Measurements were collected using a YSI meter Model 556 MPS.

Standard procedures for water quality data collection were followed. The YSI meter was calibrated prior to each day's use, to ensure accuracy. Calibration for specific conductivity, turbidity and pH measurements were completed in the lab, while DO was calibrated in the field in order to account for local barometric pressure conditions. During data collection, care was taken to minimize sediment suspension by carefully placing the probe at sampling locations with minimal disturbance to the substrate in locations upstream of crew activity. At each site, water quality parameters were measured at the bottom of the water column just above the substrate

Factorial ANOVA was performed to assess the effects of project year, season, habitat, and their interactions (factors) on water quality variables (dependent variables). Water quality data from all years of the study were pooled and were compared with federal and provincial water quality criteria and to suitable fish habitat conditions. All statistical analyses were performed with SPSS 16.0 statistical software. Assumptions of linearity, normality and independence were assessed prior to analyses. This analysis was performed to determine if significant changes in water quality conditions occurred in the constructed channel during the monitoring program. In particular, some fluctuations in water quality were expected with the establishment of biological production in the side channel and stabilization of the hydrological regime.

Unless otherwise noted, mean values ± standard deviation (SD) are reported.

Water Quantity

Water Survey of Canada was contracted to design and install a staff gauge/weir during the side channel construction. Water levels were recorded at the weir during each site visit. The water level data were used to estimate discharge using the site specific rating curve provided by BC Hydro.

Intra-gravel Dissolved Oxygen Monitoring

Two HOBO U-26 dissolved oxygen (DO) data loggers were used to measure intra-gravel DO on the constructed side channel and on the Bull River mainstem. The data loggers were calibrated using a 0 mg/L DO solution of sodium sulphate and deployed in the side channel in Year 4 and Year 5 of the study. Each unit was placed in protective wire mesh tubes and secured to a heavy anchor using steel cable (Figure 4). The loggers were buried horizontally in the spawning substrate at a depth of approximately 15 to 20 cm, which is representative of the typical egg burial depth by *Oncorhynchus nerka* as reported in DeVries (1997) and Steen and Quinn (1999).

One of the DO loggers was placed at the spawning platform located at the downstream end of glide habitat unit 1-12 (Figure 3 HU 1-12). This site was selected based on water quality data that indicated that surface water DO concentration at this location was consistently higher than at any other constructed spawning platform in the side channel. This finding was supported by the high number of Kokanee spawners observed at this particular location during Year 1 and 3 fall spawning assessments compared to other habitat units. The second DO logger was placed on the Bull River mainstem at the same location used to collect reference data during the Year 2 incubation success study. This site is located in a secondary channel, on the right downstream bank, immediately downstream of the powerhouse tailrace.

Intra-gravel DO was recorded during the entire Kokanee incubation period from September 30, 2012 to February 13, 2013 and between August 2, 2013 to December 23, 2013. The recorded data were downloaded monthly to mitigate the risk of data loss in the event that the DO loggers were damaged or lost.

During each site visit, supplemental intra-gravel DO data were collected using a YSI 556 multi-parameter water quality meter and a metal syringe to extract hyporheic water samples as described in Beblow and Guimond (2010) (Figure 5). The YSI 556 unit was calibrated during each site visit following the manufacturer's standard procedures. Three repeated measurements were taken in the vicinity of the buried DO loggers to enable QA/QC and comparison of the results obtained through the two techniques. Additional measurements were taken at two other spawning platforms in the side channel to assess the range of intra-gravel DO conditions available throughout the constructed habitat.

Figure 4 HOBO U-26 dissolved oxygen logger in protective wire mesh tube secured to anchor**.**

Figure 5 Extraction of hyporheic water sample from intra-gravel using syringe.

2.2 Structural Stability and Physical Parameters

Observations of channel stability were made throughout the monitoring period, and a full review of the side channel structural stability features was conducted on a yearly basis usually immediately after spring freshet, the period with the greatest potential for impact on the channel stability. The features reviewed included:

- Stability and erosion of the berm on the left downstream boundary of the channel, running the extent of the riverside boundary;
- Effectiveness of the berm on the right downstream bank to protect the channel from the adjacent eroding slope;
- Channel connectivity to the Bull River, including stability of the outlet protection groyne and erosion and/or scour at the channel entrance; and
- Erosion and stability of the bank along the Bull River at the upstream end of the off-channel habitat.

Other physical alterations to the channel (e.g., cattle usage of the area or beaver related activity) were also documented throughout the duration of the project.

2.3 Spring Spawning Survey

Spring spawning surveys were conducted by a two-person crew between May and June in Year 1, 2, 4, and 5. Hydrometric data from the Water Survey of Canada Station 08NG002 (Environment Canada, 2013) located on the Bull River downstream of the side channel were used as a guide for timing spawning surveys. The sampling dates occurred during the descending limb of the hydrograph, which typically corresponds to the peak spawning period for Westslope Cutthroat Trout (Schmetterling, 2000).

Surveys consisted of identifying spawning adults or constructed redds in the side channel. Westslope Cutthroat Trout and Rainbow Trout were the species most likely to spawn in the side channel during the spring. A shore based survey technique was used, with observers viewing the stream from elevated positions along the channel bank. This method limited disturbance to potentially spawning pairs.

Surveyors for the spawning assessment and all other fish sampling activities wore polarized glasses for optimal viewing through the water column. The survey was initiated at the downstream extent of the side channel (at the channel's outlet to the Bull River) and progressed up the channel. The surveyors walked at the same pace, one on each side of the channel to observe and enumerate redds and individuals. Crew members surveyed for evidence of redds (i.e., cleaned areas, excavated pits with a mound on the downstream end, and sorted substrate with pit material being somewhat larger than the tail material). We expected to find redds in hydraulic transition areas such as glide/riffle or pool/riffle habitats, which provide optimal spawning locations due to hyporheic exchange (McPhail, 2007). Pools were also surveyed for the presence of fish or redds (e.g., along shoals and at outlets).

2.4 Juvenile Habitat Use

Juvenile habitat use was assessed during summer in Years 1, 2, 4, and 5. Sampling dates were selected based on appropriate time periods for egg hatching and embryo development using accumulated temperature unit (ATU) calculations. Westslope Cutthroat Trout and Rainbow Trout spawn between mid-May and mid-June and require 475 to 500 ATUs for egg emergence (O. Schoenberger, *pers. comm.*). Year 1 and 2 ATUs were calculated using temperature data provided by BC Hydro for several theoretical development periods to ensure that appropriate time had elapsed for eggs to hatch and fry to emerge from the gravels (McPherson and Robinson, 2010, 2011). Dates of the Year 4 and 5 juvenile habitat use assessments were chosen to ensure a suitable length of time for fry emergence from gravels for enumeration in surveys.

Sampling of habitat for fish was completed using two methods, depending on habitat-type:

1) **Riffle/glide habitats** (HUs 1-10 to 1-13, 1-18 to 1-20): electrofishing of enclosed sites; and,
2) **Pool habitats** (HUs 1-07 and 1-21): fyke traps and minnow traps set in enclosed sites.

Crews blocked off the upstream and downstream ends of each site with mesh nets secured to the streambed prior to sampling to enclose sites.

Riffle/Glide Habitats

Two riffle/glide sections were sampled using electrofishing techniques. Each of these sites is representative of riffle, glide, and cascade habitats in upper (above the weir) and lower (below the weir) portions of the channel. The lower site, EF-1, included HU 1-10 through to HU 1-13 (three glides and three riffles/cascades), and had a total length of 108 m (*See*). The upper electrofishing site, EF-2, included HU 1-18 to the upper end of HU 1-20 (two glides and one cascade) and had a total length of 116 m.

A Smith-Root LR-24 backpack electro-fisher was used for closed sampling of the riffle/glide sections (set at a voltage of 300 volts and frequency of 65 hertz). Consistent with sampling in previous years, the three-pass depletion technique (Zippin 1958) was used. The following steps were applied to complete the three-pass depletion method sampling:

- Downstream and upstream stop nets were installed to prevent immigration and/or emigration of fish from sites;
- Starting at the downstream end of the enclosed site, all available fish habitat was sampled in a single pass;
- Fishes caught were measured (fork length, mm) and weighed (g). Captured fishes were not released until after all passes had been completed;
- Sampling continued using the same technique until no additional fish were collected. Sampling was discontinued if no fish were captured after the second pass. A minimum of two passes were conducted for verification purposes. Prior to conducting each pass, crews allowed fine suspended sediments to subside, to allow for maximum visibility.

Pool Habitats

The two pool habitats, HU 1-07 and HU 1-21, were sampled using fyke and minnow traps. Sites were enclosed using mesh nets prior to setting of traps. Each pool had one fyke trap and one minnow trap that were baited and set at a minimum depth of 1.0 m. Soak time was up to two-24 hour sampling periods for each site. If no fish were captured following the first 24 hours, traps and nets were removed.

Fish Handling and Data

Standard fish handling techniques were used to minimize fish stress and mortality. Captured fish were placed in a bucket containing stream water and measurements were recorded as quickly as possible. Fish recovered in large totes before being returned to the side channel.

Juvenile Westslope Cutthroat Trout and Rainbow Trout were the species most likely to utilize the side channel during summer. Since juvenile Westslope Cutthroat Trout and Rainbow Trout are difficult to distinguish from one another, VAST was prepared to voucher up to five fish samples for laboratory verification of species.

Fish Population Density Estimates

Comparisons of Year 1, 2, 4 and 5 population density and biomass estimates were made using three-pass removal data.

Assumptions of the Closed Population Removal (Hayes *et al. 2007*) are:

- All fishes are equally vulnerable to capture throughout all passes;
- All captured fishes are unable to re-enter the population until all passes are complete;

Relative abundance (number of individuals/100 m^2) and biomass (g/100 m^2) of fish within each sample area were calculated using the mean wetted width and site length.

2.5 Fall Spawning Survey

Fall spawning surveys were conducted in Years 1, 2, and 4. The timing of the surveys was based on local observations and historical data of spawning events in the Bull River. Species likely to spawn in the side channel during this period were primarily Kokanee, Eastern Brook Trout, and Bull Trout. Surveys were conducted from shore to view the in-stream environment from elevated positions along the channel bank. This method reduces disturbance to potentially spawning pairs.

Surveyors wore polarized glasses to minimize glare on the water surface during spawning assessments. Surveys were initiated at the downstream end of the side channel (at the channel's outlet to the Bull River) and continued in an upstream direction. During the surveys, surveyors walked slowly along the bank on either side of the channel. The surveyors looked for redds or for fish. Given the clarity of the water and the shallow depth of the channel, spawning individuals were easily enumerated and fish count estimates can be considered highly accurate.

Fish mortality in the side channel was also assessed. This review included enumerating kelts in each habitat unit and periodically dissecting fish to identify the reproductive status of females and to determine whether eggs had been successfully deposited.

To assess spawning habitat preferences of fish, the numbers of spawning fish were compared among habitat units. The fish density (number of fish individuals per square meter) was calculated for each habitat unit in order to account for the varying size of each unit.

$$\text{Nb of Fish per m}^2 = \frac{\text{Nb of fish in Habitat Unit}}{\text{Surface Area of Habitat Unit (m}^2\text{)}}$$

Weighted number of individuals was compared among Years 1, 3, and 4 with ANOVA for each habitat type and unit. These tests were used to identify trends in preference of fish for certain habitat types or habitat units. Results aided in understanding spawning habitat use in the side channel and may provide information upon which to base future operating decisions.

Spawner Enumeration

The area-under-the-curve (AUC) method was used to estimate escapement with the periodic counts of spawning Kokanee in the side channel. Escapement, in this case, is the number of spawning Kokanee that accessed the Aberfeldie side channel each year. Several studies have discussed methods for estimating salmon escapement based on the area-under-the-curve method (e.g., Irvine *et. al.* 1992, English *et al*. 1992, Bue *et al*. 1998, Szerlong and Rundio 2007). These studies employed various sampling methods, but the common feature of all studies was the practice of determining the quotient of the AUC and the mean residence time (RT) of fish in the survey area to estimate escapement. J. Irvine, Fisheries and Oceans Canada, (*pers. comm.*) was consulted on how to best analyse Kokanee spawner data, given the methods employed for this project. The approaches detailed below were recommended.

The RT refers to the average time that fish spend in a given area. For the purposes of this study, RT refers to the average time mature Kokanee spend in the Aberfeldie side channel prior to death. Determination of RT is stream specific and can vary from year to year based on physical conditions (e.g., stressors such as temperature may decrease RT) (English *et al.* 1992).

For this study, RT was approximated to range from 7 to 10 days (mean = 8.5 days) based on Aberfeldie field observations and Kokanee data collected by BC MoE at the Redfish side channel in West Kootenay. However, based on migration distance alone, the residence time is likely higher at the Redfish channel since it is within 500 m of Kootenay Lake, while the Aberfeldie side channel is 12 km upstream of the Bull River. Given that the RT of Aberfeldie Kokanee is presumed to be lower than that of Redfish Creek Kokanee, our RT estimate is likely high, which consequently may lead to an under-estimation of escapement (see below).

The numbers of spawning Kokanee observed during each field visit were represented in an x-y scatterplot. A 2nd-order polynomial regression was used to estimate the shape of the curve and extrapolate the start and end dates of the run. The AUC was determined by calculating the integral of $y(x)$ between the start and end dates of the run:

$$AUC = \int_{Start}^{End} y(x)dx$$

Escapement was estimated by dividing the AUC (fish*days) by the mean RT of 8.5 days. As discussed above, this calculated escapement is likely an underestimate given that the RT is based on Redfish Kokanee, which is likely higher than that of Aberfeldie Kokanee.

2.6 Overwintering Assessment

An overwintering assessment was conducted in Years 1, 3, and 4 to determine if conditions in the side channel during winter were suitable to provide overwintering refuge to fish. The assessment consisted of a single site visit that was conducted when the maximum air temperature was -7.5 ^{o}C or colder for five days prior to the assessment.

Along with collection of water quality data, the winter assessment also included recording of measurements of water levels, ice depth in pools, temperature, and DO-profiles beneath the ice. A qualitative assessment of the channel was also conducted that characterized outlet connection to the mainstem, extent of ice coverage, and quality of winter refuge for fish.

3 Results

3.1 Water Quality

Field data collected during the seasonal water quality assessments in Year 1, 2, 3, 4, and 5 are provided in Appendix 1.

Variation in water quality values between years and habitat types were tested for statistical significance using factorial ANOVA. The results from these test indicated that there were significant associations of factors year ($F_{3,90} = 7.14$, $p<0.001$), season ($F_{1,90} = 7.14$, $p<0.001$), and habitat ($F_{3,90} = 6.22$, $p<0.001$) on water quality variables. To further investigate the influence of these factors on water quality conditions and determine the direction of significant associations, we conducted one-way ANOVAs and post-hoc tests. Results from all statistical analysis are summarized in Appendix 1.

The following sections describe annual and seasonal water quality trends for each type of habitat. Factorial ANOVAs were conducted for pools and glides for which there were sufficient replication of sites. Temperature and dissolved oxygen were the only water quality parameters with guidelines by the Canadian (CCME 2007) and British Columbia (BC MoE 2006) governments. Based on these guidelines, the 5-year monitoring data show that the conditions in all habitats of the Aberfeldie side channel were not sufficient for meeting the temperature requirements for fall Bull Trout spawning and were marginally sufficient for Kokanee spawning. Dissolved oxygen concentrations were not adequate for supporting aquatic life or development of embryos and alevin in pools and glides although conditions appear to be improving in Year 4 and Year 5.

Side channel pool habitat

Pools are deep water areas built to provide refuge, rearing, and adult holding habitat as well as low velocity, deep water habitat suitable for macrophyte growth and invertebrates (Reid et al., 2008).

Figure 6, Figure 7, Figure 26, Figure 27 display annual and seasonal water quality trends over the duration of the monitoring study.

Fall mean temperature was significantly lower in Year 5 than Years 2, 3, and 4 (All $p<0.001$; Table 8, Figure 6).This is likely explain by the later date at which the measurement was taken compared to other monitoring years. Fall temperatures in pools were over the optimal range for Bull Trout spawning (5.0 - 9.0 ^{o}C; BC MOE, 2001) but were within the optimal range for Kokanee spawning (10.6 - 12.8 ^{o}C; BC MOE, 2001), except in Year 1 when mean temperatures were 6.0 (±0.67 SD) ^{o}C.

Dissolved oxygen concentrations (Figure 7) were not sufficient for the minimum requirements for aquatic life during summer, fall, and winter, although conditions appeared to marginally improve in Years 4 and 5 (but were not significantly different than dissolved oxygen concentration from other years). Winter dissolved oxygen levels were not optimal for the development of embryo and alevin and did not improve over time.

Fall pH was significantly lower in Year 5 than Year 2 ($p<0.001$).There were no significant trends in mean annual or seasonal specific conductance in pools. There were no significant trends in mean annual or seasonal salinity in pools.

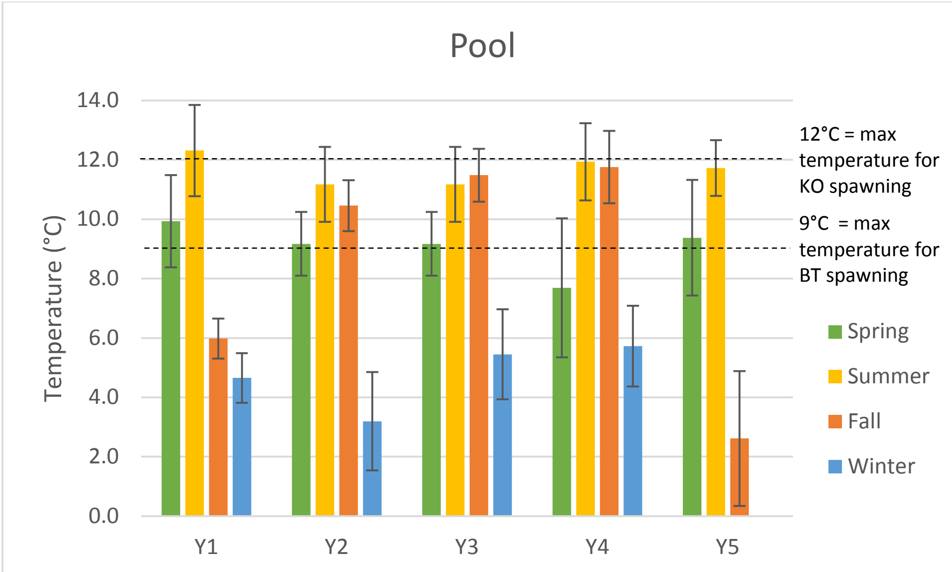

Figure 6 Annual and seasonal mean water temperature (°Celsius) of pools of the Aberfeldie side channel. Dashed lines mark the maximum temperature for Kokanee (KO) spawning (12° C) and maximum temperature for Bull Trout (BT) spawning (9°C) (BC MoE, 2001). Error bars represent ± standard error (SE).

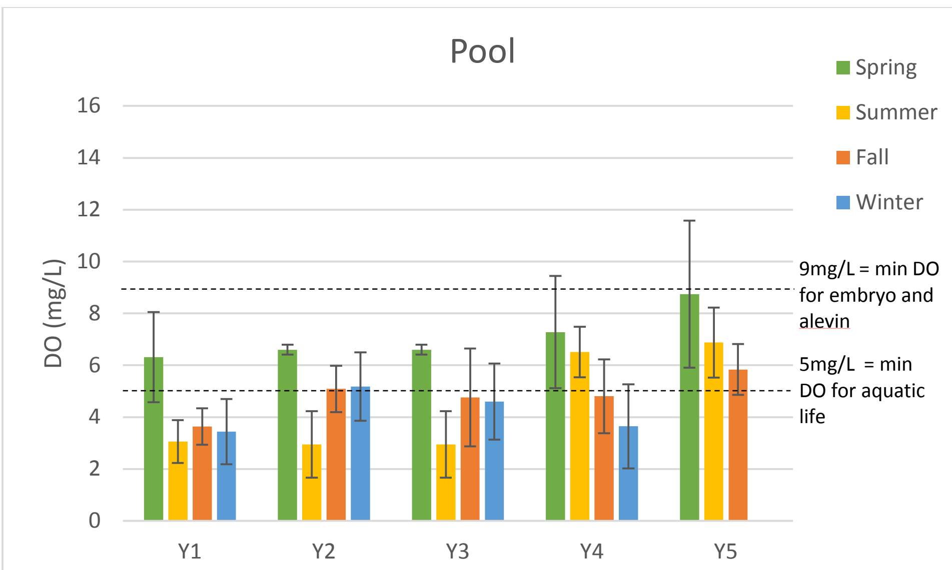

Figure 7 Annual and seasonal mean dissolved oxygen concentration of pools of the Aberfeldie side channel. Dashed lines mark the minimum dissolved oxygen concentration for cold water salmonid embryos and alevins development (9 mg/L) and minimum dissolved oxygen concentration for aquatic life (5 mg/L) (BC MoE, 1997). Error bars represent ± standard error (SE).

Side channel glide habitat

Glide habitat was intended to provide the majority of benthic production and stream rearing habitat in the side channel. Selective spawning was also expected in glides where suitable hydraulic and substrate conditions exist. Glides include LWD and boulder adding habitat complexity and creating a variety of micro-habitats (Reid et al., 2008). Sorted spawning gravel was also placed at the tail out of glides to serve as dedicated spawning areas.

Annual and seasonal water quality trends over the duration of the monitoring study are represented in Figure 8, Figure 9, Figure 26Figure 28, and Figure 29.

Fall mean temperature was significantly lower in Year 5 than Years 3 and 4 (both $p<0.007$; Figure 8). Temperatures in glides were over the optimal range for Bull Trout spawning in the fall (5.0 - 9.0 ºC; BC MOE, 2001) but were within the optimal range for Kokanee spawning in the fall (10.6 - 12.8 ºC; BC MOE, 2001), except in Year 1 when mean temperatures were 6.1 (±0.20 SD) ºC.

Dissolved oxygen concentrations (Figure 9) were not sufficient for the minimum requirements for aquatic life during summer (Year 1, 2, and 3), fall (Year 1, 2, and 3), and winter (Year 1), although conditions improved in Years 4 and 5. Winter dissolved oxygen levels were not optimal for the development of embryo and alevin in Year 1 but improved over time.

Mean specific conductance during spring in Years 2 and 3 were significantly higher that Years 1, 4, and 5; Year 5 fall mean specific conductance was significantly lower that Years 2, 3, and 4; winter Year 4 mean specific conductance was significantly lower than Years 1, 2, and 3 (All $p<0.007$).

Mean salinity was significantly higher in Years 2 and 3 than Years 1, 4, and 5 during spring while winter salinity was lower in Year 4 than Years 1, 2, and 3 (All $p<0.001$).

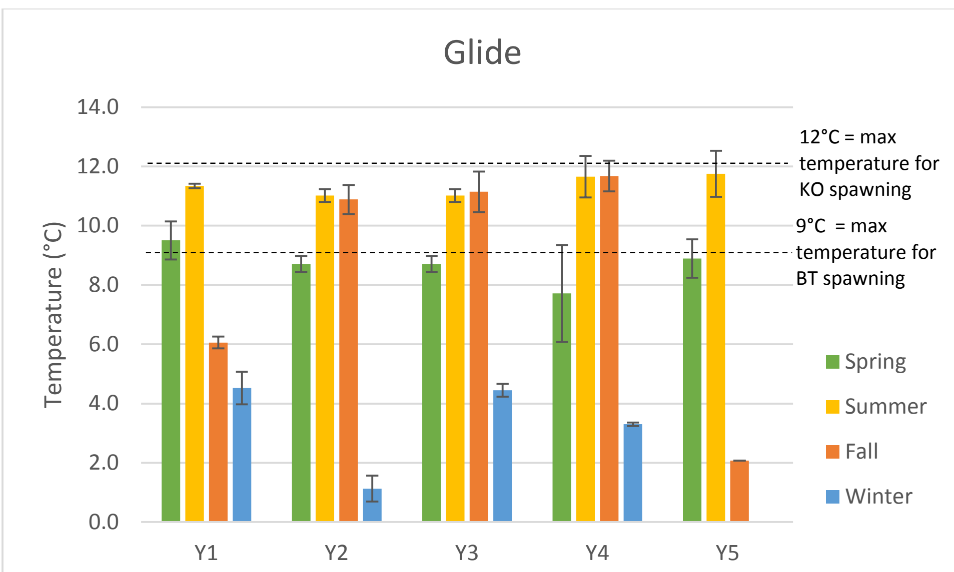

Figure 8 Annual and seasonal mean water temperature (°Celsius) of glides of the Aberfeldie side channel. Dashed lines mark the maximum temperature for Kokanee (KO) spawning (12° C) and maximum temperature for Bull Trout (BT) spawning (9°C) (BC MoE, 2001). Error bars represent ± standard error (SE).

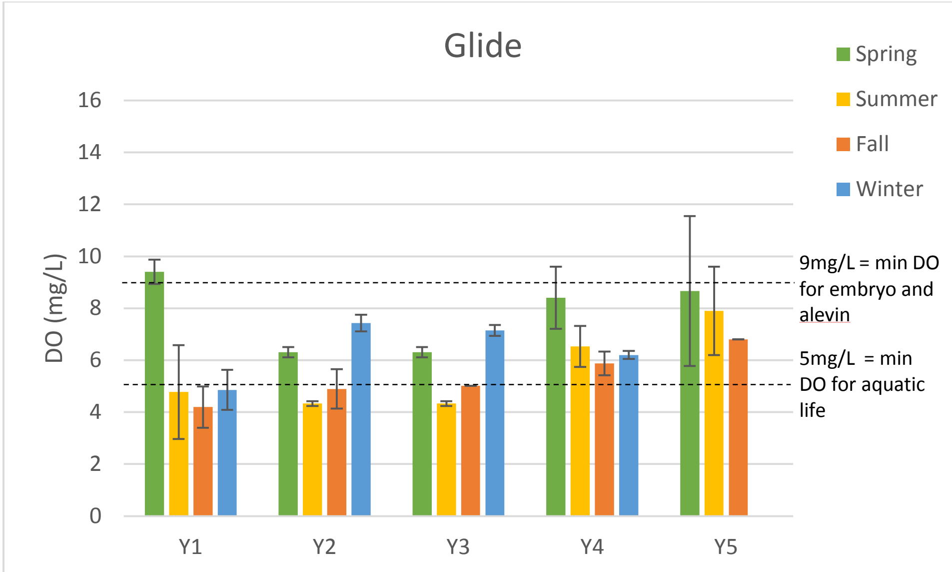

Figure 9 Annual and seasonal mean dissolved oxygen concentration of glides of the Aberfeldie side channel. Dashed lines mark the minimum dissolved oxygen concentration for embryo and alevin development (9 mg/L) and minimum dissolved oxygen concentration for aquatic life (5 mg/L) (BC MoE, 1997). Error bars represent ± standard error (SE).

Mainstem habitat

Annual and seasonal water quality trends from Years 1 to 5 are given in Figure 10, Figure 11, Figure 30, and Figure 31.

Temperatures in the Mainstem of the Bull River glides were above the optimal range for Bull Trout spawning in the fall (5.0 - 9.0 °C; BC MOE, 2001) but were within the optimal range for Kokanee spawning in the fall (10.6 - 12.8 °C; BC MOE, 2001), except in Year 1 when the temperature was 3.39 °C (Figure 10).

The range of dissolved oxygen in the Mainstem of the Bull River was within the optimal ranges for aquatic life and development of embryo and alevin (Figure 11).

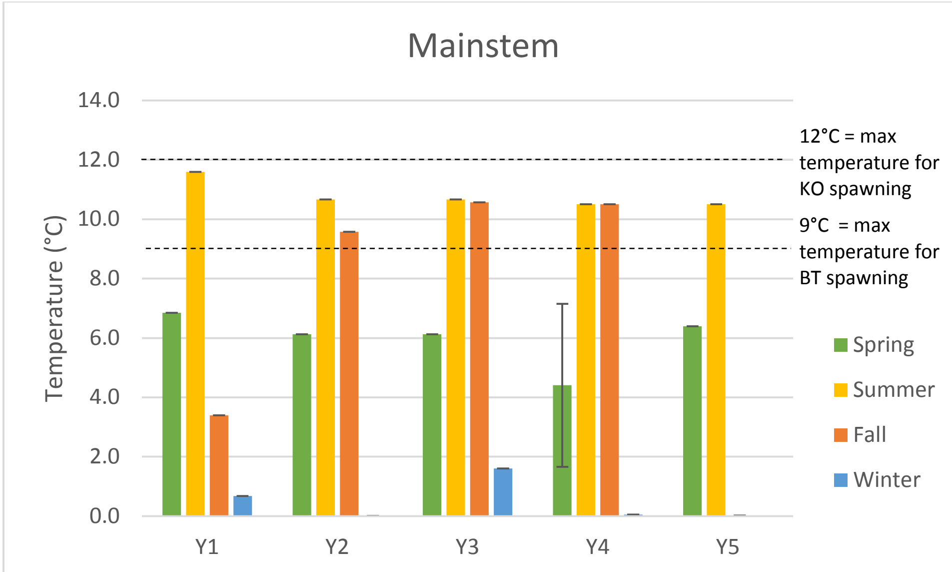

Figure 10 Annual and seasonal mean water temperature (°Celsius) of the Mainstem of the Bull River. Dashed lines mark the maximum temperature for Kokanee (KO) spawning (12° C) and minimum temperature for Bull Trout (BT) spawning (5°C) (BC MoE, 2001). Error bars represent ± standard error (SE).

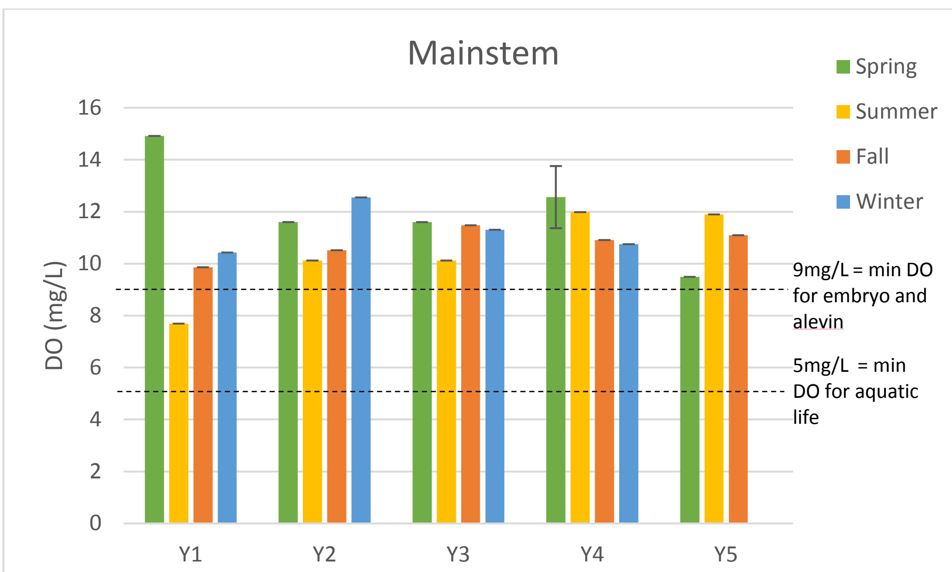

Figure 11 Annual and seasonal mean dissolved oxygen concentration of the Mainstem of the Bull River. Dashed lines mark the minimum dissolved oxygen concentration for embryo and alevin development (9 mg/L) and minimum dissolved oxygen concentration for aquatic life (5 mg/L) (BC MoE, 1997). Error bars represent ± standard error (SE).

Water Quantity and Water Velocity

There was no significant difference in discharge of the Aberfeldie side channel among project years ($p<0.05$). Figure 14 shows average discharge in the side channel and in the Bull River mainstem in Years 1, 2, 3, 4, and 5 of the monitoring program. During Year 5, discharge ranged from a low winter discharge of 0.005 m^3/s measured on February 14, 2012, to a spring peak of 0.036 m^3/s on June 7, 2013. Discharge gradually decreased through the summer, reaching a low of 0.003 m^3/s on October 11, 2013. Through the fall and winter, levels dropped to a low of 0.002 m^3/s. These observations were consistent with the fluctuations of the Bull River mainstem discharge measured during the same period (Environment Canada 2013; Figure 14).

Water velocity in each habitat unit was characterized in Year 4 of the study. Mean water velocity across all glide habitats was 0.10 (± 0.075 SD) m/s. There was a highly significant difference in water velocity among habitat units ($p<0.01$). The mean water velocity of habitat unit 1-20 (0.22 ± 0.053 SD m/s) was significantly higher ($p<0.01$) than all other habitat units. The channel morphology of the Aberfeldie side channel was originally designed to ensure a minimum water velocity of 0.3 to 0.5 m/s on constructed spawning platforms to support spawning and egg development (Reid *et al.*, 2008). None of the spawning platforms met this minimum water velocity requirement.

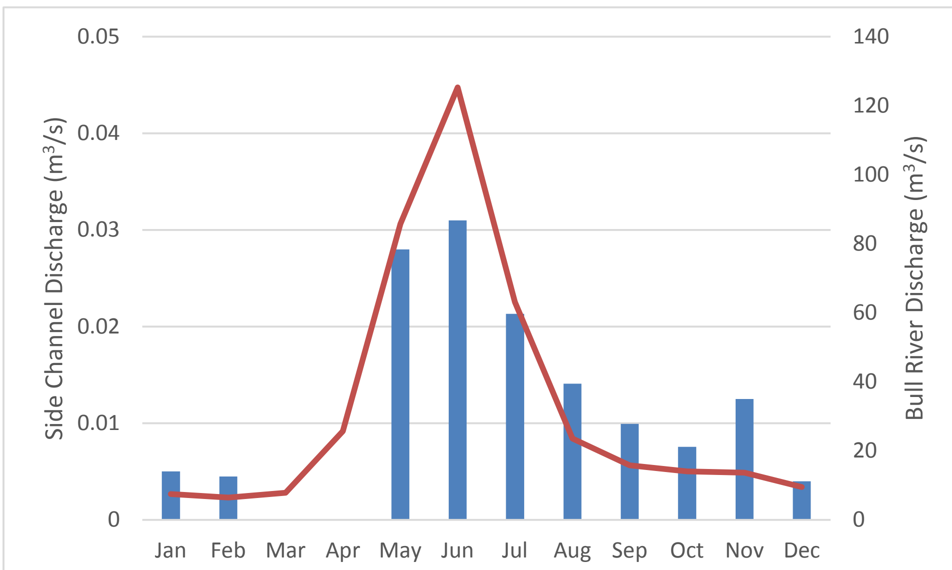

Figure 12 Average discharge of Aberfeldie side channel and Bull River between Year 1 and Year 5 of the monitoring study. The red line represents the Bull River discharge and the blue bars represent the side channel discharge.

Algae

In all five years of the study, significant algal growth was observed in the Aberfeldie side channel. Algae were typically observed on gravel and water surfaces in glide HUs 1-10, 1-12, 1-14, 1-16, and 1-20 and pool HUs 1-07, 2-02, 3-02, and 1-21. *Chara* spp. mats were also observed in HU 1-21, which had the most abundant algae growth (Figure 15).

Primary productivity in the constructed side channel was characterized as part of the studies ABFMON-2 and ABFMON-5a (Perrin and Bennett, 2013a and 2013b).

Figure 13 Algal growth on water surface and bottom surface in HU 1-21 Pool (May 28, 2012). *Chara* spp. was also observed growing on the pool bottom.

Intra-gravel dissolved oxygen monitoring

The results from the intra-gravel DO monitoring work completed in Year 4 and Year 5 are presented in Figure 16 and Figure 17. This work intended to characterize intra-gravel DO conditions in the side channel and determine if the constructed habitat offers suitable conditions for successful development and hatching of buried embryos.

The intra-gravel DO concentration at HU 1-12 in the constructed side channel fluctuated between 4 mg/l and 10 mg/L in Year 4 and between 4 mg/l and 9 mg/L in Year 5. It was consistently lower than at a reference site on the Bull River mainstem where intra-gravel DO level fluctuated between 9 and 14 mg/L in Year 4 and between 4 and 10 mg/L in summer of Year 5. A dramatic drop of intra-gravel DO (below 2 mg/L) in the mainstem was measured in October of Year 5. This event was likely related to a flash flood on the Bull River that transported significant amounts of sediment and covered the DO sensor (see hydrograph on Figure 17).

Some similarities were noted in Year 4 between mainstem and side channel intra-gravel DO variations (Figure 16) when peak in concentration often occurred simultaneously at the two locations. It is not clear if this phenomenon was caused by varying atmospheric conditions or if it could be indicative of a sub-surface connection between the Bull River Mainstem and the side channe. This pattern was not as apparent in Year 5 of the study.

During both years, intra-gravel DO in the side channel gradually increased as winter conditions established and water temperature dropped. As expected, there was a negative correlation between intra-gravel DO concentration and water temperature.

Hyporheic samples collected upstream of HU 1-12 in Year 4 (orange points on Figure 16) showed that intra-gravel DO concentration decreases in the upstream reaches of the constructed side channel. This result is consistent with water column DO measurements collected as part of the water quality monitoring.

Hyporheic samples collected downstream of HU 1-12 in Year 4, had relatively similar DO concentrations than at Hu 1-12 (blue points on Figure 16).

In Year 5, this pattern of decreasing intra-gravel DO in the upstream reaches of the side channel was not as evident. Results may have been compromised by measurement errors caused by the low repeatability of the sampling syringe technique (i.e., off-gassing during sample extraction, introduction of sediment in sample, etc.).

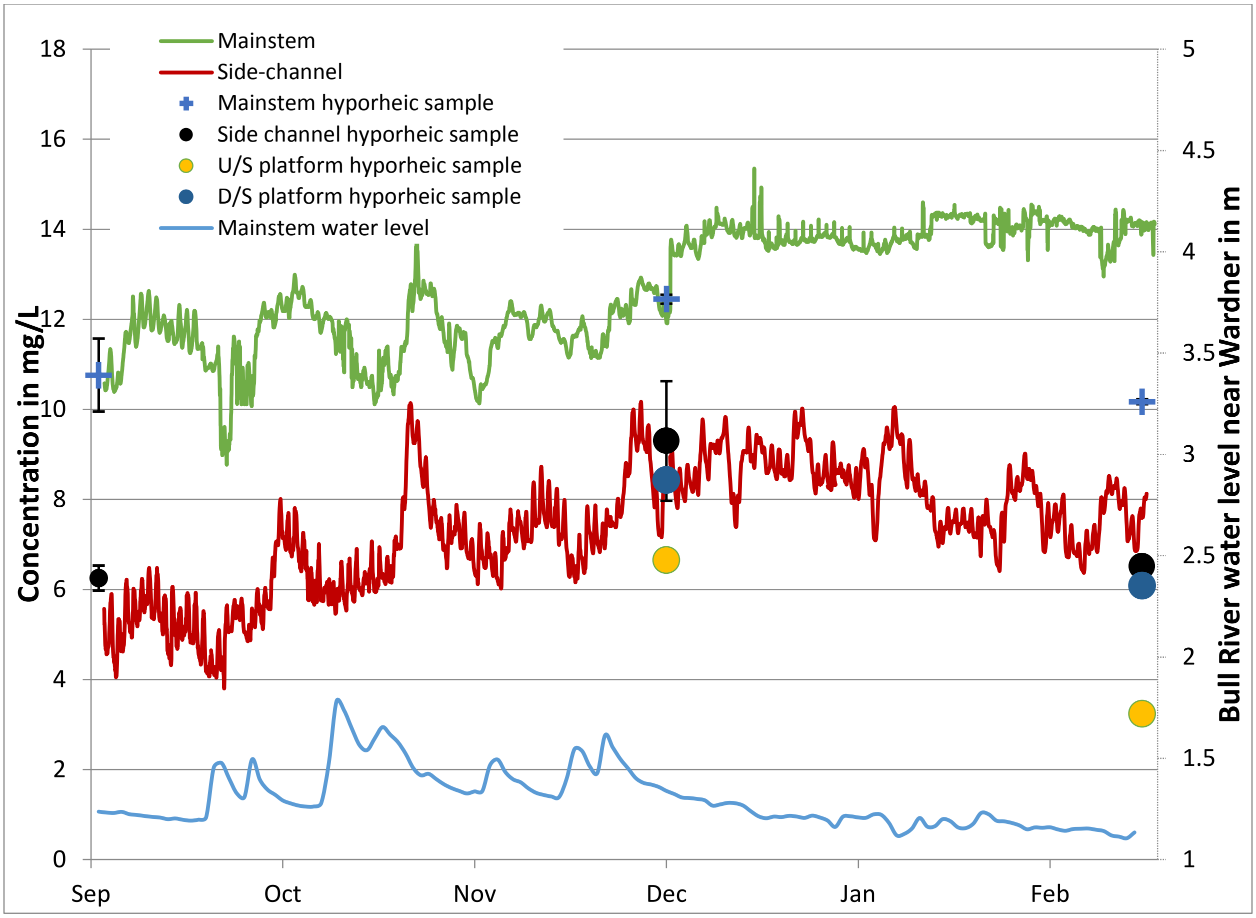

Figure 14 Summary of Year 4 intra-gravel DO and Bull River water level

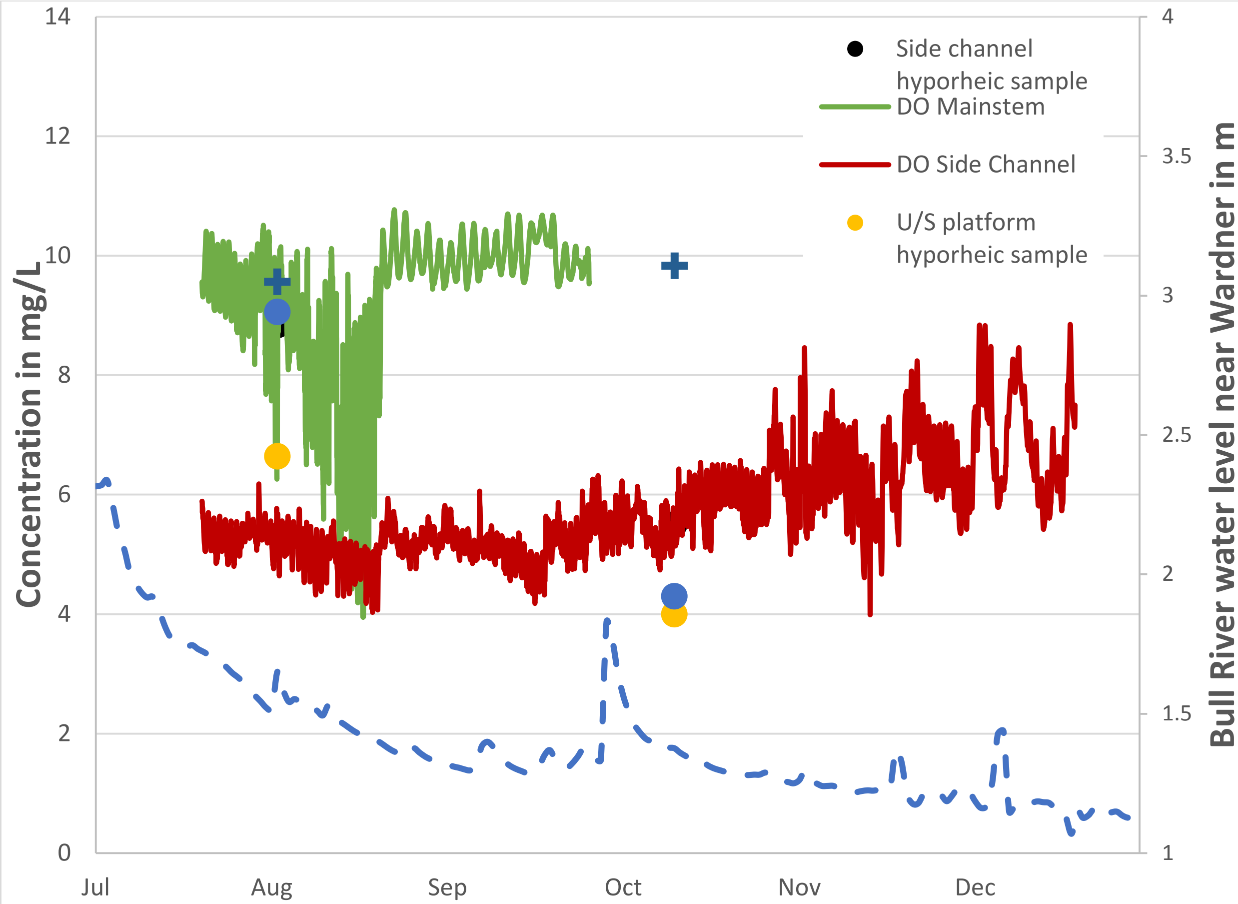

Figure 15 Summary of Year 5 intra-gravel DO and Bull River water level.

3.2 Structural Stability and Physical Parameters

Outlet protection groyne

A riprap groyne was constructed at the downstream end of the channel to help preserve connectivity with the Bull River mainstem by promoting scour and controlling infilling of sediment at the side channel outlet (Reid *et al.* 2008).

The monitoring of this section of the side channel over the first 5 years of operation showed that the groyne does not function as intended by its design. Infilling of sediment in the lowest reach of the side channel bordered by the groyne was first noted in Year 2 and then in all subsequent years of the study. It was found that during high water conditions, the groyne is often submerged, creating an area of slack water where large amounts of sediment deposit. Figure 16 to Figure 17 show the groyne during freshet in Year 4 and the resulting sedimentation once the water receded. In Year 5 of the study, the riffle and glide habitat of HUs 1-01 to 1-06 had been completely covered by a thick layer of sand and silt resulting from this entrance of silt. Most of the flow in this section of the side channel occurred sub-surface which limits surface connectivity with the Bull River mainstem especially during the low flow season.

Figure 16 Aberfeldie side channel outlet and groyne under spring high flow conditions (June 7, 2013).

Figure 17 Sediment accumulation through rip rap at groyne after spring high flows (July 30, 2012).

North berm, near channel outlet

A berm was built along the north bank of the side channel near the confluence with the Bull River mainstem to deflect and contain potential sediment inputs from a tributary gully on a nearby unstable slope (Reid *et al.* 2008). The monitoring of this section of the side channel revealed that the berm was functioning as intended by its design and was effective at controlling sediment input into the wetted perimeter of the constructed channel.

Outer perimeter berm

The berm constructed around the perimeter of the side channel was stable and functioning as intended. The downstream and middle section of the berm did not show any signs of scour or erosion. Some scour and undercutting has occurred on the upstream section of the berm which is the most exposed to the mainstem hydraulic forces due to its location at an outside bend of the river. However, the scour does not pose any threats to the berm's structural stability.

While most planted seedling have failed to establish along the outer perimeter berm, results from ABFMON-5 Task 2C indicate that grass and legume species exceed 60% mean cover, which satisfies most structural stability criteria for the berm (Przeczek and Isaac, 2013).

Cattle activity

Cattle activity has been a recurrent problem at the Aberfeldie side channel since the first year of operation and is of particular concern as animals crossing the channel significantly increase bank erosion and contribute to the in-filling of the channel with fine sediments. New evidence of cattle was found in the side channel area in Year 5 of the study.

Beaver activity

Some beaver activity was noted in Year 2 specifically in areas such as the crests of riffles (HU1-11, HU 1-13, and HU 1-15), and the upstream end of the weir. The issue was addressed by trapping and relocating the beavers. No beaver activity has been noted at the side channel since Year 2 of the monitoring program.

Slope Stability and Re-vegetation

While the assessment of riparian vegetation establishment and its effectiveness in providing slope stability was addressed in Task 2C (Przeczek and Isaac, 2013), observations of bank erosion and sediment transport were made during the completion of Task 2B as they directly affect fish habitat.

Overall, it was observed that banks throughout the side channel are inadequately stabilized. The banks are generally too steep, and are composed of coarse dry ravelling material with a high proportion of sand and gravel. In several locations, there was evidence of sloughing of the banks into the channel caused by natural erosion and animal activities (Figure 20 and Figure 21). This sloughing is particularly significant at glide HUs 1-14, 1-18, and 1-20. Bank re-vegetation and bioengineering work have not been effective in stabilizing the slopes. Sedimentation has also been noted around the periphery of pools, which are utilized by Kokanee for spawning. A number of trees fell across the side channel during Years 4 and 5 illustrating the ongoing degradation of the bank stability. Results from Task 2C (Przeczek and Isaac, 2013) indicate that the side channels banks do not satisfy any of the structural integrity criteria.

The input of fine sediments from the banks into the wetted perimeter of the side channel has negatively impacted aquatic habitat quality, particularly in riffles and glides, by infilling interstitial spaces of the substrate. In some areas, bank sloughing has also reduced the effective width of the channel.

Figure 18 Erosion along slope of glide habitat unit 1-18 (upstream view) of the Aberfeldie side channel (June 17, 2012).

Figure 19 Sedimentation at glide habitat unit 1-14 (left upstream boundary) of the Aberfeldie side channel (May 28, 2012).

3.3 Spring Spawning Assessment

Despite a total of 16 sites visits conducted during the peak spring spawning period, no spawning fish or signs of spawning activity was detected in the side channel during the first five years of operation. Target species expected to spawn at this time of the year include Westlsope Cutthroat Trout and Rainbow Trout.

3.4 Summer Juvenile Habitat Use

Electrofishing and trapping studies were conducted in Years 1, 2, 4, and 5 to characterize the fish community in the constructed side channel during summer.

Community composition

Westslope Cutthroat Trout (WCT) was the dominant species in the side channel during summer (Figure 22). The second most dominant species was Kokanee (KO). Other species caught in the side channel include Rainbow Trout (RT) and Torrent Sculpin.

Based on the length of the fish captured in the side channel (Table 4), most WCT and RT were juvenile fish (year 1+ or 2+), which had likely immigrated into the side channel from the Bull River mainstem. In contrast, KO were most likely young-of-the-year individuals that had hatched in the side channel during the preceding winter. Only one Torrent Sculpin was captured in Year 2 of the study. This fish was likely a mature fish that had moved into the channel from the Bull River.

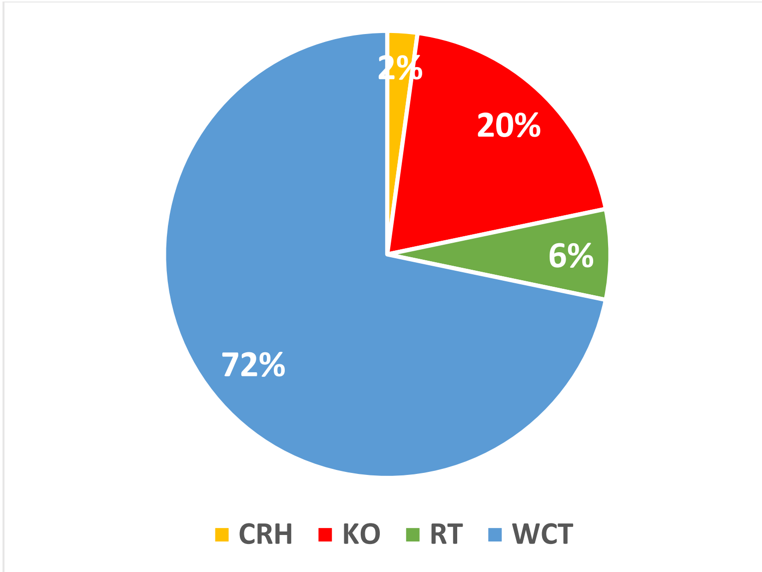

Figure 20 Fish community composition in Aberfeldie side channel (all years and sampling techniques combined). CRH = Torrent Sculpin; KO = Kokanee; RB = Rainbow Trout; WCT = Westslope Cutthroat Trout.

Table 4 Number of captured fish and mean fork length of each species (all years and sampling techniques combined). CRH = Torrent Sculpin; KO = Kokanee; RB = Rainbow Trout; WCT = Westslope Cutthroat Trout.

	N	Mean length (mm) ±SD
CRH	1	84±0
KO	9	53±6.7
RT	4	139±17.0
WCT	32	82±28.4

Abundance

Figure 23 presents the total number of fish caught in the side channel for all sampling techniques and habitat units combined. Sampling efforts and sample sites were consistent among study years so the number of captured fish is representative of the relative abundance of fish in the side channel. The mean fish density over the first five years of operation was 0.43 (± 0.41 SD) fish/100m^2. This value is very low compared to comparable habitat in other streams in BC (see review in discussion section). There was a marked increase in abundance of juvenile WCT caught in the side channel in Year 4 but this increase was not sustained in Year 5 when abundance was back down to the Year 1 and 2 levels.

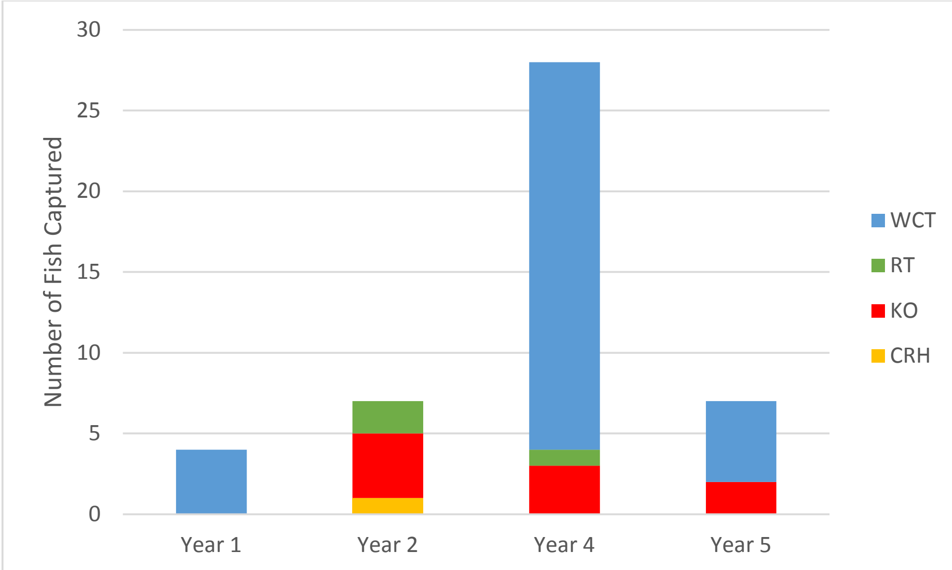

Figure 21 Total catch in Aberfeldie side channel (for all years and sampling techniques combined). CRH: Torrent Sculpin; KO: Kokanee; RB: Rainbow Trout; WCT: Westslope Cutthroat Trout.

Distribution

Most fish captured during the summer juvenile habitat use study were found in glide and riffle habitat (Figure 24). Only two fish were ever caught in pool habitat (it should be noted that this difference could be an artefact of sampling technique effectiveness as pool and glide habitat were not sampled using the same technique). All fish captured in glide and riffle habitat were found in the downstream section of the channel between HU 1-08 to HU 1-13. No fish were ever caught or observed in the upper section of the channel between HU 1-18 and HU 1-20 during summer.

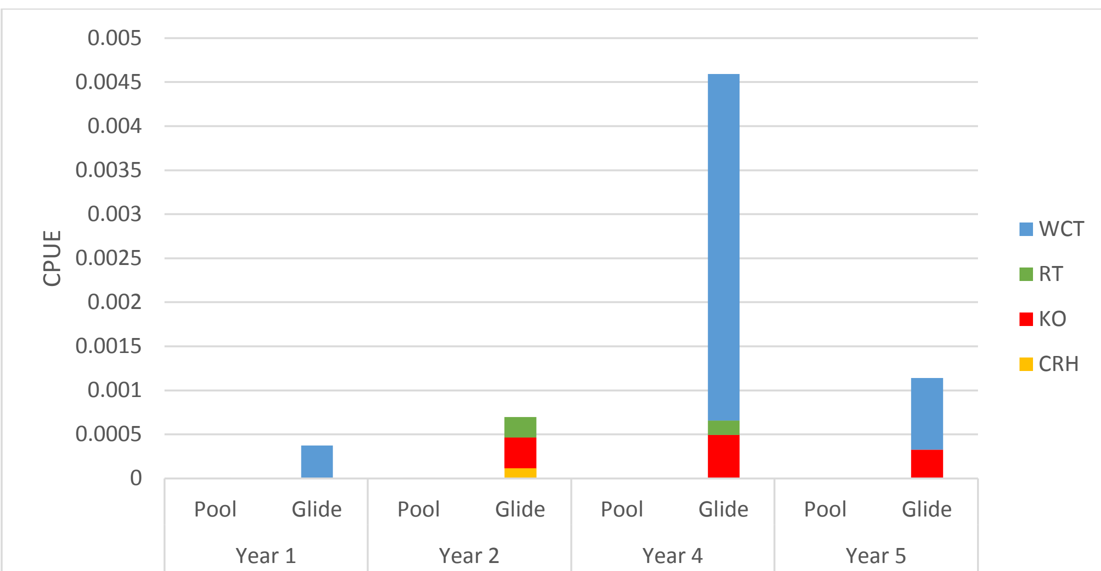

Figure 22 Distribution of fish by habitat types in Aberfeldie side channel. CRH: Torrent Sculpin; KO: Kokanee; RB: Rainbow Trout; WCT: Westslope Cutthroat Trout.

3.5 Fall Spawning Assessment

In all five years of the study, large numbers of Kokanee utilized the constructed channel for spawning in September and October. Detailed enumerations of spawners were conducted in Year 1, 3, and 4. No other species were observed in the side channel at the time of these surveys.

Abundance of spawners

The mean abundance of Kokanee that utilized the side channel each year ranged from 3,285 (± 416 SD) to 4,692 (± 595 SD) (Table 5). This estimate was calculated using weekly counts in the field and the AUC method for calculating salmon escapement (English *et al.*, 1992). It was based on an estimated residence time of fish in the side channel of 7 to 10 days. The number of spawning Kokanee utilizing the side channel appeared relatively constant during the study period.

Table 5 Kokanee escapement estimate for Years 1, 3, and 4

	Kokanee Escapement Estimates	
	Min.	Max.
Year1	2,835	4,050
Year3	3,657	5,224
Year4	3,362	4,803
Mean	**3,285**	**4,692**
SD	**416**	**595**

Habitat Association

Spawning Kokanee were more associated with glide habitat than with any other habitat types in the side channel (Figure 25). Higher densities of Kokanee were consistently observed in glide habitat. Adequate spawning substrate, water velocity, and depth most likely explain this association. Like most salmonid species, Kokanee favour clean, well oxygenated gravel for spawning. In all years, the highest density of fish were noted in glide habitats HU 1-12 and 2-01 where spawning platforms have been installed. Water quality conditions at these two adjacent habitat units are characterized by relatively high DO level (5.32 mg/l ± 0.77) and moderate water velocity (0.181 m/s ± 0.030). These correspond to the highest DO concentration in the side channel but not the highest water velocity.

Interestingly, some Kokanee were also observed in Year 3 and 4 congregating and building redds in the margin of pools. Fish were likely attracted to these areas by water upwellings. Kokanee are known to have higher spawning success in upwelling areas despite the presence of substrate with a high proportion of fines (Garret *et al*., 1998). Substrate along the pool margins was mostly composed of sand and gravel that had fallen from the eroding banks.

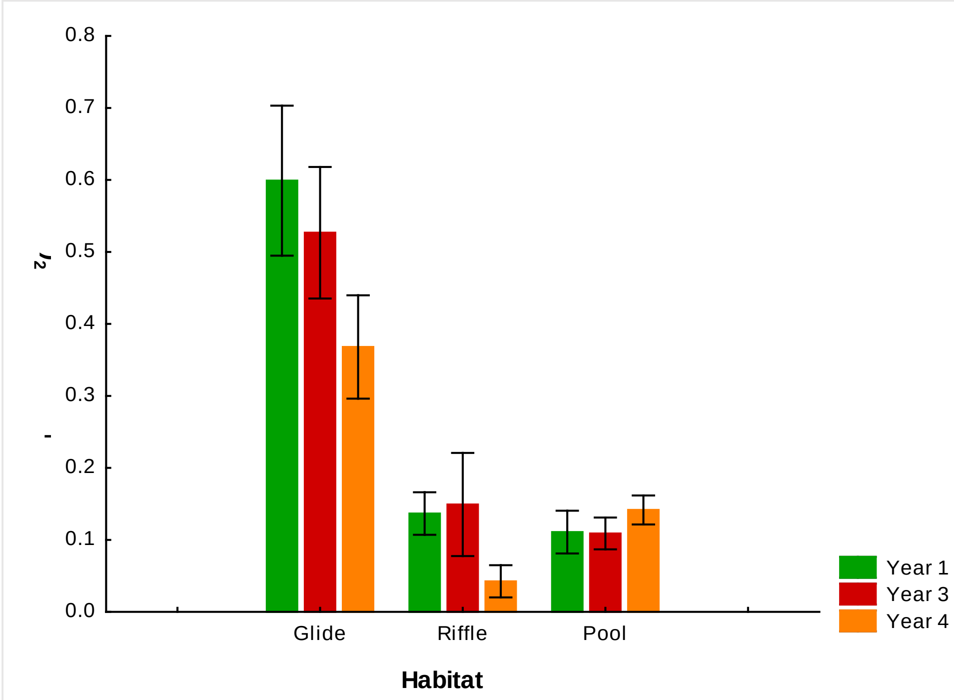

Figure 23 Density of Kokanee (fish/m²) at each habitat type for 2009, 2011, and 2012 fall spawning assessments of the Aberfeldie side channel. Bars represent SE.

Spawning Success

While active spawning behaviour was never directly observed in the side channel (likely because it occurred at night), the presence of well-defined redds and buried eggs confirmed that Kokanee successfully spawned in the side channel. This was supported by observations that most spent females had successfully released their eggs from dissections of female carcasses. Eyed eggs and buried alevins were observed in the water column on several occasions during winter and early spring site visits.

Due to the low dissolved oxygen levels (see water quality section) measured in the channel, there were concerns that Kokanee eggs laid in the constructed side channel habitat may have very low survival rates. In response to these concerns, a study was conducted in Year 2 to quantify incubation success of Kokanee eggs in the side channel using a hydraulic sampling technique (McPherson and Robinson, 2011). The study showed that while some eggs successfully incubated in the side channel, incubation success in the constructed habitat was nearly 50% lower than at a control site on the Bull River mainstem. The study concluded that a combination of low dissolved oxygen level, low water velocity, and inadequate spawning substrate in the side channel habitat likely explained the difference in incubation success.

3.6 Overwintering Assessment

Winter water quality

Seasonal water quality data collected during the overwintering assessment are reported in Section 3.1. Water quality conditions in the side channel during winter were characterized by higher water temperature than in the Bull River mainstem and low DO concentrations.

The average winter water temperature measured in the first five years of operation was 4.1ºC ± 1.66 in the side channel compared to 0.6ºC ± 0.74 SD in the mainstem. This difference in water temperature is likely explained by the hydrology of the side channel, which is fed by ground water upwelling and not by surface water. Measurements taken at different depths in pool habitat showed a marked stratification phenomenon with warmer water found near the bottom and colder water near the surface.

The average winter DO concentration in the side channel was 5.1 (± 1.7 SD) $mg.L^{-1}$ which marginally satisfies the provincial standard for the support of aquatic life (9 mg/L) and does not meet the minimum requirement for the development of embryos and alevins (5 mg/L). Conditions were the most limiting in pool habitat where the average DO concentration was 4.2 (± 1.5 SD) $mg.L^{-1}$. Concentration of DO in pools was negatively correlated to depth. Measurements collected in Year 2 in HU 1-7 and HU 2-2 showed that DO concentration in these pools dropped below 1 mg/L at depths greater than 1 m.

Winter physical habitat

Connectivity with the Bull River mainstem was maintained throughout winter during the first five years of operation. However, gradual infilling of sediment at the channel outlet had severely restricted water depth at the outlet by Year 5. In glide and riffle habitat, a thin layer of ice (approximately 1 cm deep) typically covered the channel margins, but did not restrict fish movements to upstream sections of the side channel. Ice cover and thickness in pool habitat fluctuated considerably between years and between habitat units.

A FHAP conducted on the side channel in Year 1 indicated that the side channel provides suitable physical habitat for fish overwintering. The average maximum depth at pool is 1.39 m (±0.20) and abundant cover is provided by LWD (50 to 75 %) in both glide and pool habitat. These characteristics are consistent with the original design which intended a residual pool depth of 1.5 to 2.0 m and no less than 25% throughout the channel (Reid et al. 2008).

Despite the suitability of physical habitat, limiting DO conditions occurring in pool habitat in winter restrict the overwintering potential of the side channel to the deeper glide sections with LWD.

4 Discussion

Table 6 provides an overview of habitat requirements for each life stage of the species targeted by the Aberfeldie compensation works. Results from the ABFMON-5 Task 2A and 2B were used to indicate the aspects in which the constructed side channel fulfilled or failed to fulfill its objective of providing suitable habitat for these species.

Table 6 List of habitat requirements for target species based on literature review by Ford *et al*. (1995). Green cells highlight suitable conditions in the Aberfeldie side channel based on the results of the monitoring program; yellow cells highlight conditions that may or may not be suitable depending on season and habitat unit; red cells highlight conditions that are not suitable.

	Westslope Cutthroat	Kokanee	Bull Trout	Mountain Whitefish	Rainbow Trout
EGGS					
Temperature tolerance range	6 to 12°C	2 to 15°C	0 to 8°C	0 to 12°C	2 to 20°C
Optimum incubation temperature	10°C	6.0°C	2 to 4°C	6°C (upper limit)	11°C
Recommended oxygen concentration	6 - 8.2 mg/L	6.5 to 9.75 mg/L	9.5 mg/L	8.0 mg/L	> 5.3 mg/L
Lower lethal oxygen concentration	3 mg/L	3.98 mg/L	NA	NA	4.3 mg/L
Lower lethal pH	NA	4.5 to 5.0	NA	NA	5.3
Recommended current velocity	NA	high, with stable spawning materials	below level causing gravel scour	in areas where the velocity will not displace spawning bed materials	yields 50% mortality @ 5.3 mg/L DO and 2 cm/s
Substrate	<5% fines & 2 to 64 mm gravel	NA	cobble and boulder	sand/ gravel	gravel with < 5% fines
JUVENILES					
Temperature tolerance range	0 to 22°C	6. 7 to 24.4°C (for sockeye)	0 to 18°C	0 to 20.6°C	0 to 24°C
Optimum temperature for growth	9 to 13°C	15°C	<12°C	9.0 to 12.0°C	10 to 14°C
Recommended oxygen concentration	9 to 11 mg/L	> 7.88 mg/L	7.75 mg/L	>5.63 mg/L	> 7 mg/L
Lower lethal oxygen concentration	3 to 5mg/L	4.16 mg/L	NA	3.98 mg/L	3 mg/L
Habitat type preference	gravel / cobble substrate	lake	pools	lakes, rivers, tributaries	margins of lakes or streams
Depth preference	up to 40 cm	variable, diel vertical migration	up to 1.0 m	< 3.0m	3 to 6 m in lakes, 0.3 to 1.2 m in streams
Preferred current velocity	7 to 12.5 cm/s	none	< 0.5 m/s	slow to moderate	8 to 20 cm/s
Turbidity tolerance	NA	<10 mg/L	NA	<10 mg/L	NA
Primary food category	dipterans, Ephemeroptera	plankton	benthic insects	benthic invertebrates	benthic invertebrates and terrestrial insect larvae

Secondary food taxa	Trichoptera, Plecoptera	benthic invertebrates	drift	zooplankton	zooplankton, adult insects
ADULTS					
Temperature tolerance range	0 to 22°C (<20°C preferred)	6. 7 to 24.4°C	0 to 12.8°C	0 to 20.6°C	0 to 28°C
Optimum temperature for growth	10 to 13°C	15°C	NA	9.0 to 12.0°c	10 to 14°C
Recommended oxygen concentration	9 mg/L	> 7.88 mg/L	7.75 mg/L	7.75 mg/L	>7 mg/L if<15°C, >9 mg/L if >15°C
Lower lethal oxygen concentration	3 mg/L	4.16 mg/L	NA	4.25 mg/L	3 mg/L
Habitat type preference	riffle - pool complexes	lake	lake or large river	lakes, rivers, tributaries	margins of lakes or streams
Depth preference	50 cm in streams	variable, diel vertical migration	up to 18m	< 3.0m	variable, based on water temperature
Preferred current velocity	10 to 14 cm/s; 36 to 44 cm/s in St. Mary River	none	NA	slow to moderate	20 to 30 cm/s
Turbidity tolerance	NA	<10 mg/L	NA	<JO mg/L	NA
Primary food type	Ephemeroptera, terrestrial insects	plankton	fish	benthic invertebrates	terrestrial insect larvae, benthic invertebrates
Secondary food type	*Daphnia* , fish (for larger cutthroat)	benthic invertebrates	benthic insects	zooplankton	fish
Preferred spawning temperature	6 to 17°C	4.0 to 15.0 °C	< 9•c	> 6.0°C	7.2 to 13.3°C
Preferred spawning depth	6 to 40 cm	> 6 cm to at least 0.46 m	0.15 to 0.84 m	0.10 to 1.0 m	0.15 to 2.5 m
Preferred spawning substrate	2 to 64 mm gravel	gravel/ cobble	cobble/ gravel	gravel/ cobble	typically 4 to 100 mm
Preferred spawning current velocity	30 to 60 cm/s	0.15 to 0.85 m/s	0.25 to 0.65 m/s	0.89 to 1.02 m/s	30 to 90 cm/s

4.1 Water Quality

Water quality conditions during the first five years of operation of the Aberfeldie side channel rarely met the provincial requirements for rearing and reproduction of the targeted fish species (BC MoE, 2006), particularly for DO concentrations.

Water Temperature

At the design stage, it was expected that the fluctuation of water temperature in the side channel between summer and winter would be smaller than in the Bull River mainstem (Bates, 2008). In fact, groundwater temperature is usually cooler than surface water in spring/summer and warmer in fall/winter. This temperature pattern was confirmed by measurements in test pits completed in November 2007 that indicated that groundwater temperature in the area selected for the future side channel was between 4.7 and 6.9 ºC while the mainstem water temperature was only 0.7ºC (Bates, 2008). This presented an opportunity to create temperature refugia for fish and supported the selection of groundwater as a source for the side channel.

Water quality measurements in the side channel during the first five years of implementation show that water temperature does not follow the expected pattern. While the side channel was on average warmer than the mainstem in fall/winter, it remained warmer in spring/summer. Only HU 1-12 (the most upstream pool) exhibited temperatures consistent with the predicted pattern. Potential sub-surface connections with the Bull River mainstem and water retention time in the side channel are two factors that can affect water temperature in the constructed habitat. However, there is insufficient evidence to determine which factor is the main driver of water temperature in the side channel.

Overall, water temperature in the side channel was suitable to support the different target species and life stages. In the spring and early summer, water temperatures were adequate for spawning and incubation of Westslope Cutthroat Trout (9-12 ^{o}C; BC MoE, 2001) and Rainbow Trout (10.0-12 ^{o}C; BC MoE, 2001) but relatively high compared to the water temperature in the mainstem. Fall water temperatures were adequate for Kokanee spawning (below 12 ^{o}C; McPhail, 2007) but exceeded the maximum temperature for Bull Trout spawning (9 ^{o}C; McPhail, 2007).

There were no significant yearly variations in seasonal water temperature, suggesting that these observations are representative of the general water temperature conditions in the side channel.

Water Column Dissolved Oxygen

Water column dissolved oxygen (DO) saturation in the side channel (51.1% ± 18) were markedly lower than in the Bull River mainstem (94.0% ± 14). Concentrations of DO were generally higher in glide habitat than in pool habitat. Concentrations of DO were particularly concerning in pool habitat where fall and winter levels consistently fell below the minimum requirement for the support of aquatic life (5 mg/L; BC MoE 2006). The recommended level for the development of fish embryos and juveniles (9 mg/L; BC MoE 2006) was almost never attained in any of the side channel's habitat units.

Interestingly, concentration of DO was generally higher in the downstream section of the constructed channel and lower in the upstream section. The best DO conditions in the side channel consistently occurred in adjacent glide habitat units 1-12 (6.7 ± 1.57 SD mg/L) and 1-13 (6.4 ± 1.26 SD mg/L), which are located in the middle of the side channel. The most limiting DO conditions were found in the most upstream pool habitat units 1-21 (5.0 ± 2.8 SD mg/L) and 3-02 (5.2 ± 2.21 SD mg/L). These observations suggest that groundwater in the area may be depleted in dissolved oxygen. DO concentration increases as the water flows over riffle sections of the side channel and becomes aerated. It is also possible that biological oxygen demand affects DO concentrations in the side channel through the decomposition of organic matter and the respiration of macrophytes and algae. However, low DO in groundwater appears to be the most plausible explanation of the low DO concentrations in the side channel since poor DO conditions are particularly prevalent in winter when biological organic demand is low.

A slight improvement in DO levels was observed in Year 4 and Year 5, but this increase was not statistically significant. Trends in seasonal data suggest that this increase was restricted to spring and summer of these two years and was observed across all habitat units. There was no detectable DO increase in fall and winter. This observation could be indicative of an input of well oxygenated water from the Bull River through sub-surface connection during high flows. However, there are no other lines of evidence supporting this hypothesis as no variations in temperature or in discharge were detected in the side channel between Year 4/5 and previous monitoring years.

In view of these results, it appears that poor water column DO concentration is a factor that significantly constrains the effectiveness of the side channel in providing suitable pool habitat for rearing and overwintering of target species. DO conditions in glide habitat, although not optimal, are sufficient to support some rearing and spawning of target species.

Intra-gravel Dissolved Oxygen

The average intra-gravel DO concentration measured at the spawning platform HU 1-12 in Year 4 and Year 5 was 6.5 mg/L (± 1.37). This value is lower than at a reference site on the Bull River mainstem (10.1 mg/L (± 4.25)) but is sufficient for the incubation of Westslope Cutthroat Trout, Kokanee, and Rainbow Trout embryos (Table 4).

DO concentrations in the hyporheic layer are typically reduced due to sediment oxygen demand. However, average water column DO concentration measured at HU 1-12 during the same period was very similar (5.9 mg/L (± 1.47) to intra-gravel levels. This indicates good water exchange between surface flow and the hyporheic layer of the streambed creating suitable conditions for embryo development. The relationship between water column DO and DO concentration is dependent on a number of parameters, including water velocity, substrate permeability, and temperature (Bjornn and Reiser, 1991; Slaney and Zaldokas, 1997).

Few studies have investigated DO requirements for the embryo and alevin stages in *Oncorhynchus nerka*. Cope and MacDonald (1998) indicated that Sockeye Salmon rarely spawn in habitat where intra-gravel DO concentration is lower than 3 mg/L. Other studies reported a lethal DO concentration of 3 mg/L for Westslope Cutthroat Trout, 3.98 mg/L for Kokanee, and 4.3 mg/L for Rainbow Trout embryos. Based on these references, it appears that intra-gravel DO conditions at the spawning platform HU 1-12 of the constructed side channel, although not optimal, satisfy these minimum requirements.

Hyporheic water sampled at spawning platforms upstream of HU 1-12 had generally lower DO concentrations than downstream platforms. Their DO concentrations were sometimes as low as 3 mg/L, indicating poor intra-gravel conditions for embryo development. This observation is consistent with water column DO measurements that indicated poorer DO conditions in the upstream section of the side channel. Hyporheic water samples collected at spawning platforms in the downstream section of the side channel had generally similar DO concentrations than at HU 1-12.

Some similarities were noted in Year 4 between variations of intra-gravel DO concentrations in the side channel and in the mainstem but are believed to be artefacts of changing atmospheric conditions.

pH

The pH measurements in the side channel were satisfactory and generally within the 6.5-9 range as recommended in BC MoE guidelines for the support of aquatic life. The average pH value measured in the side channel was 7.5 (± 0.48 SD) which is comparable to the average value of 7.4 (± 0.74) for the Bull River mainstem. While a few measurements anecdotally varied from the optimal recommended range, there were no significant changes in pH conditions during the first five years of implementation and pH was never a water quality concern in the constructed side channel.

Conductivity and Salinity

Specific conductance and salinity measurements collected during the five years of the monitoring study were generally higher in the side channel than in the Bull River. This result was expected as conductivity is commonly higher in groundwater than in rainwater, snowmelt, or glacial melt water because of its longer contact time with rock and/or soils.

There were some seasonal and yearly variations in conductivity and salinity in glide habitat. There were no significant temporal variations in pool habitat but it was noted that habitat unit HU 1-07 (most downstream pool) had significantly higher conductivity and salinity than all other habitat units. These observations suggest that there are different origins of the water entering the side channel. Fluctuations occurring in the water table, influx of surface water through sub-surface connections, and precipitation are factors that may be causing the observed variations in conductivity and salinity in the side channel. However, the data did not exhibit any clear patterns that would enable further characterization of these potential sources of variation.

4.2 Water Quantity and Water Velocity

Water level measurements collected at the Water Survey Canada weir during the five year monitoring program show that there were no significant variations in discharge in the side channel among years. It was also confirmed that enough groundwater was intercepted in order to maintain surface flow throughout the side channel during all seasons. However, water velocity measurements collected in Year 4 indicated that the side channel discharge was not sufficient to maintain adequate water velocity over spawning platforms. Therefore, the side channel did not meet the flow velocity objective of 0.3 to 0.5 m/s developed at the design stage to support spawning and egg development (Reid *et al.*, 2008).

The existence of a sub-surface connection with the Bull River mainstem creating an influx of surface water in the side channel is suspected due to the increase in DO concentration observed in the side channel during particularly high spring flows in Year 4 and Year 5. However, there were no clear variations in discharge in these two years to support this hypothesis. It should be noted that the resolution of the discharge data is relatively low as it was collected infrequently. Further data is needed to better characterize the influence of the Bull River mainstem on the side channel hydrology (and water quality).

4.3 Spawning Habitat

Spring

Despite the fact that connectivity with the mainstem and water quality conditions are best during spring and early summer months, there was no sign of spring spawning activity in the constructed side channel during the first five years of operation.

The factors likely limiting spawning opportunities in the side channel include substrate composition, DO oxygen levels, water velocity, and spawning behaviour of target species.

At the design stage, a D50 of 25mm was prescribed for gravel placed at spawning platforms to suit spawning habitat preferences of WCT and RT (Reid et al., 2008). However, a pebble count conducted in Year 1 showed that the D50 of the substrate at spawning platform was actually 45mm. Spawning substrate is most suitable when small enough to allow fish to construct redds, but also large enough to enable sufficient through flow. Substrate in the side channel also comprise a high proportion of sand and fine sediments. Fine sediments are detrimental to egg survival due to the infilling of interstitial spaces of the spawning substrate, decreasing DO transport. Decomposition of organic particles also contribute to the depletion of intra-gravel DO levels.

Water velocity measured at spawning platforms in Year 4 was below the design target of 0.3 to 0.5 m/s (Reid et al., 2008) and below the preferred water velocity of target species (Table 6).

Site fidelity has been reported in these species (Westslope Fisheries, 2003) and may also explain why WCT and RT do not select the new habitat as suitable spawning site.

In view of these results, it appears that the constructed habitat does not meet its objective of supporting spawning of Bull River WCT and RT.

Fall

Kokanee was the only fish species utilizing the Aberfeldie side channel for spawning during the fall. Although this period also corresponds to the Bull Trout spawning season, low water levels associated with low flow velocity, large substrate size, low DO concentrations, and water temperatures greater than 9º C likely prevented gravid Bull Trout from selecting the side channel as a suitable spawning site. Large numbers of spawning Bull Trout were regularly observed in the Bull River mainstem in the vicinity of the side channel during the spawning season.

Approximately 3,000 to 5,000 Kokanee used the side channel each year for spawning. Hatching success appeared 50% lower than on the mainstem of the Bull River likely due to poor dissolved oxygen conditions and low water velocity. However, eyed eggs, alevins, and fry were observed in the side channel indicating some degree of spawning success.

Spawning activity was observed in both glide and pool habitat. In pool habitats, redds were consistently located at the periphery of pools over material that had entered the channel from the eroding banks. Spawning Kokanee were particularly abundant at the spawning platform located on HU 1-12. This observation was supported by water column and intra-gravel DO measurements that indicated that this site had relatively suitable water quality conditions.

Based on these results, it appears that the constructed side channel partially fulfills its objective of providing spawning habitat to fall spawning species. Although Kokanee is non-native of the area, it has become an important species serving as food items for native piscivorous species such as Bull Trout and providing popular angling opportunities. Large numbers of Kokanee migrate each year up the Bull River for spawning despite the paucity of suitable spawning habitat on the stream (Meunier and Kang 2012). While the constructed side channel does not provide optimal spawning conditions for this species, it did create some spawning opportunities that did not exist in this section of the Bull River mainstem prior to construction.

4.4 Rearing Habitat

After five years of operation, the juvenile fish community in the side channel includes Kokanee, Rainbow Trout, Westslope Cutthroat, and Torrent Sculpin. Other species occurring in the Bull River drainage, such as Bull Trout and Mountain Whitefish, were never observed in the side channel.

Results from the FHAP assessment conducted in Year 1 indicated that the side channel provides abundant cover for rearing of target species. Approximately 70% of glide habitats have at least two LWD pieces per channel length (or 530 pieces per stream Km) and pools have between 50 and 70% estimated cover. This results in a high score in the FHAP standard diagnostics rating (Johnston and Slaney, 1996). A comprehensive literature review by Peterson et al. (1992) found that the number of pieces of LWD in small streams less than 5m wide flowing through unmanaged forests varies between 180 and 610 pieces per kilometer. While it appears that LWD density in the side channel is adequate, it is not clear if it is optimal as there are concerns that excessive LWD affects DO levels through decomposition and reduction of water velocity.

The average water velocity measured in glide habitat in summer of Year 4 was 0.12 m/s ± 0.13, which is within the range of 0 to 0.3 m/s velocities prescribed for glide habitat at the design stage and satisfies the preferred water velocity of target species juveniles (Table 6). However, water velocity in most habitat units is below the preferred range for target species adults.

The Kokanee fry captured during the surveys likely hatched in the side channel. The average length of these fish was 52.6 mm ± 6.7. Upon emergence, Kokanee fry usually migrate to a nursery lake before starting to feed. They typically reach 40-50 mm by the end of their first summer (McPhail, 2007). This observation suggests that the side channel provide adequate food sources to support growth of Kokanee fry. Results from ABFMON-5 Task 2a indicated that the invertebrate community in the side channel is dominated by dipterans (Perrin and Bennett, 2013b), which are often an important food source for Kokanee fry (McPhail, 2007).

Juvenile WCT and RT individuals captured in the side channel were likely in their second year of growth (age 1+). Based on the lack of spawning evidence for these species in the spring, it appears that the captured fish had immigrated to the side channel from the Bull River mainstem. Fish were often found under LWD cover and were generally in good condition. These observations suggest that the side channel provides suitable physical habitat and food sources for rearing of these species at least during summer. It is not clear whether these fish remained in the side channel during winter.

The abundance of rearing fish in the side channel was on average 0.43 fish/100m^2 (± 0.41). This value is very low compared to comparable habitat in the vicinity of the Bull River and in other regions in BC. For instance Oliver et al. (1997) reported WCT densities of 9 fish/100m^2 in Baribeau Creek in the St. Mary River Drainage, a tributary to the Kootenay River North of the Bull River confluence. Cope (2001) reported 3.9 to 20.6 fish/100m^2 in Bighorn Creek a tributary of the Kootenay River South of the Bull River confluence. Both studies used a three pass removal technique similar to the technique used during the ABFMON-5 monitoring program. In the West Kootenay Region, Arndt (2000) reported 115 fish/100m^2 for YOY RT and 12 fish/100m^2 for older fish in an artificial side channel on Murphy Creek, a tributary to the Columbia River near Castlegar, BC. In other regions in BC, Epps (2000) reported 1,600 juvenile Coho Salmon (*Oncorhynchus kisutch*) per 100m^2 in the Tsuk-si-Tay channel, an artificial groundwater channel constructed in the Caycuse River drainage.

Although abundance of rearing fish in the Aberfeldie side channel appeared to have increased in Year 4, a very low number of fish were found in Year 5. One factor that could explain the low abundance of rearing fish in the constructed habitat is the degradation of the connectivity with the Bull River mainstem caused by gradual infilling of fine sediment at the side channel outlet. This issue is discussed in section 4.6.

Fish were very unevenly distributed in the side channel. Over 95% of fish captured during the surveys were found in glide and riffle habitat in the section of the channel between HUs 1-10 to 1-13. No fish were caught in glide habitats HU 1-18 to 1-20 or in pool habitats HU 1-07 and 1-21. Factors that could explain this uneven distribution include food availability, variations in physical habitat, and water quality issues. ABFMON-5 Task 2a (Perrin and Bennett, 2013b) did not report any changes in benthic invertebrates abundance between the downstream and upstream reaches of the side channel. The FHAP completed in the side channel in Year 1 of the study reported fair to good LWD cover conditions for both the HU 1-10 to 1-13 and HU 1-18 to 1-20 sections of the channel. Concentration of DO is poorer in the upstream section of the side channel and likely restricts habitat use in these habitat units. The hydrometric weir located at HU 1-13 may also represent a barrier to upstream movement of juvenile fish. While spawning Kokanee easily clear this 20 cm step, the passability of the weir by juvenile target species has not been assessed.

In view of these results, it appears that the constructed habitat only partially meets its objective of providing rearing habitat for juvenile target species. While some summer rearing use was detected, water quality and accessibility issues restrict rearing and overwintering habitat potential.

4.5 Overwintering Habitat

The monitoring study showed that overwintering habitat availability within the side channel was severely limited by low DO concentrations in pools (below the minimum requirement to support aquatic life), glides (often below the minimum requirement for the development of embryo and alevins), and by low water levels in glide habitats. Stratification in pool habitats resulted in DO concentrations near the pool bottom that were periodically below the lethal level for aquatic life.

The side channel remained physically accessible to Bull River fish during winter despite some ice formation and sediment deposits near the channel outlet, which severely restricted water depth. Deeper glide sections with LWD and the upper water layer of pool habitats were the best available overwintering habitat.

In view of these results, it appears that the constructed side channel is not effective at providing suitable overwintering habitat to target species. Despite the very limiting conditions during winter, Kokanee fry were consistently observed in early spring in the side channel, indicating some degree of hatching success.

4.6 Connectivity and Structural Stability

The structural stability monitoring confirmed that the outer structure of the Aberfeldie side channel functions as intended and provides suitable protection against the Bull River flood flows. Monitoring of the inner channel structure revealed significant stability concerns. Evidence of bank erosion was present throughout the side channel, likely caused by the steep slope of the banks. Bank erosion was aggravated by precipitation and wildlife/cattle activity in the side channel area. Bioengineering and re-vegetation efforts have not been effective in reinforcing banks and preventing erosion of unstable hill slopes. Sediment input from bank erosion may directly affect fish spawning habitat availability through the settling of fines in spawning gravel interstitial spaces and the reduction of the channel effective width.

The groyne at the downstream end of the channel offers suitable protection to the outlet during high spring flows but is not efficient in promoting scour and removal of sediment. Significant sedimentation has occurred at the side channel outlet during the first five years of operation. The deposited sediment have markedly reduced the connectivity of the side channel with the Bull River mainstem therefore limiting fish access.

5 Conclusion

The effectiveness monitoring program ABFMON-5 Task 2B, in combination with ABFMON-5 Tasks 2A and 2C, provided qualitative and quantitative assessments to verify whether the Aberfeldie compensation side channel meets the requirements of Fisheries Act Authorization 05-HPAC-PA7-00188 for the Aberfeldie Upgrade Project. The objective of the compensation works was to offset any loss of productive capacity caused by the new flow regime in the diversion reach and result in no-net-loss of productive capacity from the redevelopment of the Aberfeldie Dam.

Baseline assessments (Cope, 2006) indicated that, as a whole, fish habitat in the diversion reach prior to redevelopment was not high quality (Cope 2006). Therefore, the offsetting of lost primary and secondary production (i.e., periphyton and benthic invertebrates) was considered the main priority for compensation efforts.

The results from the ABFMON-5 program provided sufficient information to address management questions 1 and 2 as follows:

1. There was no significant effect of post-redevelopment change in flow on the composition, diversity and total biomass of periphyton and benthic invertebrates in the Bull River mainstem (Task 2A; Perrin and Bennet 2013a).
2. There was a 19% decline in abundance of benthic invertebrates caused by loss of wetted area in the diversion reach but the productivity achieved through the constructed side channel was sufficient to offset this loss (Task 2A; Perrin and Bennett 2013b).
3. The construction of the side channel successfully created additional primary and secondary productive capacity. However, the effectiveness of the constructed system in providing suitable habitat to fish is poor mainly due to water quality, water quantity, and physical habitat issues (Task 2B). The long term sustainability of the constructed habitat is also threatened by active bank erosion and decreasing connectivity with the Bull River mainstem (Task 2B and 2C).
4. Due to poor effectiveness of the constructed habitat and concern on long-term sustainability, further reduction of summertime flows in the diversion reach should not be implemented (Task 2A and 2B).

6 REFERENCES

Arndt, S. 2000. Effectiveness Evaluation and Maintenance Recommendations for WRP Instream Works in Bighorn Creek Reach 2. Prepared for Fish and Wildlife Compensation Plan.

Bates, A. 2008. Aberfeldie redevelopment project: off-channel habitat site investigation. Prepared for BCHydro.

BC Hydro. 2006. Aberfeldie Redevelopment Project Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. 24pp.

BC Hydro. 2008a. Aberfeldie Water Use Plan, Monitoring Terms of Reference: ABFMON 5 – Effectiveness Monitoring Fish Habitat Works and ABFWORKS 1 – Benthic Habitat Physical Works. September 2008. 15 pp.

BC Hydro. 2008b. Aberfeldie Project Water Use Plan – Physical Works Terms of Reference. ABFWORKS#1 – Fish and Benthic Habitat Physical Works Design. August 13, 2008. 15 pp.

BC MoE (British Columbia Ministry of Environment). 1997. Ambient Water Quality Criteria for Dissolved Oxygen. Overview Report and Technical Appendix. Environmental Protection Division, Ministry of Environment, Government of British Columbia.

BC MoE. 2001. Water Quality Guidelines for Temperature. Environmental Protection Division. Government of BC.

BC MoE. 2006. A Compendium of Working Water Quality Guidelines for British Columbia. 2006 Edition. Science and Information Branch, Environment and Lands Division, Government of BC.

Beblow and Guimond, 2010. FLSMON-2. Falls River Water Use Plan Monitoring Program: Falls River Fish Spawning Habitat Monitoring. Year 2. Prepared for BC Hydro.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 in W.R.

Bue, B.G., S.M. Fred, S. Sharr, D.G. Sharp, J.A. Wilcock and H.J. Geiger.1998. Estimating Salmon Escapement using Area-Under-the-Curve, Aerial Observer Efficiency, and Stream-Life Estimates: The Prince William Sound Pink Salmon Example. North Pacific Anadromous Fish Commission Bulletin. No. 1:240-250.

Canadian Council of Ministers of the Environment (CCME). 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Summary Table. Update 7.1.

Cope, S. 2006. Environmental Impact Assessment of the Aberfeldie Redevelopment Project, Bull River, British Columbia. Prepared by Westslope Fisheries Ltd., for BC Hydro. April 2006 (Revision 4).

Cope, S. 2001. Effectiveness Evaluation and Maintenance Recommendations for WRP Instream Works in Bighorn Creek Reach 2. Prepared for Tembec Industries Inc.

Cope, R.S. and J.S. MacDonald. 1998. Responses of Sockeye Salmon (*Oncorhynchus nerka*) Embryos to Intragravel incubation Environments in Selected Streams within the Stuart-Takla Watershed. Pages 283-294 in M.K. Brewin and D.M.A. Monita, tech. coords. Forest-fish conference: land management practices affecting aquatic ecosystems. Proc. Forest-Fish Conf., May 14, 1996, Calgary, Alberta. Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-356.

Department of Fisheries and Oceans (DFO). 2006. Authorization for Works or Undertaking Causing the Harmful Alteration, Disruption or Destruction of Fish Habitat. Section 35(2) Authorization – DFO Referral 05-HPAC-PA7-000-000188. Issued November 14, 2006.

DeVries. P. 1997. Riverine salmonid egg burial depth: Review of published data and implication for scour studies. Canadian Journal of Fisheries and Aquatic Sciences. 54: pp.1685.

English, K.K., R.C. Bocking and J.R. Irvine. 1992. A Robust Procedure for Estimating Salmon Escapement Based on the Area-Under-the-Curve Method. Canadian Journal of Fisheries and Aquatic Sciences. 49:1982-1989.

Environment Canada. 2013. Hydrometric Archive for British Columbia and Yukon - Hydrometric Report for Bull River near Wardner Station (08NG002). Water Survey of Canada. Vancouver, British Columbia, Government of Canada. Data set at: http://www.ec.gc.ca/rhc-wsc/.

Epps, D. 2000. Nitinat River WRP: Tsuk-si-tay Groundwater Side Channel and Upslope Management. Watershed Restoration Technical Bulletin, Streamline. Vol. 5 No. 1.

Ford, B.S., P.S. Higgins, A.F. Lewis, K.L Cooper, T.A. Watson, C.M. Gee, G.L. Ennis, and R.L Sweeting. 1995. Literature reviews of the life history, habitat requirements and mitigation/ compensation strategies for thirteen sport fish species in the Peace, Liard and Columbia River drainages of British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 2321: xxiv+342 p.

Garret, J.W., D.H. Bennett, F.O. Frost and R.F. Thurow. 1998. Enhanced Incubation Success for Kokanee Spawning in Groundwater Upwelling Sites in a Small Idaho Stream. Management Briefs. North American Journal of Fisheries Management 18:925-930.

Hayes D.B, J.R. Bence, T.J. Kwak, and B.E. Thompson. 2007. Abundance, biomass, and production. pp. 327-374. In C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American fisheries society. Bethesda, Maryland, USA.

Irvine, J.R., R.C. Bocking, K.K. English and M. Labelle. 1992. Estimating Coho Salmon (*Oncorhynchus kisutch*) Spawning Escapements by Conducting Visual Surveys in Areas Selected Using Stratified Random and Stratified Index Sampling Designs. Canadian Journal Fisheries and Aquatic Sciences. 49:1972-1981.

Johnston, N.T. and P.A. Slaney. 1996. Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8. Revised April 1996.

McArthur M., G. Martel, J. Berdusco, A. Leake. 2010. ABFMON#4: Monitoring of Winter Habitat Maintenance Flows.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. The University of Alberta Press, Edmonton, Alberta. 620 pp.

McPherson, S. and M. Robinson. 2010. Aberfeldie Side Channel – Effectiveness Monitoring of Fish Habitat Works. Year 1 Reporting. Prepared for British Columbia Hydro and Power Authority, Burnaby, BC. Prepared by Interior Reforestation Co. Ltd., Cranbrook, BC.

McPherson, S. and M.D. Robinson. 2011. Report In Prep. - Swift Project Overwintering Assessment. Prepared by Lotic Environmental. Consultant report prepared for Teck Coal Ltd.

Meunier, B. and M. Kang. 2012. Kookanusa Reservoir Kokanee Enumeration (2012). Prepared for Columbia Basin Trust, Cranbrook, BC. Prepared by Vast Resource Solutions Inc., Cranbrook, BC.

Oliver, G.G., R.G. Colombo and B.M. Pennington. 1997. Fish and Fish Habitat Assessment in an unlogged headwater stream in the East Kootenay. Prepared for Ministry of Environment, Lands and Parks.

Perrin, C.J. and S.A. Bennett. 2013a. Aberfeldie water use plan: Primary and secondary productivity monitoring. Report prepared by Limnotek Research and Development Inc. for BC Hydro. 52p.

Perrin, C.J. and S. A. Bennett. 2013b. Effectiveness monitoring fish habitat works, Task 2a: Primary and secondary productivity monitoring. Report prepared by Limnotek Research and Development Inc. for BC Hydro. 47p.

Perrin, C.J. and C. Canning. 2010. Change in wetted habitat area due to water diversion in the Bull River, British Columbia: Final report for project ABFMON#3. Report prepared by Limnotek Research and Development Inc. for BC Hydro. 16p.

Peterson, N.P., A. Hendry, and T. Quinn. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and threshold values. Center for Streamside Studies. University of Washington, Seattle, WA.

Przeczek, J, and L.A. Isaac. 2013. Effectiveness monitoring fish habitat works, Task 2C: Riparian Vegetation Monitoring. Report prepared by Pryzm Environmental Ltd.

Reid, D., A. Bates and J. Bisset. 2008. Aberfeldie Redevelopment Project, Off-Channel Compensation Design (Draft). Prepared by BC Hydro Engineering, Streamworks Unlimited and Interior Reforestation Ltd for BC Hydro Engineering Services.

Schmetterling, D.A. 2000. Redd Characteristics of Fluvial Westslope Cutthroat Trout in Four Tributaries to the Blackfoot River, Montana. North American Journal of Fisheries Management. 20:776–783.

Slaney, P.A. and D. Zaldokas. 1997. Fish Habitat Rehabilitation Procedures. Watershed Restoration Technical Circular No. 9. Ministry of Environment, Lands and Parks.

Steen, R.P. and T.P. Quinn. 1999. Egg burial depth by sockeye salmon (Oncorhynchus nerka): Implication for survival of embryos and natural selection on female body size. Canadian Journal of Zoology. 77:5. pp.836.

Szerlong, G.R. and D.E. Rundio. 2007. A Statistical Modelling Method for Estimating Mortality and Abundance of Spawning Salmon from Time Series of Counts. Canadian Journal of Fisheries and Aquatic Sciences. 65:17-26.

Westslope Fisheries. 2003. Elk River westslope cutthroat trout radio-telemetry study: 2000–2002. Report prepared for Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C.

Zippin, C. 1958. The Removal Method of Population Estimation. Journal of Wildlife Management. 22:82-90

7 APPENDICES

7.1 Appendix 1: Results of statistical analysis on water quality data

Table 7 F-values from factorial ANOVAs examining the effects of project year, season, habitat, and their interaction on water quality variables (temperature, pH, dissolved oxygen, specific conductivity, and salinity) for the Aberfeldie side channel monitoring study. Asterisks indicate significant effects at the Holm modified Bonferroni level: *p < 0.007. Degrees of freedom are shown in parentheses.

Dependent Variables ($df_{denominator}$)	**Source of variation ($df_{numerator}$)**						
Water Quality Variables	Year (3)	Season (1)	Habitat (3)	Year Season (10)	Year Habitat (9)	Season Habitat (5)	Year Season Habitat (32)
Temperature (ºC)	2.90	*45.38**	2.56	*15.10**	0.13	0.91	0.15
pH	*12.23**	6.18	0.94	*3.82**	0.61	0.88	1.64
Dissolved Oxygen (mg/L)	3.02	*15.93**	*45.62**	*2.80**	0.18	1.10	0.51
Specific Conductance (µS/cm)	*7.09**	*5.51**	3.76	*4.06**	0.22	0.68	0.36
Salinity (ppt)	4.11	*7.51**	*4.52**	*4.99**	0.40	1.44	0.59

Table 8 F-values from one-way ANOVAs examining the effects of year and season on water quality variables for each habitat type for the Aberfeldie side channel monitoring study. Asterisks indicate significant effects at the Holm modified Bonferroni corrected level (*p < 0.007, **p < 0.001). Degrees of freedom and direction of significant differences are shown in parentheses. 'Y1' = study period 2009-2010; 'Y2' = study period 2010-2011; 'Y3' = study period 2011-2012; 'Y4' = study period 2012-2013; 'Y5' = study period 2013-2014.

Dependent Variables ($df_{denominator}$)			Source of variation ($df_{numerator}$)
WQ Variable	Habitat Type-Season		Year (3)
Temp (^{o}C)	Pool	Fall (15)	8.575** (Y5<Y2, Y5<Y3, Y5<Y4)
		Winter (15)	ns
		Spring (15)	ns
		Summer (15)	ns
	Glide	Fall (7)	12.491** (Y5<Y3, Y5<Y4)
		Winter (7)	ns
		Spring (7)	ns
		Summer (7)	ns
pH	Pool	Fall (15)	4.805** (Y5<Y2)
		Winter (15)	ns
		Spring (15)	ns
		Summer (15)	ns
	Glide	Fall (7)	5.780**(Y5<Y2)
		Winter (7)	89.72** (Y1<Y2)
		Spring (7)	ns
		Summer (7)	ns
Dissolved Oxygen (mg/L)	Pool	Fall (15)	ns
		Winter (15)	ns
		Spring (15)	ns
		Summer (15)	ns
	Glide	Fall (7)	ns
		Winter (7)	ns
		Spring (7)	ns
		Summer (7)	ns
Specific Conductance (µS/cm)	Pool	Fall (15)	ns
		Winter (15)	ns
		Spring (15)	ns
		Summer (15)	ns
	Glide	Fall (7)	30.655* (Y5<Y2, Y5<Y3, Y5<Y4)
		Winter (7)	61.100** (Y4<Y1, Y4<Y2, Y4<Y3)
		Spring (7)	30.655** (Y1<Y2, Y1<Y3, Y4<Y2, Y4<Y3, Y5<Y2, Y5<Y3)
		Summer (7)	ns
Salinity (ppt)	Pool	Fall (15)	ns
		Winter (15)	ns
		Spring (15)	ns
		Summer (15)	ns
	Glide	Fall (7)	ns
		Winter (7)	42.378* (Y4<Y1, Y4<Y2, Y4<Y3)
		Spring (7)	29.156** (Y1<Y2, Y1<Y3, Y4<Y2, Y4<Y3, Y5<Y2, Y5<Y3)
		Summer (7)	ns

7.2 Appendix 2: Water Quality Results

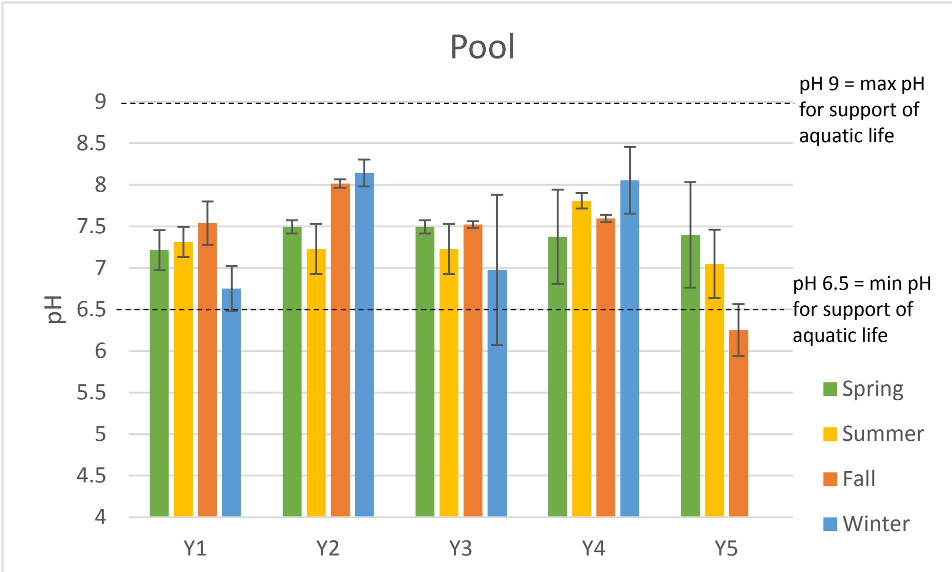

Figure 24 Annual and seasonal mean pH of pools of the Aberfeldie side channel. Error bars represent ± standard error (SE).

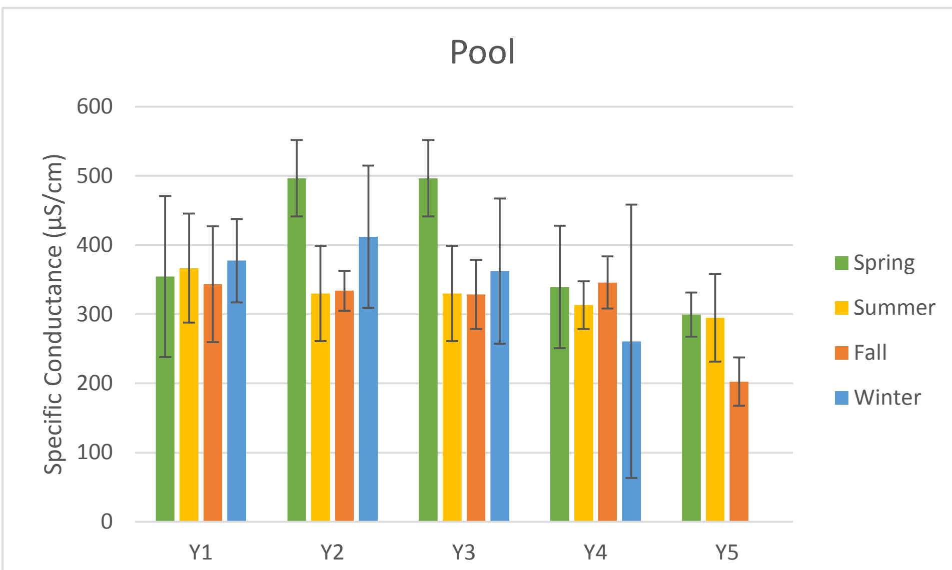

Figure 25 Annual and seasonal mean specific conductance of pools of the Aberfeldie side channel. Error bars represent ± standard error (SE).

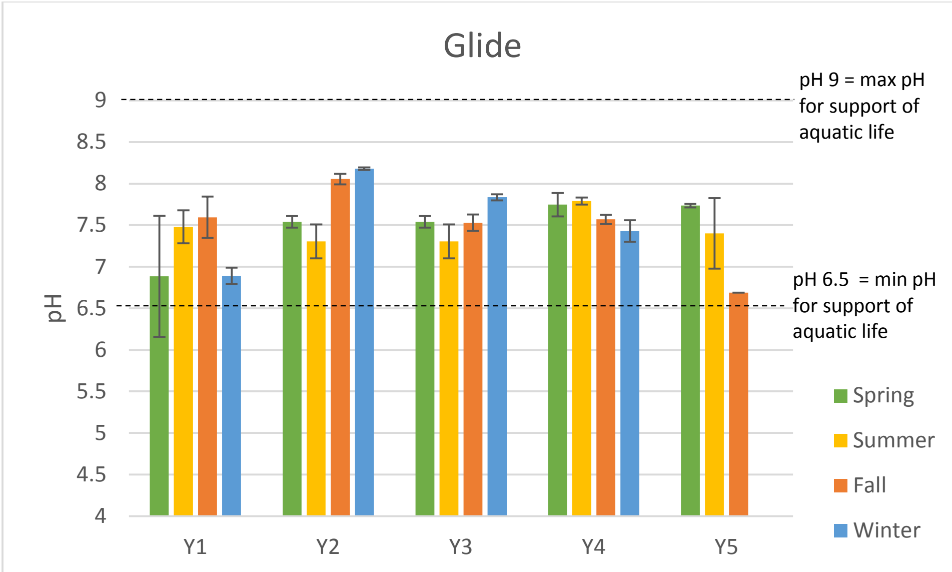

Figure 26 Annual and seasonal mean pH of glides of the Aberfeldie side channel. Error bars represent ± standard error (SE).

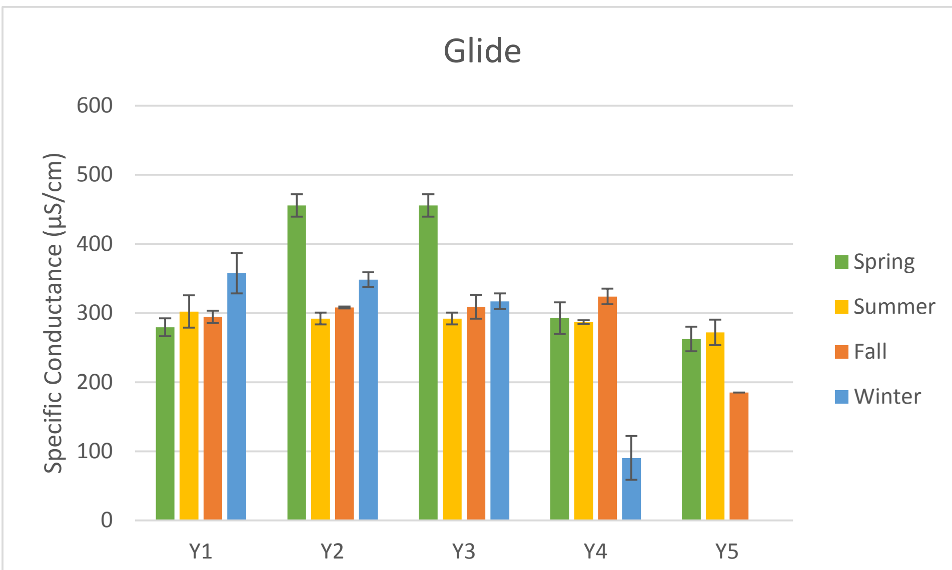

Figure 27 Annual and seasonal mean specific conductance of glides of the Aberfeldie side channel. Error bars represent ± standard error (SE).

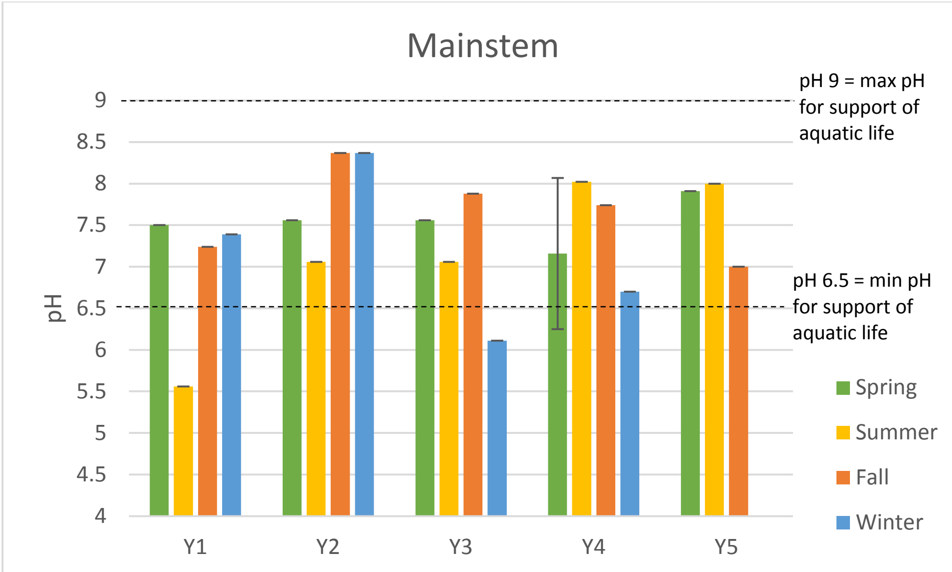

Figure 28 Annual and seasonal mean pH of the Mainstem of the Bull River. Error bars represent ± standard error (SE).

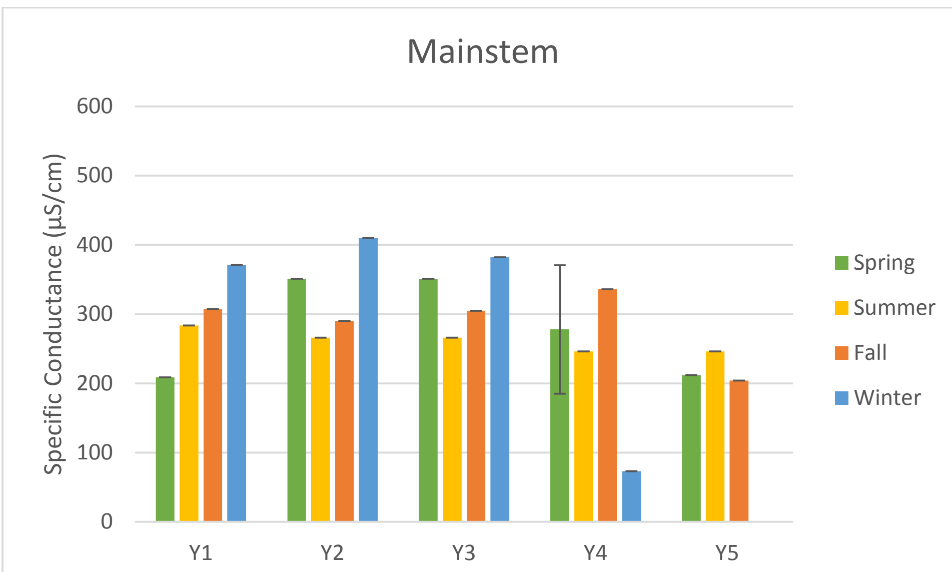

Figure 29 Annual and seasonal mean specific conductance of the Mainstem of the Bull River. Error bars represent ± standard error (SE).