JORDAN RIVER WATER USE PLAN
SYNTHESIS OF MONITORING PROGRAMS CONDUCTED FROM 2005 TO 2011

Prepared For:

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EXECUTIVE SUMMARY

The Jordan River Water Use Plan (JOR WUP) was initiated in 2000 and finalized in 2003. In 2004, the Comptroller of Water Rights (CWR) issued Orders in response to the JOR WUP under the Water Act that included implementation of a fish flow release of 0.25 m^3/s from Elliott Dam, and the undertaking of 5 monitoring projects to assess for anticipated benefits to fish, fish habitat, and recreational activities. These 5 monitoring projects were conducted over the years 2005 – 2011. With these now complete, BC Hydro has scheduled a Water Use Plan Order Review (WUP OR) to occur in 2017–2018. This document was prepared as part of the Order Review process, and summarizes results from the 5 monitors, and outlines whether benefits anticipated by the WUP Consultative Committee (CC) are being realized under the current operating constraints.

The physical works and 5 monitors were as follows:

- JORWORKS-1 – Water Release Mechanism at Elliott Dam (Physical Works): design and plan for the installation of a fish-water release valve in Elliott Dam to enable a minimum flow release of 0.25 m^3/s into the Lower Jordan River.
- JORMON-1 – Lower Jordan River Inflow Monitoring: assess the performance of modelled flows used in the minimum flow decision relative to measured flows in the Jordan River below Elliot Dam.
- JORMON-2 – Fish Index – Lower Jordan River: assess the performance of the minimum flow release using fish abundance and fish condition as performance measures.
- JORMON-3 – Lower Jordan River Salmon Spawning Assessment and Enumeration: assess spawning success of salmon in the anadromous reach of the Lower Jordan River.
- JORMON-4 – Diversion Reservoir Fish Indexing: assess the impacts of extensive drawdowns on Diversion Reservoir rainbow trout condition factor and water quality.
- JORMON-5 – Monitoring Surfing Quality below the Jordan River Generating Station: assess the performance of generation constraints on surf quality.

The installation of the fish release pipe, pneumatic gate valve, and gauging instrumentation (JORWORKS-1) were initiated in 2006, and completed in 2008, with fish flow releases commencing in January 2008. The 5 monitors were 6-year programs and collected data for 3 years prior to, and 3 years after the flow release. These commenced in 2005 and were complete in 2011. An important change from the WUP plan was that issues with flow control mechanism resulted in the pneumatic gate valve being locked in the full open position for the duration of the post flow release monitoring. This resulted in a release discharge ranging from approximately 0.3 – 0.4 m^3/s (depending on headpond elevation) as opposed to the intended 0.25 m^3/s.

The following table summarizes the objectives of each of the 5 monitors, the management questions they were to address, and the response documented by the studies.

Summary of objectives, outcomes, and implications for the 5 Jordan WUP monitoring programs.

Study	Objectives	Management Questions	Response	Operational Implications
Monitor 1: Lower Jordan River Inflow Monitoring	Assess the accuracy of the modelled inflows and the performance of the fish flow release in delivering the anticipated discharge. August was selected as the critical month (month of summer base flow).	1) How accurate were the inflows modelled for the WUP for the region downstream of Elliott Dam? 2) What are the reasons for differences between monitored and modelled inflows? 3) What implications do measured inflow data have on the WUP release flow recommendation	1a) WUP flows overestimated August inflows between Elliott Dam and the JOR tailrace by 0.105 m^3/s. 1b) There was a loss of 0.03 – 0.05 m^3/s of the flow release to groundwater conveyances. 2) The overestimation by WUP flows was due an erroneous assumption in the modelling process. 3) Implications – see next column As noted in the text, release flows ranged from ~0.3 – 0.4 m^3/s as opposed to the intended 0.25 m^3/s.	1) Due to overestimation of local inflows, and losses of the flow release to groundwater, in order to achieve the WUP rearing area and wetted stream length targets, the flow release at Elliott Dam would need to be 0.395 m^3/s as opposed to 0.25 m^3/s. 2) Due to the control valve being locked fully open, the above revised flow requirement and associated targets were largely achieved under the existing flow release (0.3 – 0.4 m^3/s).
Monitor 2: Lower Jordan River Fish Index Study	Assess for measureable benefits of the flow release to rearing salmonids and their habitat. Additional objective: assess water quality before/after the flow release (including copper).	1) How will the flow release affect standing stock of rainbow trout? 2) How will the flow release affect rainbow trout condition (weight to length ratio)? 3) Will the flow release restore habitat continuity?	1) Density of age 1^+ and 2^+ rainbow trout increased after the flow release. Juvenile trout and coho fry repopulated the copper impacted zone after the flow release (Reach 2). 2) No change in condition factor. 3) Habitat continuity was greatly improved; wetted channel right up to Elliott Dam; sufficient depths in riffles for fish to freely disperse between habitat units.	The flow release was successful in providing measureable biological and habitat benefits for resident rainbow trout in reaches below Elliott Dam. The flow release provided sufficient dilution of copper in Reach 2 to allow successful rearing of resident and anadromous species (coho and steelhead can now produce smolts) Benefits were achieved under a 0.3 – 0.4 m^3/s release; it is unknown whether benefits would be sustained if the release is reduced to the original intent of 0.25 m^3/s. A reduction to 0.25 m^3/s could re-introduce copper toxicity issues.
Monitor 3: Assessment of spawning and incubation success, anadromous reaches	Assess whether the flow release improves spawning and incubation success in the anadromous reaches. Quantify anadromous spawning habitat and whether availability is influenced by the flow release. Assess the effects of copper on incubation and rearing, and whether the flow release mitigates effects.	1) Will the flow release improve spawning habitat for salmon and steelhead in anadromous reaches? 2) Will the flow release improve incubation success for salmon and steelhead? 3) What effects, if any, will the flow release have on chronic toxicity affecting rearing and incubating salmonids?	1a) Snorkel counts of adult salmon and steelhead were low within the study years, but subsequent surveys by FWCP projects showed an increase in coho and chum salmon. 1b) The flow release was estimated to have little effect on the quantity of available spawning habitat as spawning tends to occur after the arrival of fall rains; however, the release appears to have improved adult access into Reach 2. 2) The flow release did not appear to influence incubation success (survival of coho eggs within incubators was high both before and after the flow release).	The dilution of copper provided by the flow release, and subsequent ability of the anadromous portion to support rearing (and potentially produce smolts) represents a significant ecological response. Increased abundance of adult coho and chum found by recent snorkel surveys suggest benefits are beginning to manifest in adult returns. The positive response in anadromous rearing and adult returns suggest that the needs of anadromous fish may require review in the WUP OR process.

Study	Objectives	Management Questions	Response	Operational Implications
			3a) Incubation success appeared to be unaffected by levels of copper in the water (high egg-to-alevin survival throughout the study). 3b) Rearing was not viable within the copper impacted zone prior to the flow release but was successful after the flow release (see Monitor 2)	
Monitor 4: Diversion Reservoir Fish Index Study	Monitor lentic trout populations for potential benefits from reduced drawdown and evaluate the effects of extensive drawdown on these fish.	1) What are the benefits to rainbow trout condition (weight to length ratio) associated with a reduced allowable drawdown? 2) What are the impacts on rainbow trout condition associated with a prolonged extensive drawdown?	1a) No significant increase was found in trout condition factor under reduced drawdown. 1b) However, abundance increased significantly and was concluded to be a better indicator of drawdown performance. 2) Limnological conditions can develop where trout are sandwiched between warm surface waters, and an anoxic bottom layer. Extensive drawdown at these times can result in the HCV drawing off water from the crucial mid-water layer.	The increased abundance of lentic trout suggests a positive response to reduced drawdown. Thus, the reduced drawdown operating protocol should be maintained. Consideration should be given to avoiding HCV releases during periods when critical mid-water layer is at the level of the HCV intake.
Monitor 5: Surf Quality Survey	Assess the benefits of constrained generation discharge (≤ 30 m^3/s) on the quality of the surfing experience off the mouth of the Jordan River.	How do constraints on generation benefit surf quality at the Jordan River? Assessed by surfer response to a questionnaire.	25% of surfers reported an effect of generation on surf quality when there was no generation flows, 32% at constrained flows, and 49% at unconstrained generation flows.	Concluded that maintaining constraints at times when it contributes to surf quality would be desirable, but the range of environmental conditions, and the variability in their nature and occurrence, limit the ability to predict when flow constraints would improve surf conditions.

For the most part, the 5 WUP monitors were successful in addressing the management questions posed by the WUP CC. Remaining uncertainties are related to the fact that monitoring results were based on a fish flow release of 0.3 – 0.4 m^3/s, as opposed to the 0.25 m^3/s prescribed in the Jordan WUP. Thus, it is uncertain whether key benefits (increased rainbow trout abundance, alleviation of disconnected habitat issues, and alleviation of copper toxicity on rearing in the anadromous reaches) would be sustained if the flow release is reduced to the original intent of 0.25 m^3/s.

It is also important to acknowledge that the release of 0.25 m^3/s was selected by the WUP CC based on modelled inflows, which predicted certain gains in rearing habitat (weighted usable area), and wetting of an additional 3 km of stream length downstream of Elliott Dam. Monitor 1 found that, due to overestimation of modelled inflows, and losses to subsurface conveyances, that a release of 0.395 m^3/s would be required to achieve the WUP habitat targets. As it turned out, the existing release of 0.3 – 0.4 m^3/s was reasonably close to this revised flow requirement, and thus monitoring studies inadvertently captured habitat conditions close to the WUP target.

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ACKNOWLEDGEMENTS

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1. INTRODUCTION

The Jordan River Water Use Plan (JOR WUP) was initiated in 2000 and finalized in 2003, at which time it was submitted to the Comptroller of Water Rights (CWR). In 2004, the CWR issued Orders in response to the JOR WUP under the Water Act that included implementation of a fish flow release of 0.25 m^3/s from Elliott Dam, and the undertaking of five monitoring projects to assess for anticipated benefits to fish, fish habitat, and recreational activities (Comptroller of Water Rights 2004). The 5 monitoring projects included:

1. A hydrology study to measure and assess flows in the Jordan River downstream of Elliott Dam.
2. An assessment of fish and fish habitat in the same region.
3. A study to inventory adult salmon spawners and assess incubation success in anadromous reaches of the lower river.
4. An assessment of fish and fish habitat in Diversion Reservoir.
5. A surf quality monitoring study off the mouth of the Jordan River.

These monitoring projects were conducted over the years 2005 to 2011.

With these projects now complete, BC Hydro has scheduled a Water Use Plan Order review to occur in 2015. The review responds to the Jordan WUP Consultative Committee recommendation to undertake a review upon completion of the monitoring programs.

This document was prepared as part of the Order Review process. It summarizes results from the above 5 monitors, and outlines whether benefits anticipated by the Consultative Committee are being realized under the current operating constraints. The specific objectives of this report are to:

1. Provide a summary of the objectives, activities, and results for each of the 5 monitors.
2. Relate monitor findings to the objectives of the Jordan River WUP.
3. Describe any data gaps, particularly those that affect the ability of a monitor to address the WUP objectives and the Orders issued in response to the WUP.
4. Provide recommendations to address any of the above data gaps.
5. Provide a list of operational options with recommendations.

The report begins with a Background section due to new information on the Jordan River that was not available at the time of the WUP, and because this will help in an understanding of WUP monitor results.

2. BACKGROUND

2.1 Hydroelectric Facilities

Hydroelectric facilities were first constructed in the Jordan River in 1911 by the Victoria Light & Power Company. These early facilities consisted of Bear Creek Dam and Reservoir, Diversion Dam and Reservoir, a flume that carried flows from Diversion Dam to Forebay headpond, and penstock leading to a 26 MW powerhouse located on the east side of the river above the village of Jordan River (BC Hydro 2000). Flows generated by the powerhouse discharged into a 500 m long excavated channel that emptied into the Lower Jordan River 200 m upstream of the current West Coast Highway bridge crossing. The operation of the original powerhouse was to provide a constant supply of power and as such, year-round flows occurred in the tailrace channel.

From 1969 to 1971, BC Hydro undertook a major rebuild of the Jordan River hydroelectric project. This included upgrades to Bear Creek and Diversion Dams, construction of Elliott Dam and Headpond, construction of a new tunnel and penstock from Elliott Dam to a new powerhouse built on the west side of the river 800 m upstream of the West Coast Highway bridge crossing (Figure 1). The new powerhouse contains a single large 170 MW generator capable of discharging up to 65 m^3/s into the Jordan River downstream of the tailrace. With these upgrades, operation of the powerhouse changed from supplying a base-load to the power grid, to supplying a peak-load, providing energy to the power grid during periods of heavy electrical demand (BC Hydro 2003). Fisheries benefits associated with the original tailrace channel and its consistent baseflow provided by the powerhouse, were replaced by a 30 m concrete tailrace and much more variable flows associated with the new powerhouse configuration.

The rebuild of the Jordan River project and change to peaking plant operation have had a number of adverse consequences to fish and fish habitat (detailed in Burt 2012, Burt and Hill 2015). Decommissioning of the old tailrace channel removed 500 m of copper-free water from production. Peaking operation of the new plant has resulted in a fluctuating flow regime in the reach downstream of the tailrace, and the turbine discharges of up to 65 m^3/s have flushed away spawning gravels that were historically important for pink and chum spawning. Construction of Elliott Dam reduced the supply of spawning gravels to downstream reaches, and resulted in no flows being released below the dam except when spilling was required during flood events. The lack of flows from Elliott Dam resulted in a dry channel in the first 800 m downstream of Elliott Dam, and disconnected flows for much of the remaining lower river. In the reach immediately upstream of the new generating station, discharges dropped to 10 – 12 L/s (0.010 – 0.012 m^3/s) during summer base flow periods (Burt and Hudson 2008, 2009).

A stipulation of the Water Act Orders for the Jordan River Generating Station was that Elliott Dam be outfitted with a pipe to provide flow releases to downstream reaches for fisheries purposes. This modification to Elliott Dam occurred in two phases. Phase 1 involved insertion of an upper section of pipe through the upstream face of Elliott Dam. This was completed during a maintenance period in 2004 when the headpond was drained. Phase 2 was completed in January 2008 and involved installation of the downstream pipe section, pneumatic gate valve, and flow meter (BC Hydro 2008). The first flow releases from the pipe commenced on January 16, 2008 (Burt and Hudson 2009).

The Orders issued for the Jordan River Generating Station included maintaining a year-round minimum discharge of 0.25 m^3/s from the release pipe. However, due to problems with the pneumatic valve, and concerns with the valve tripping (which would result in valve closure and subsequent loss of fish flows), the release valve has been maintained in a locked open position since its installation. In this configuration, flow releases at the dam are determined by headpond elevation and have generally cycled between 0.30 and 0.40 m^3/s as Elliott Headpond is drawn down and then refilled from Diversion Reservoir.

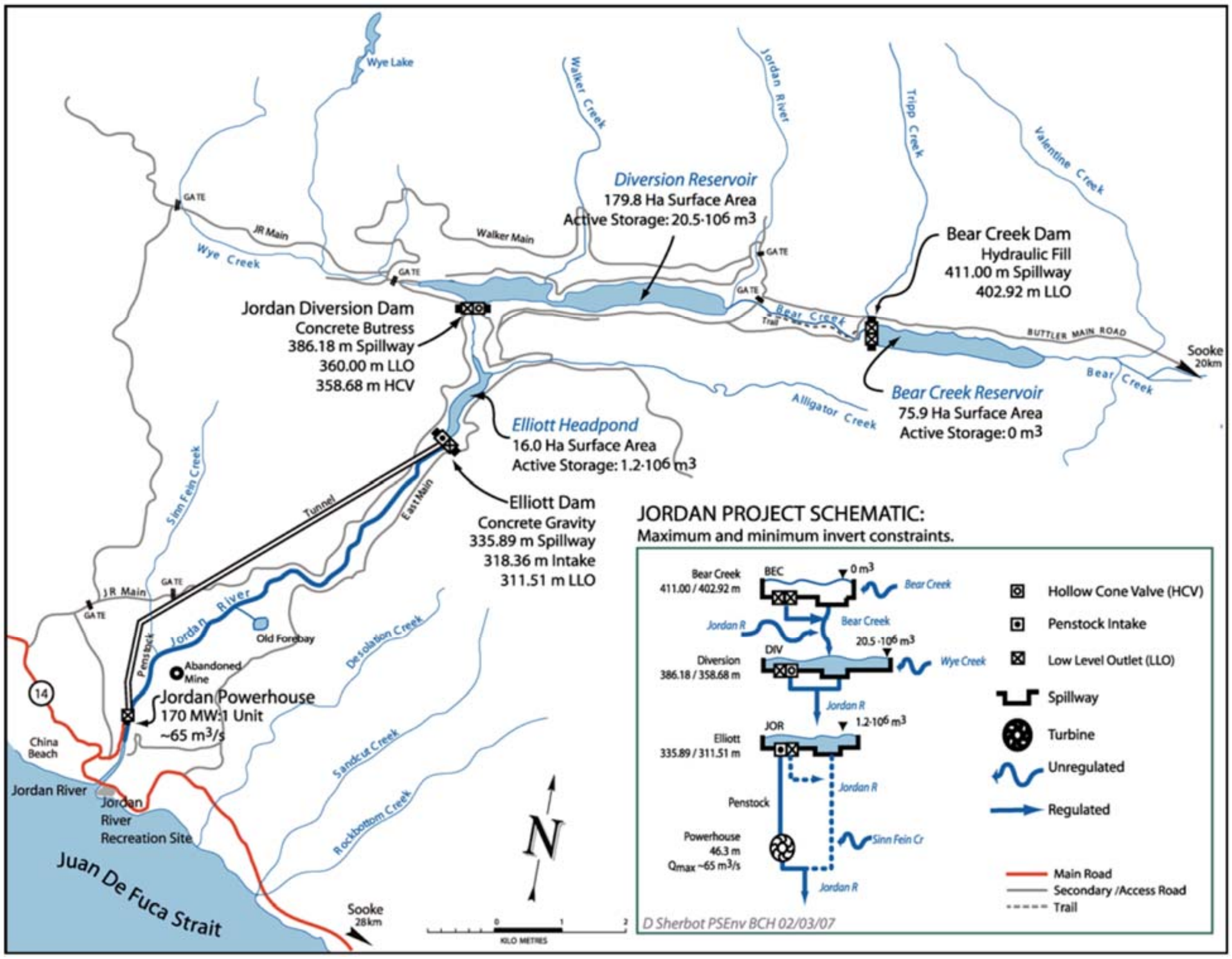

Figure 1. Map of the Jordan River Watershed showing BC Hydro facilities (from BC Hydro 2003).

2.2 Non-Hydro Activities in the Watershed

Forestry and mining are the two main non-hydro activities in the watershed that potentially influence the fisheries productivity in the Lower Jordan River.

Logging operations have occurred in the Jordan River Watershed since the 1880's (Wright and Guimond 2003). Possible impacts from forest harvest activities include destabilization of tributaries resulting in increased sediment supply, and increased flashiness in flows during rainfall events due to reduced water retention. In the lower 350 m of the river, construction of the dryland sort (late 1960's) on salt marsh habitat, combined with log booming and periodic dredging have undoubtedly reduced the productive capacity of the estuary with adverse consequences for anadromous species that rely on these habitats prior to marine migration. Loss of estuarine habitat, and dredging/booming activities were referenced in the Jordan River Water Use Plan discussions as possible contributors to the declines in salmon runs (BC Hydro 2002).

Copper mining operations occurred periodically in the Jordan River from 1919 to 1977. The actual mine site was located underground below the old BC Hydro Forebay (Figure 2). Access to the mine was upgraded by construction of a 2.4 km tunnel from 1956 to 1958. The portal for the tunnel was located on the east side of the river 400 m upstream of the current BC Hydro powerhouse. Material from excavation of the tunnel, including copper seams encountered, were deposited in an 80 m long pile along the river bank adjacent to the portal entrance. During a flood event in December 1963, the roof of one of the adits northwest of the old Forebay collapsed resulting in the river flowing into the mine and down the tunnel. Debris carried by the flows caused a blockage in the tunnel and the pressure buildup resulted flows erupting to the surface 800 m from the portal. Repairs were made to the adit roof and access tunnel; however, further cave-ins within the access tunnel in January 1977 prompted the BC Ministry of Mines to order closure of the tunnel. This was achieved by installing a rock plug in the tunnel at the mill room entrance.

Impacts from copper mining activities have been substantial. Most significant has been the leaching of copper into the river from the waste pile adjacent to the portal (probably since tunnel excavation in 1956–58). Lab analysis of water samples showed that the river immediately upstream of this section of bank is free of copper, while waters adjacent and downstream of it have elevated levels of copper (Burt 2012). Prior to the flow release, no juvenile salmonids could rear in the copper affected zone, while rearing fish occurred immediately upstream of this bank material. Because this deposit is situated near the top of the anadromous portion of the river, the majority of river length available to anadromous species was unsuitable for rearing. Thus, anadromous species with a freshwater rearing phase (coho salmon, steelhead trout, and anadromous cutthroat trout) could not complete their life history and sustain an ongoing population. This situation changed dramatically after initiation of the Elliott Dam fish flow releases in 2008. The additional water has provided sufficient dilution of copper to alleviated rearing issues and greatly improved the quantity and quality of rearing habitat. The dilution effect of the Elliott Dam fish flow releases, and the positive response of rearing salmonids are described in the synopsis of Monitor 2 – Fish Index – Lower Jordan River.

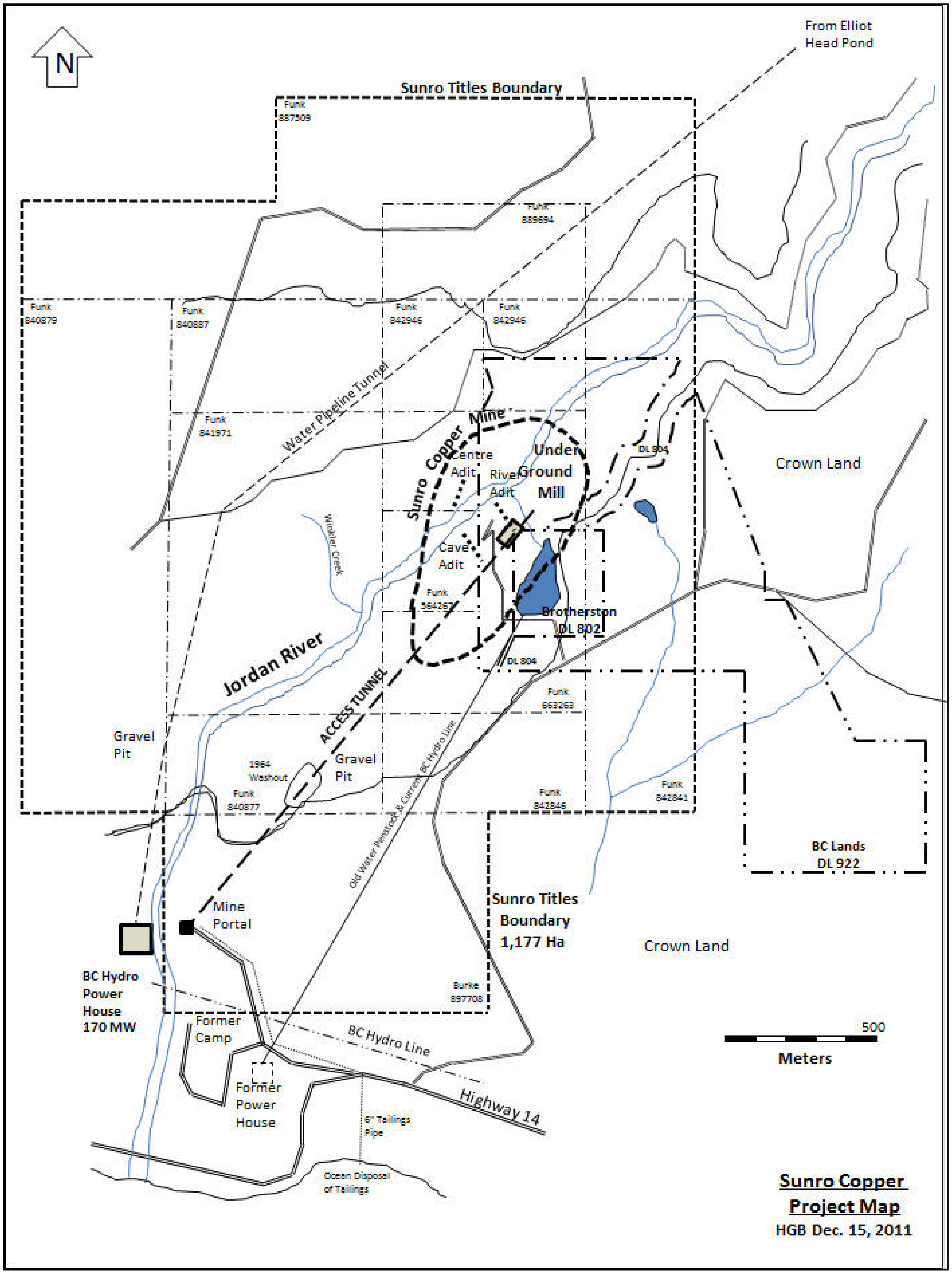

Figure 2. Location and features of the Sunro Copper Mine on the Jordan River.

Another impact from copper mining activities was that tailings from the underground mill room were pumped via pipe to a discharge site in the ocean 1 km southeast of the Jordan River mouth. Anecdotal comments from First Nation Elders suggested this practice impacted intertidal fauna for 3 km on either side of the outfall (Recreation Resources 2001a).

In 2014, the Ministry of Environment issed an ordered for the undertaking of a Site Risk Classification on areas affected by copper on the lower Jordan River. The landownder, Western Forest Products, and Teck Resources Ltd. took on the task of implementing this assessment and results were reported in (SNC-Lavalin Inc. 2016). Three main sources of copper contamination were identified: 1) the waste pile described above (termed north waste rock pile by SNC-Lavalin), 2) the south waste pile on the east bank of the river 200 m downstream from the tunnel portal, and 3) water discharging from the tunnel portal. These results triggered follow-up investigations entailing a Detailed Site Investigation and Remediation Plan. These works are currently ongoing and scheduled for completion in late 2018 with implementation of the preferred remediation plan in 2019 (Steve Hilts, Teck Resources, pers. comm.).

2.3 Fisheries Resources

Anadromous Species

The following is an abbreviated version of information given in the Jordan River Water Quality Report (Burt 2012). Hirst (1991) reported that the anadromous reaches of the Lower Jordan River once supported runs of coho salmon (*Oncorhynchus kisutch*), chum salmon (*O. keta*), and pink salmon (*O. gorbuscha*), while Griffith (1996) found that Provincial records show that steelhead (*O. mykiss*) and sea-run cutthroat trout (*O. clarki clarki*) were also once present. Fisheries and Oceans escapement records for the Jordan River are intermittent with many years reported as "no data" or "not inspected". Nevertheless, years with data demonstrate that the lower reaches of the Jordan River once supported sizeable runs of coho, chum, and pink salmon (Figure 3). These early abundances are consistent with levels of production described by T'Sou-ke Nation elders (Recreation Resources Ltd 2001a).

Coho and chum salmon were present in the very first escapement records (1936) with annual spawner estimates of about 750 coho and 1500 chum (Figure 3). Coho numbers first declined in 1951, then dropped to just 25 fish from 1954 to 1965, followed by no fish observed from 1966 on. Chum salmon returns followed a similar pattern with an initial decline in 1951 and then no fish observed beginning in 1958. The rather abrupt loss of these runs in the 1950's was likely due to the copper contamination discussed in Section 2.2, exacerbated by the mine blowout in December 1963, which resulted in large accumulations of gravel in the lower end of the river, and subsequent use of this material to create the dryland sort.

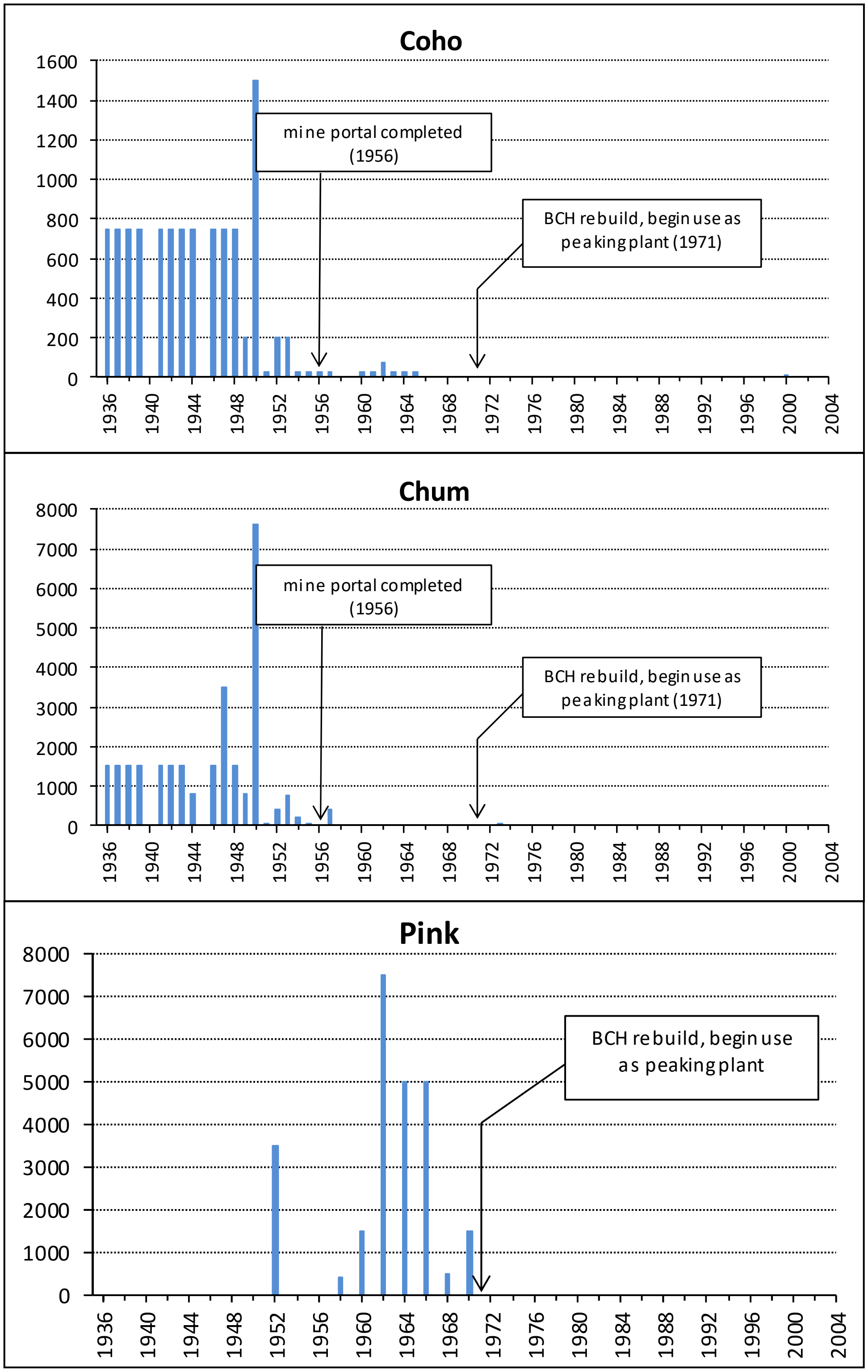

Figure 3. Escapement estimates for the Jordan River, 1936–2004. Sources: 1936–52 (Hirst 1991); 1953–2004 (nuSEDS database, DFO 2011).

In the case of pink salmon, returns do not appear in the escapement records until 1952 (though this may be in part a function of late timing of river surveys). The records show 8 years with pink returns (1952–1970), all on even years, with a mean escapement of roughly 3000 fish based on years with escapements (Figure 3). These fish were reported to spawn mainly in the 500 m long tailrace channel, though some spawned in the first 500 m of the mainstem in some years (Hirst 1991). Runs of this species disappeared in the same year that BC Hydro moved operations to the west side of the river, and has been attributed to decommissioning of the tailrace channel, along with fluctuating flows and scour of spawning gravel in the mainstem from peaking operation of the new power plant (Burt 2012, Hirst 1991).

In recent years, there has been a reappearance of small numbers of adult coho, chum, and pink salmon, as well as steelhead and sea-run cutthroat trout returning to the anadromous reaches of the Jordan River. Information on the status of adult salmon returns and spawning success is reviewed in the synopsis of the Monitor 3 – Salmon Spawning Assessment and Enumeration study below.

Resident Species

Resident species reported in the Jordan Watershed include rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*O. clarki*), and threespine stickleback (*Gasterosteus aculeatus*). Lotic (riverine) habitats are occupied mostly by rainbow trout while lentic (lakes and reservoirs) habitats support populations of both species (BC Hydro 2000, Griffith 1996). Threespine sticklebacks are report to occur in Bear Creek Reservoir (BC Hydro 2000). The presence of rainbow and cutthroat trout in Bear Creek Reservoir is supported by a Provincial stocking program. The majority of lotic habitat in the Lower Jordan River occurs below Elliott dam, and experienced significant flow diversion following hydroelectric redevelopment in 1971. Leakage flows from Elliott Dam were insufficient to provide continuous wetted habitat throughout the lower reaches of the Jordan River and were the subject of considerable discussion in the Water Use Planning process (BC Hydro 2002).

3. JORDAN RIVER WUP PROCESS

The Jordan River Water Use Plan (JOR WUP) process was implemented over a 3-year process starting in 2000 which followed the Water Use Plan Guidelines developed by the province (Province of British Columbia 1998). The process created the following outputs (in chronological order):

- Jordan River Consultative Committee Report (BC Hydro 2002) – documentation of the structured decision making process which evaluated operating alternatives against objectives represented by the Consultative Committee, and documented uncertainties that would define the study program for implementation following WUP approval.
- JOR WUP (BC Hydro 2003) – submitted by BC Hydro to the Comptroller of Water Rights as the summary of operating constraints and implementation commitments (studies and physical works) to be appended to its Water Licenses.

- Jordan River Facility Order (Comptroller of Water Rights 2004) – the Water Act Order issued by the Comptroller of Water Rights (CWR) to implement the Water Use Plan as a condition of the 5 licenses associated with the Jordan River projects.

- Water License Requirements (WLR) (Monitoring) Terms of References (BC Hydro 2004) – for monitoring studies Ordered by the CWR, management questions and methodologies were prepared to address uncertainties defined in the WUP consultative process and submitted to the CWR for Leave to Commence.

- WLR Physical Works Terms of Reference (BC Hydro 2006) – for the physical works (Elliot Dam flow release mechanism) Ordered by the CWR, statement of objectives and project plans were submitted to the CWR for Leave to Commence.

- Study progress reports and Annual watershed reports – reports summarizing annual data collection results for ordered studies were prepared and watershed activities were summarized each year in a watershed report and submitted to the CWR. All reports were published to the web: http://www.bchydro.com/about/sustainability/conservation/water_use_planning/vancouver_island/jordan_river.html

The operating conditions for the Jordan River Hydroelectric System Ordered by the CWR are shown in Table 1. In addition, the CC felt there was uncertainty of the benefits associated with the following operating conditions. (BC Hydro 2003):

- Changes in flows downstream of Elliott Dam.
- Modifying the minimum level of Diversion Reservoir.
- Altering turbine discharges for recreational surfing on weekend days in March.

Table 1. Operating conditions recommended by the WUP for the Jordan River Hydroelectric System (from BC Hydro 2003).

System Component	Constraint	Time of Year	Purpose
Bear Creek Reservoir	BC Hydro shall not operate the low level outlet in a manner which drafts the elevation below 411 m.	All year	Reservoir productivity; recreation
Diversion Reservoir	Minimum normal elevation of 376 m	1 July – 30 Sept.	Reservoir productivity and reduced fish stress
	minimum normal elevation of 372 m	1 Oct. – 30 June	
	BC Hydro shall not operate the reservoir below the stated minimum elevations. In low water situations, when the reservoir elevation is expected to drop below the normal minimum operating level, BC Hydro shall notify the appropriate federal and provincial agencies and proceed with providing a 0.25 m^3/s flow below Elliott Dam.		
Elliott Headpond	No operating constraints	All year	Reservoir productivity

System Component	Constraint	Time of Year	Purpose
Elevations			
Elliott Dam Outlet	Base target flow of at least 0.25 m³/s with an accepted deviation to 0.225 m³/s.	All year	River ecosystem health
Turbine Discharge	BC Hydro shall plan to operate the generation with a discharge of not greater than 30 m³/s from 6:00 am to 6:00 pm on a minimum of 4 weekend days during the month of March. Higher releases are permissible when required to manage basin inflow, or in emergency situations.	March	Recreational surfing

To address the above data gaps and uncertainties in the Jordan River WUP, the CWR Ordered the undertaking of 5 monitoring programs, to assess whether anticipated benefits from changes to operation of the Jordan River Hydroelectric System were actually achieved. Results from these monitors were to be reviewed upon completion, and used to provide information needed to determine whether the Jordan River WUP Order needed further changes. As above, the required studies and physical works were implemented under BC Hydro's Water License Requirements program according to the following terms of references:

- JORWORKS-1 – Water Release Mechanism at Elliott Dam (Physical Works): design and plan for the installation of a fish-water release valve in Elliott Dam to enable a minimum flow release of 0.25 m^3/s into the Lower Jordan River.
- JORMON-1 – Lower Jordan River Inflow Monitoring: 6-year monitoring program to assess the performance of modelled flows used in the minimum flow decision relative to measured flows in the Jordan River below Elliot Dam.
- JORMON-2 – Fish Index – Lower Jordan River: 6-year monitoring program to assess the performance of the minimum flow decision using fish abundance and fish condition as performance measures.
- JORMON-3 – Lower Jordan River Salmon Spawning Assessment and Enumeration: 6-year monitoring program to assess spawning success of salmon in the anadromous reach of the Lower Jordan River.
- JORMON-4 – Diversion Reservoir Fish Indexing: 6 year monitoring program to assess the impacts of extensive drawdowns on Diversion Reservoir rainbow trout condition factor and water quality.
- JORMON-5 – Monitoring Surfing Quality below the Jordan River Generating Station: 6-year monitoring program to assess the performance of generation constraints on surf quality.

4. ORDERED PROGRAM SUMMARY

4.1 JORWORKS-1 – Water Release Mechanism at Elliott Dam

The Ordered installation of a water release valve at Elliott Dam to provide a minimum flow release of 0.25 m^3/s or greater was initiated in 2006 and completed in 2008. The completed valve has the capacity to release between 0 and 0.375 m^3/s, and was designed to regulate the valve opening relative to headpond elevation in order to maintain a constant flow. The January 2008 implementation of the minimum flow was one year later than scheduled under the Jordan River WUP monitoring program. The delayed implementation timing did not undermine the study effectiveness, as the comparison of biologic response using 3 years prior/3 years post flow implementation still adequately described flow effects.

Flow regulation through the valve was intended to be powered using onsite electrical sources, but emergency backup power was not installed until 2010. To ensure minimum flow compliance in the event of a power failure at the Elliott Dam, the valve needed to remain fully open until back up power was installed. While not in use, valve regulation controls became corroded and were not functional when backup power was installed. As a result, the valve has released an average of 0.35 m^3/s during the 3 years of monitoring that followed valve installation.

Repairs to the control valve are currently awaiting the results of the Jordan River Water Use Plan Order Review deliberations, which will likely determine the necessity of such repairs to meet intended WUP flow objectives for the Lower Jordan River.

4.2 JORMON-1 – Inflow Monitoring Study

The Jordan River CC's recommendation for a flow release at Elliott Dam was based on a modelling exercise, which predicted that a 0.25 m^3/s rate of release, combined with estimated tributary inflows below the dam, would provide a target amount of rainbow trout rearing habitat in the Lower Jordan River during the month of August (the lowest flow month). Rearing habitat was gauged using a parameter termed weighted usable area (WUA), which in turn was a function of local discharge (Q). Thus, for a given section of river (x), the amount of habitat (WUA) was a function of inflows between Elliott Dam and that section, plus flows released at the Elliott Dam. This relationship can be expressed as follows:

$$WUA_{(x)} = f\,(Q_{Inflow(x)} + Q_{Release})$$

Development of the above model was based on depth and velocity data collected on 29 transect on the Lower Jordan River at 4 different flow regimes ranging between 0.4 and 9.2% of the mean annual discharge[1] (Cascadia Biological Services 2001).

In addition to rainbow rearing habitat expectations, the prescribed flow release was anticipated to result in an additional 3 km of wetted stream length in the channel immediately downstream of Elliott Dam.

The CC identified two main uncertainties associated with the above WUA and wetted stream length expectations. First, no flow gauging stations were present on the Lower Jordan River and so tributary inflows were estimated using BC Hydro inflow records for upstream reservoirs, and the ratio of drainage area below Elliott Dam to drainage area for upstream reservoirs. This exercise modelled mean daily discharge for the river immediately upstream of the tailrace for the period 1967 to 1998 (32 years). The second uncertainty was whether a significant portion of the 0.25 m^3/s release would be lost to subsurface conveyances.

The Lower Jordan Inflow Monitoring program (JORMON-1) was implemented to address these flow uncertainties. The primary management questions identified in the terms of reference (BC Hydro 2007) for JORMON-1 were:

1) How accurate were the local inflow estimates used in the WUP recommendations?
2) What are the reasons for differences, if any, between the monitored inflows and those estimated by the WUP?
3) What implications, if any, do measured inflows from monitoring have on the WUP recommendations?

Methods and Implementation

The Inflow Monitoring Program was conducted over 6 years from November 2005 to September 2011. Annual reports were compiled for each study year and the 6th year report summarized results for all 6 study years and addressed the management questions listed above. All 6 reports are available via BC Hydro's WUP website:

http://www.bchydro.com/about/sustainability/conservation/water_use_planning/vancouver_island/jordan_river.html.

The Inflow Monitoring Program was implemented by installation of 3 gauging stations on the Lower Jordan River mainstem, and one station on Sinn Fein Creek. Locations of these gauging stations are shown in Figure 4. Each station was outfitted with a water level transducer connected by insulated cable to a data logger above the high water mark. The loggers were programmed to record water level at 15-minute intervals, and recorded data were downloaded at 3–4 month intervals. Each

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[1] Mean annual discharge (MAD) was taken as 13.7 m^3/s.

of the mainstem stations was equipped with a permanent staff gauge to provide quick visual identification of water level, and to serve as a fixed reference for validating the logger records.

Discharge measurements were undertaken at each station during the first three years of the study. Gauging was performed using salt dilution methods as described in Hudson and Fraser (2005). These data were combined with associated water levels to construct a relationship between stage and discharge (rating curve) for each station. Rating curves were fitted using the Chapman Richards asymptotic exponential curve (Sit 1994). JMP statistical software was used to generate best-fit curves.

Since stream gauging was only undertaken at low to moderate flows, the rating curves were only applicable to the range of gauged discharges. For higher flows, BC Hydro total release data for Elliott Dam (spillway + fish flow releases) and estimates of local inflows were paired with station water level data to construct high flow rating curves.

Results

As summarized in section 4.1, since initiation of the fish flow releases at Elliott Dam in January 2008, tripping concerns resulted in the control valve being locked in the full open position as opposed to being controlled by the valve mechanism. This has resulted in fishwater releases greater than the 0.25 m^3/s prescribed in the WUP. Under this configuration, releases are dependent on the water elevation in Elliott Headpond. During summer baseflow periods, it was found that release flows generally cycle up and down between roughly 0.30 and 0.40 m^3/s as Elliott Headpond was drained and then refilled by releases from Diversion Reservoir.

The following summarizes key findings of the Inflow Monitoring Program:

1) The modelled flows constructed for the Jordan WUP overestimated actual inflows to the lower river during summer baseflow periods. The amount of overestimation was calculated to be up to 289% for the months of June through September. For the month of August (the month used for the WUA calculations), the WUP estimates estimated a mean monthly flow of 0.160 m^3/s compared with 0.055 m^3/s measured in the monitoring program.
2) This overestimation was due to an assumed minimum summer base flow in the WUP modelling that was about 6 times greater than actual summer base flows.
3) Another relevant finding was that there appeared to be an immediate loss of a portion of the release flow to subsurface conveyances. The data indicated that this loss amounted to 0.03 –0.05 m^3/s during base flow periods. Thus, under the prescribed release of 0.25 m^3/s, the “inriver” flow below the dam would be reduced to 0.20 – 0.22 m^3/s. This would directly influence the ability of the flow release to achieve the WUA objective, and could potentially affect the objective for flow connectivity in the lower river as tested in JORMON-2.

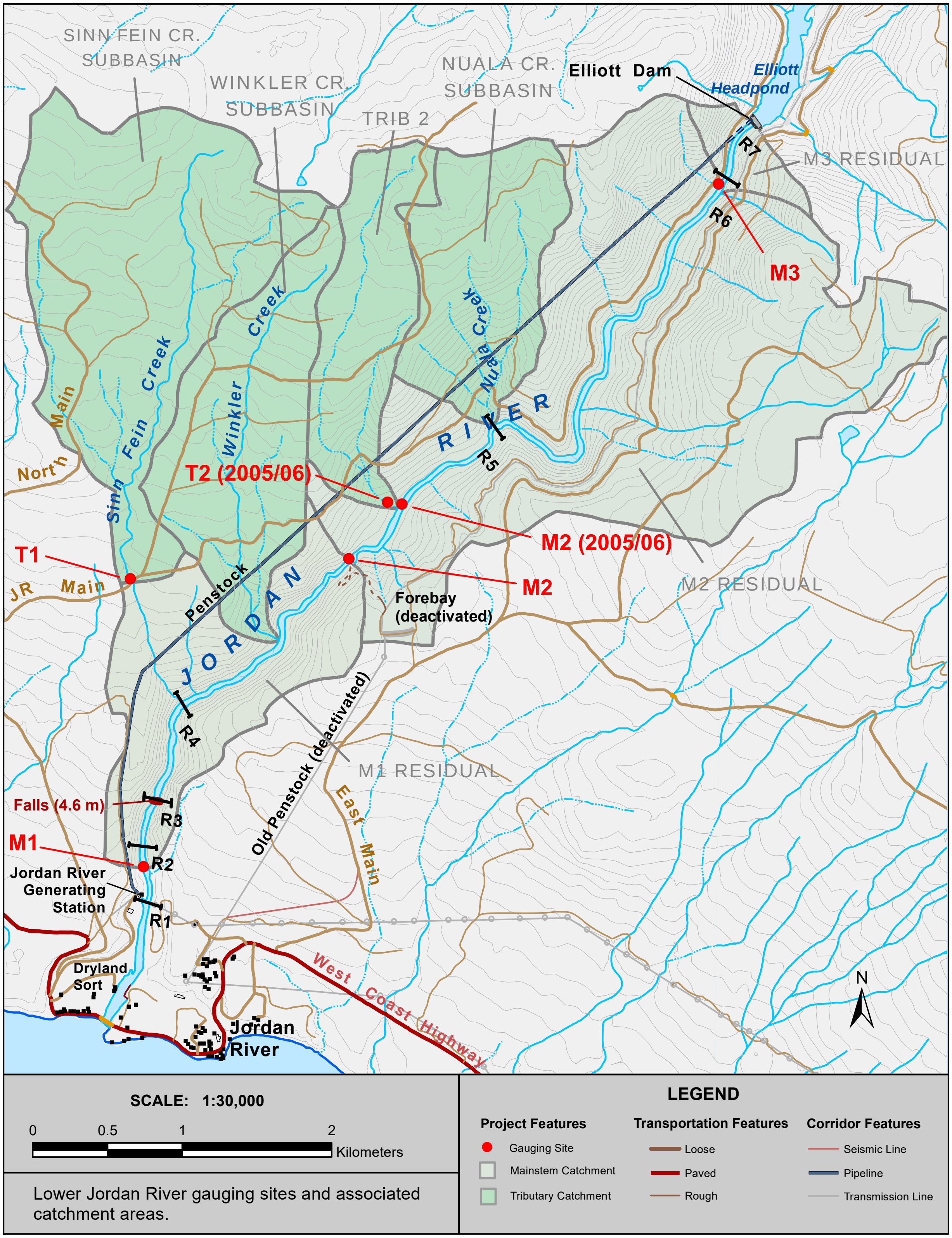
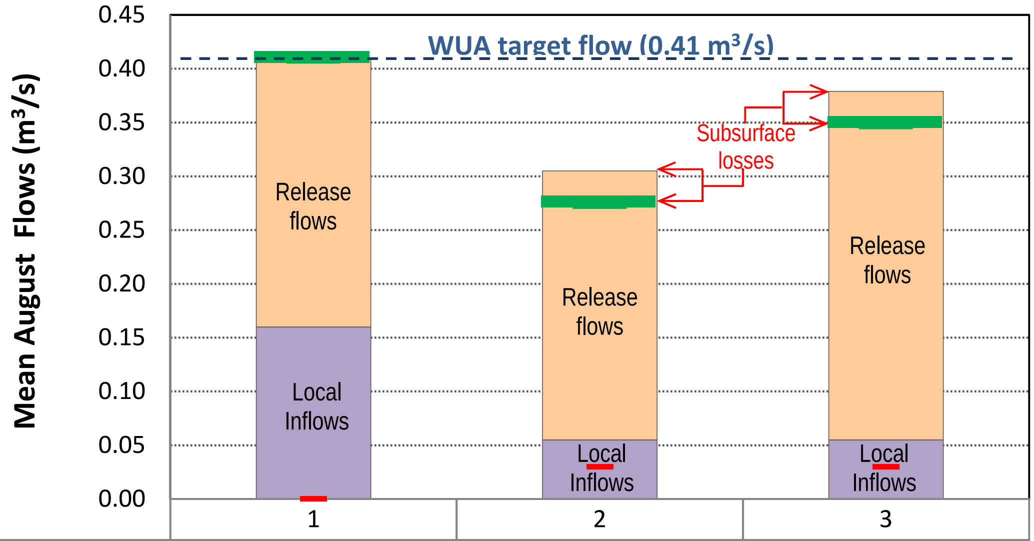


Figure 4. Map of the Inflow Monitoring Program study area showing gauging stations and catchment areas.

Implications

These findings have significant implications for the Jordan WUP. The above results indicate that the mean August flow upstream of the tailrace under the prescribed release is anticipated to be 0.265 m^3/s (0.055 m^3/s from finding 1 above + 0.21 m^3/s from finding 3 above). This is 0.145 m^3/s less than the WUP target of 0.41 m^3/s for the lower river (0.25 m^3/s prescribed in the WUP + 0.16 m^3/s assumed WUP August base flow). To achieve the WUP target flow and the associated level of rearing WUA, the prescribed release at Elliott Dam would have to be increased to 0.395 m^3/s.

Despite these findings, actual flows experienced in the river since the flow release have been close to the WUP target due to the control valve in the release pipe being locked in the full open position. Under the "fully opened" configuration, release flows are dependent on the water elevation in Elliott Headpond and generally cycle up and down between 0.3 and 0.4 m^3/s as the headpond is systematically drained and then refilled. Figure 5 illustrates the three flow scenarios discussed here: 1) WUP inflow estimates, prescribed flow release, no groundwater losses; 2) inflow estimates by this study, prescribed flow release with groundwater losses; 3) the current flow situation (inflow estimates by this study, current average flow release with groundwater losses). The current scenario (Scenario 3) shows that the locked-open gauged releases come close to achieving the WUP minimum flow objective of 0.41 m^3/s despite subsurface losses and lower than predicted local summer inflows.



	1	2	3
🟧 Release flows	0.250	0.250	0.324
🟪 Local Inflows	0.160	0.055	0.055
– Subsurface losses	0.000	0.030	0.030
– Resultant lower river flow	0.410	0.275	0.349

Figure 5. Comparison of water balance for the month of August as predicted by: 1) the Jordan WUP, 2) from the Inflow Monitoring Program with a 0.25 m^3/s release, and 3) from the Inflow Monitoring Program under current average flow release from Elliott Dam (note: the release flow of 0.324 m^3/s is the mean August flow for years 2009 – 2011 as measured by the gauge in the release pipe).

4.3 JORMON-2 – River Fish Index Study

The prescribed flow release of 0.25 m^3/s at Elliott Dam was selected in part, from modelling of the relationship between stream discharge and weighted usable rearing area for rainbow trout (BC Hydro 2004). Due to the theoretical nature of this exercise, monitoring was warranted to validate biological benefits predicted by the modelling. The management questions to be addressed by the study, as outlined in the terms of reference, were:

1) Does the flow release restore habitat continuity (i.e. are all habitat units connected by flowing water)?
2) How will the planned flow releases affect the standing stock of the rainbow trout population?
3) How will the planned flow releases affect the distribution of fish condition (weight to length) by age within the rainbow trout population?

The specific objectives of the of the Fish Index Study were to assess the biological benefits of the fish flow release using 3 performance measures (PMs): 1) rainbow trout standing stock, 2) rainbow trout condition factor, and 3) continuity of habitat (BC Hydro 2004). These three performance measures were assessed annually in the three years prior to the flow release (2005 – 2007), and then in the three years after initiation of the flow release (2008 – 2010).

The monitoring program included annual fish sampling, habitat inventories and environmental water quality monitoring in part to assess possible dilution benefits of the flow release on copper contamination to Lower Jordan River from past mine activities.

Unless cited otherwise, the information presented for this monitor are from the final year report (Burt 2013).

Methods

As with all JOR WUP monitors, this study assessed fish and habitat metrics 3 years prior and 3 years post Elliott Dam fish flow releases. While the terms of reference prescribed an assessment of the effectiveness of a 0.25 m^3/s flow release, the study was limited to assessing the results of the actual flow releases, which varied from 0.3 – 0.4 m^3/s during the 3 years of post-assessment.

Fish sampling was conducted annually near the end of the growing season (September) at 15-17 index sites distributed along the Lower Jordan River between the Elliott Dam and the generating station tailrace (Figure 6). The lower 4 sites were within the anadromous portion of the river, while the remaining sites were above the anadromous barrier. Sampling was by electrofisher and employed either 3-pass or 1-pass removal techniques. Each pass involved 2 circuits through the site with the electrofisher. If required, sites were isolated using stop nets to prevent fish immigration\emigration. After each pass, fish were identified, measured for length, and weighed. Estimation of the fish population within 3-pass sites relied on computer software which generated maximum likelihood estimates (MLE). For 1-pass sites, a regression relationship between catch in pass 1 and the MLE population estimate for 3-pass sites was used to estimate the population size. Condition factor was calculated for each fish from length and weight measurements inserted into Fulton's condition factor equation (Anderson and Neumann 1996).

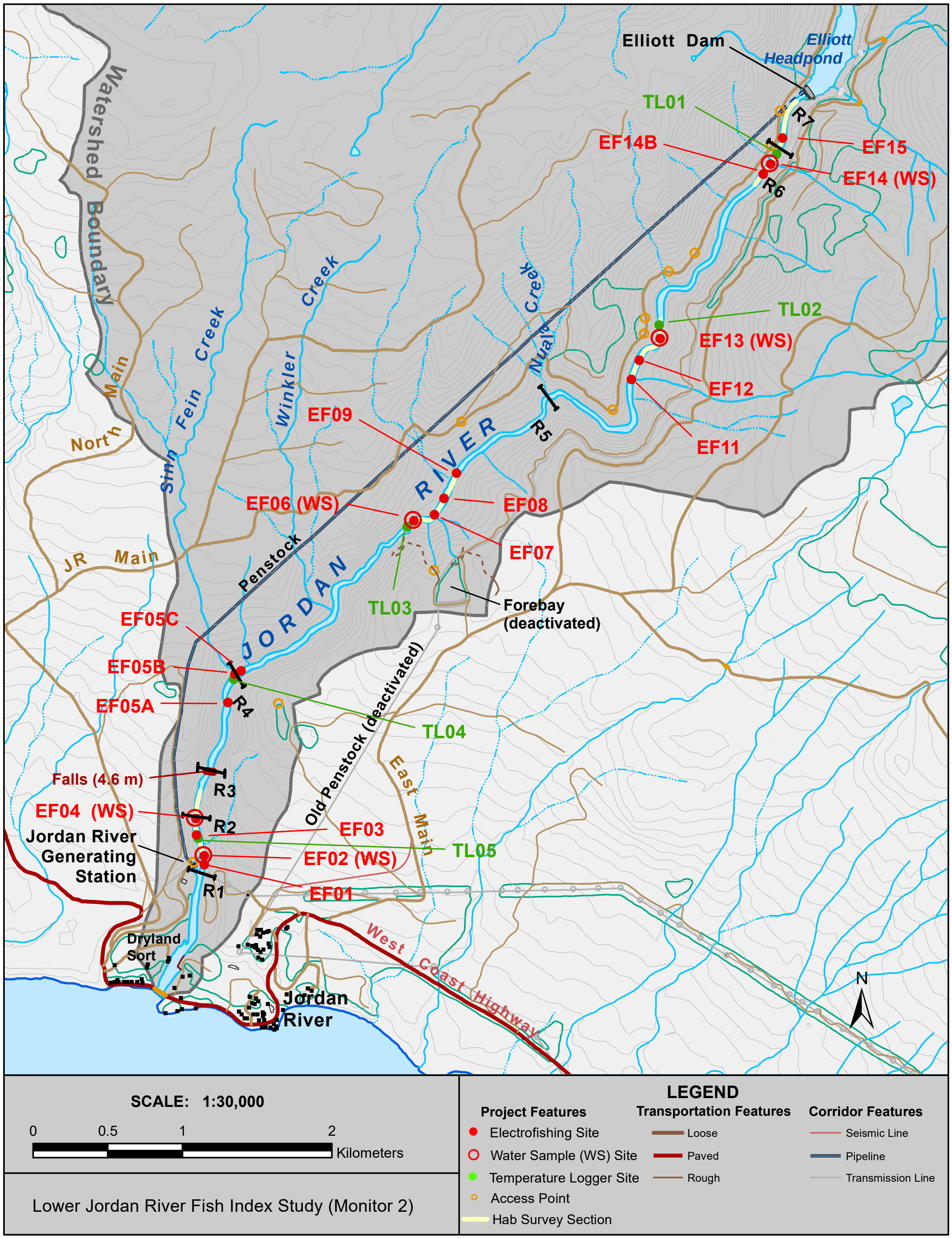


Figure 6. Map of the Fish Index study area showing locations of electrofishing index sites (EF01-EF15), water temperature monitoring sites (TL01-TL05), water sample sites, and habitat survey sections. Reach designations shown (R1-R7) were consistent among the 5 monitors.

For the habitat component, 6 index sections were inventoried ranging in length from 181 m to 511 m. Locations of these sections are shown in Figure 6. Habitat surveys involved walking each stream section with a running hip chain and assessing each habitat unit for type, length, depth, wetted width, mean velocity, substrate composition, and fish cover.

Environmental monitoring was conducted at 5 index sites (shown in Figure 6). Continuous water temperature data were collected using Tidbit temperature loggers, while spot measurements of the other parameters were collected using hand held meters (pH and conductivity), a titration kit (alkalinity), or by laboratory analysis of water samples collected in the field (copper).

Results

Performance measure 1 (standing stock) was assessed in terms of rainbow trout density by age group, the results of which are summarized in Figure 7. All 3 age groups showed an increase in mean density after the flow release, with age 1^+ and $2/3^+$ age groups showing the most notable increases. While only the difference in the $2/3^+$ age group was statistically significant, the author, felt that failure to show a significant difference in the 1^+ rainbow parr age group was likely a Type II error that would be remedied with additional sampling. These results suggest that the flow release resulted in an increase in standing stock of older age groups of rainbow trout.

Results for performance measure 2 (rainbow trout condition factor) are summarized in Figure 8. For this PM, mean condition factor after the flow release was slightly lower than before the flow release, however, nested ANOVA indicated no significant difference between the means. This suggests that the flow release had no effect on rainbow trout condition factor.

Results for performance measure 3 (habitat continuity) showed obvious benefits from the flow release. The reach immediately downstream of Elliott Dam (Reach 7) was mostly dry before the flow release, but exhibited continuous flows after the release. In fact, no subsurface flows were found in any of the survey sections after the flow release. Furthermore, prior to the flow release, riffle habitats often had only seepage flows during the summer and this was felt to restrict upstream/downstream dispersal of trout. After the flow release, these habitats were well wetted and no longer an impediment to fish dispersal. In terms of quantifiable habitat changes, the flow release increased wetted stream length by 771 m, while wetted area increased by an average of 85%. Riffle habitats, which are typically the main zones of aquatic invertebrate production, increased from an average of 6.1% of wetted area before the flow release, to 15.5% after the flow release.

Results from the environmental monitoring found that dissolved copper (mg/L) in the impacted zone went from a range of 0.04 – 0.085 before the release, to 0.007 – 0.015 after the release. The biological response in the copper affected zone was significant in that rearing trout were found at all sites in this zone (perhaps for the first time in decades), and their condition factor was similar to fish upstream of the impacted zone. These results suggest that the dilution factor from the flow release was successful in reducing copper concentrations below a critical rearing threshold.

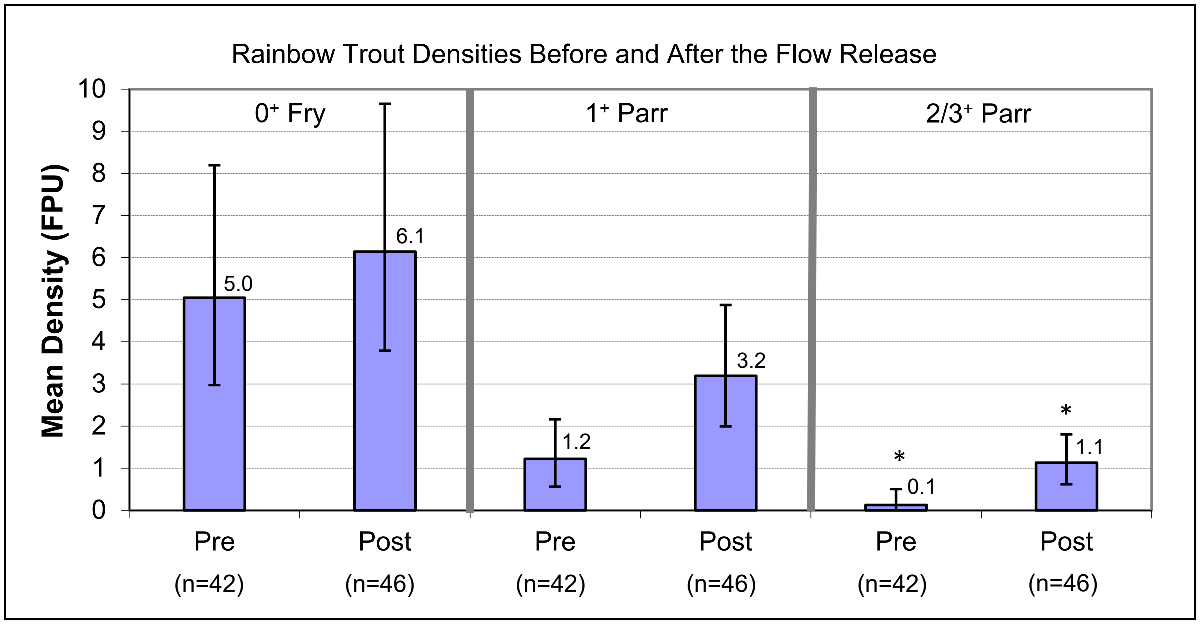


Figure 7. Geometric mean density (fish/100 m^2) of rainbow trout before and after the flow release. Data are segregated by age group. Pre flow release years = 2005 – 2007; post flow release years = 2008 – 2010. Error bars represent 95% confidence limits using a pooled variance; asterisks indicate means that are significantly different; and "n" refers to the number of sites per group.

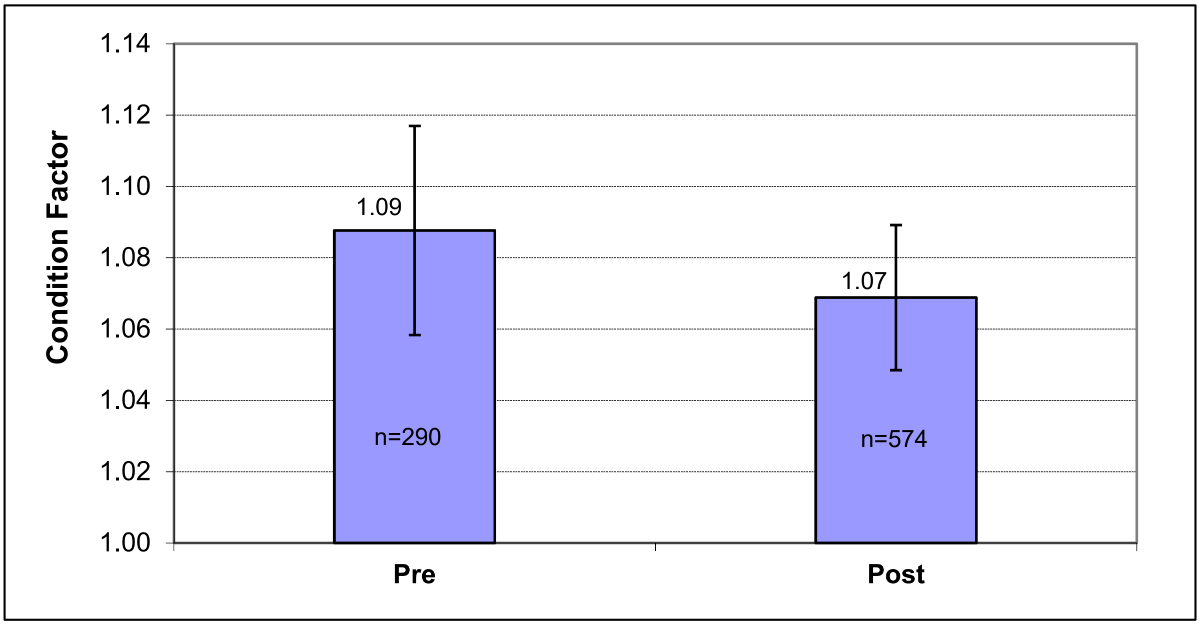


Figure 8. Condition factor of rainbow trout before and after the flow release. Means are arithmetic based on fish sampled during 2005 – 2010. Error bars are 95% confidence limits using a pooled variance; "n" indicates the sample size for each group.

Implications

The results of this monitor provide evidence that the flows released from Elliott Dam resulted in:

1) Greater quantity of rearing habitat and alleviation of disconnected habitat issues.
2) An increase in standing stock of older age groups of rainbow trout.
3) Sufficient dilution of the copper in the anadromous reach to allow fish to successfully rear within this zone.

The lack of a response in rainbow trout condition factor is not surprising. It appears that increases in rearing habitat and food production after the flow release were met with increased trout abundance leaving the influence of density-dependent factors on condition factor unchanged.

It must be emphasized that the benefits listed above are based on a flow release of 0.3 – 0.4 m^3/s and not the initially prescribed release of 0.25 m^3/s. It is uncertain whether the benefits achieved under the current release would be sustained if reduced to the initial WUP prescription of 0.25 m^3/s.

4.4 JORMON-3 – Salmon Spawning Assessment and Enumeration

The anadromous portion of the Jordan River is just under 1.6 km in length and contains three distinct reaches (Burt 2012). Reach 1 is 920 m in length and extends from the mouth to the first riffle upstream of the generating station tailrace (Figure 6). This reach is influenced by tidal cycles as well as sudden changes in flow associate with power generation at the Jordan River Generating Station. Reach 2 is 340 m in length and extends from the top of Reach 1 to a partial barrier rock falls. This reach contains high quality rearing habitat and pockets of spawning habitat, however, at the time of the WUP development, all but the upper 20 m was unusable for rearing due to copper toxicity (Burt 2006, 2012). Reach 3 is 320 m in length and extends from the partial barrier at the top of Reach 2 upstream to a 4.6 m rock falls, considered to be a complete barrier to anadromous migration.

The Jordan WUP CC acknowledged that only a short length of the Lower Jordan River was accessible to anadromous species, and that existing habitat for these species was impaired by a number of factors, including copper toxicity from mine activities, flow alteration from BC Hydro operations, loss of salt marsh habitat from creation of the log sort, and degradation of estuarine habitat from booming operations. Furthermore, at the time the Jordan WUP was developed, there were no sustaining anadromous salmonid populations in the river (BC Hydro 2002). For these reasons, the flow requirements for anadromous species were not considered in the WUP. However, it was agreed that the provision of a base flow might be adequate to a) improve effective incubation habitat for anadromous species, and b) provide sufficient dilution of copper to allow anadromous fish to rear in the zone impacted by copper leachate. Further, if the 0.25 m^3/s flow augmentation resulted in improvements to anadromous habitat conditions, then anadromous values may be more prominent in future Jordan River flow management decisions (BC Hydro 2004). To test for these outcomes, the

Jordan WUP CC recommended a monitoring program to assess for signs of successful spawning, incubation, and rearing by anadromous species following initiation of the flow release at Elliott Dam.

The management questions defined in the study terms of reference were:

1) Will the planned flow releases improve spawning habitat for spawning salmon and steelhead in the anadromous reaches of the Lower Jordan River?
2) Will the planned flow releases improve effective incubation habitat for salmon and steelhead that spawn in the anadromous section?
3) What effects, if any, do the planned flow releases have on chronic toxicity affecting rearing and incubating salmonids?

The primary objective of this monitor was to determine whether the prescribed flow release improved spawning and incubation success of salmon and steelhead within anadromous reaches of the Lower Jordan River. The question on effects of the flow release on chronic toxicity to rearing salmonids was better addressed by JORMON-2. Performance measures selected to assess potential benefits to spawning and incubation were 1) number of adult salmon spawners observed in the study area, and 2) survival rate of *in situ* salmon eggs. The first performance measure was to be assessed by annual snorkel counts in the years before and after initiation of the flow release. The second performance measure was to be assessed either by hydraulic sampling of natural redds, or by planting incubators within existing gravel beds. An additional task was to quantify available spawning habitat and assess whether the flow release resulted in more favorable depths and velocities in these habitats.

Methods

Activities for this monitor focused on Reaches 2 and the first 230 m of Reach 3 (Figure 9). Performance Measure 1 (PM1, spawner enumeration) was completed by conducting snorkel surveys during coho and steelhead spawning periods. For coho salmon, this involved 5 surveys between September 21 and December 21 of each study year. For steelhead trout, 3 surveys were conducted between April 15 and May 31 of each study year. Given that the flow release commenced in January 2008, the coho surveys captured 3 years of pre-release data (fall 2005 – fall 2007), and 3 years of post-release data (fall 2008 – fall 2010). The steelhead surveys captured 2 years of pre-release (spring 2006 – spring 2007), and 4 years of post-release data (spring 2008 – spring 2011).

Performance Measure 2 (PM2, incubation success) was assessed by annually planting 3 Jordan-Scotty cassette incubators in 5 gravel sites within Reaches 2 and 3 (Figure 9). Each cassette was loaded with 200 eyed coho eggs from Jack Brooks Hatchery (Sooke, BC). Sites were revisited at the hatch, emergence, and post-emergence stages, upon which one incubator was pulled from each site to assess survival to that stage.

Spawning habitat within the study area was assessed and quantified during stream walks, and locations mapped on orthophotos. Each potential spawning location was also assessed in terms of flows required to keep the habitat wetted.

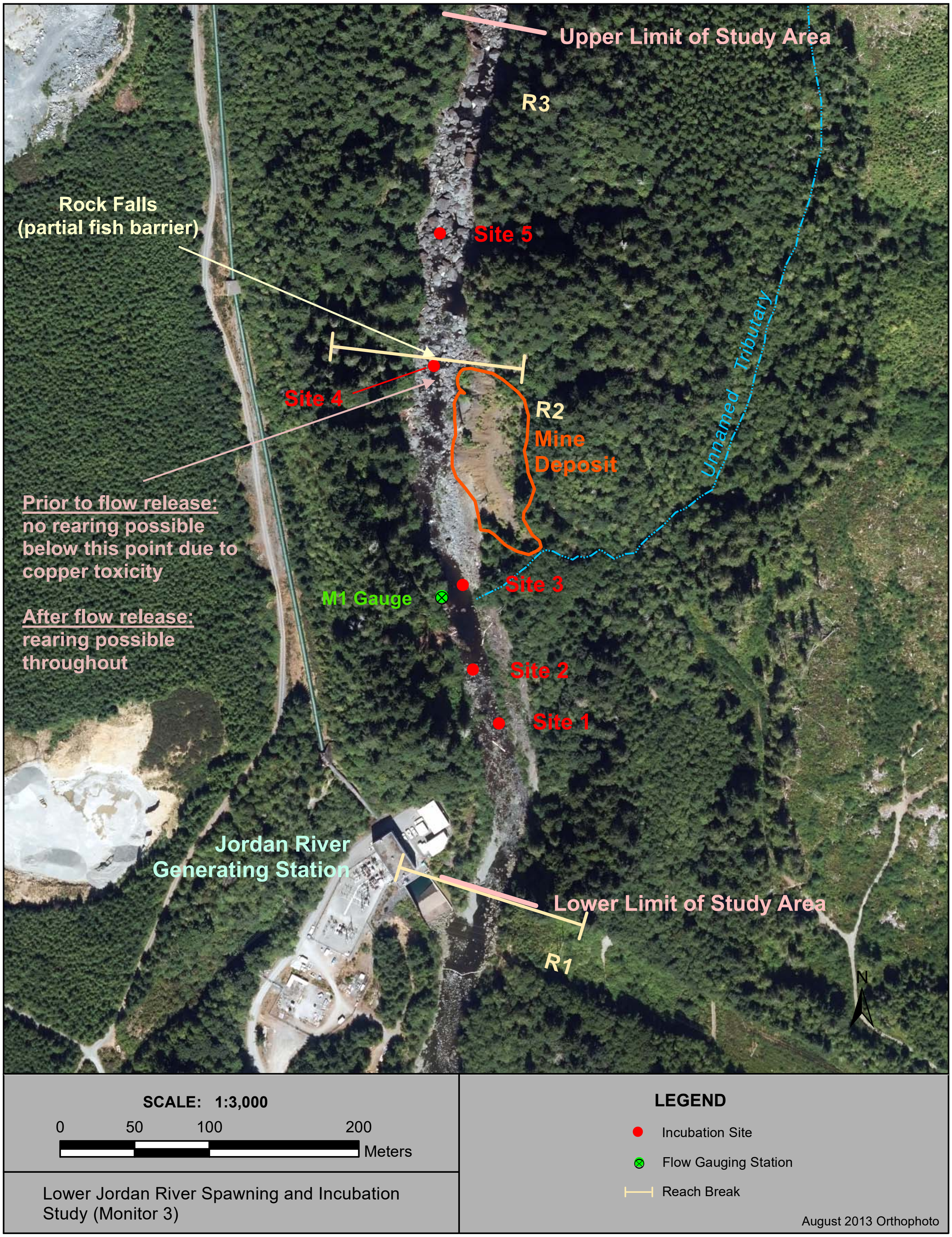


Figure 9. Map of Monitor 3 study area showing locations of incubation sites and local features.

Results

Results from the snorkel surveys are summarized in Figure 10. Chart A shows total salmon counts per study year from the fall surveys, while Chart B shows total steelhead count per study year from the spring surveys. The data for Chart A were expanded to include snorkel surveys conducted from 2013 to 2016 as part of Fish and Wildlife Compensation Program (FWCP) projects (Burt 2014, Northwest Hydraulic Consultants and D. Burt and Associates 2017). In the case of coho, annual total counts ranged from 0 to 4 adults over the 6 years of Monitor 3, while FWCP surveys observed 26 adults in 2014 and 25 adults in 2016. In the case of chum, Monitor 3 only observed this species in 2006 when 13 adults were counted, whereas FWCP surveys observed 6 adults in 2014 and a more sizeable return of 61 adults in 2016. For steelhead, annual total counts ranged from 0 to 2 fish during WUP surveys and were not assessed by the FWCP surveys. Results do not include observations of pink salmon, which have occurred in the past by generating station staff (Dwayne Walsh, Jordan River Generating Station, pers. comm.) and during JORMON-2 activities.

The results in Figure 10 do not show any clear increase in adult abundance within the 3 post flow release years of Monitor 3 (fall 2008 to spring 2011); however, FWCP surveys appear to show an increase in abundance of adult coho and chum salmon in recent years. These improvements may be an indication that benefits of the flow release are beginning to manifest in adult returns. A delay in improvement is not surprising given the finding from JORMON-2 that progeny from successful spawning were unlikely to survive the rearing stage of their life history until summer 2008 when flow releases provided sufficient dilution of copper to allow successful rearing. This, coupled with age of return for coho (generally 3 years), chum (generally 3-5 years), and steelhead (generally 4–6 years), suggests that benefits of the flow release to spawning, incubation, and rearing, would not be expected manifest in adult returns until at least fall 2010.

Results from the incubation component are shown in Figure 11 (combined with earlier incubation studies to expand the dataset). With the exception of Sites 2 and 3 in 2002\03, and Site 3 in 2005\06, egg-to-emergence survival rates were high, generally greater than 90%. These data suggest no significant difference between sites within the copper zone (brown bars) and sites upstream of this zone (blue bars), and no compelling evidence of improved survival after initiation of the flow release in January 2008. For cases with low survival (Site 3), the study authors felt that siltation from a left bank tributary was the most likely cause of the poor survival (in Monitor 3, Site 3 was subsequently moved upstream to avoid this tributary).

Results from the spawning habitat assessment indicated 119 m^2 of potential spawning habitat in Reach 2, and 25 m^2 in Reach 3, for a total of 144 m^2. Of this total, 118 m^2 were estimated to be available at flows of 1.9 – 13.1 m^3/s, with higher flows required to inundate the remaining 26 m^2. At flows in this range, the authors estimated that the additional of a 0.25 m^3/s from the fish release would have minimal effect on increasing available spawning habitat. However, it should be noted that flows of 1.9 m^3/s and greater would not occur until the advent of fall rains. In addition, it is likely that the flow release has improved fish access at the riffle leading into Reach 2, thus substantially increasing habitat availability. The improvements in fish access at this point are shown by the series of photos in Figures 12-14.

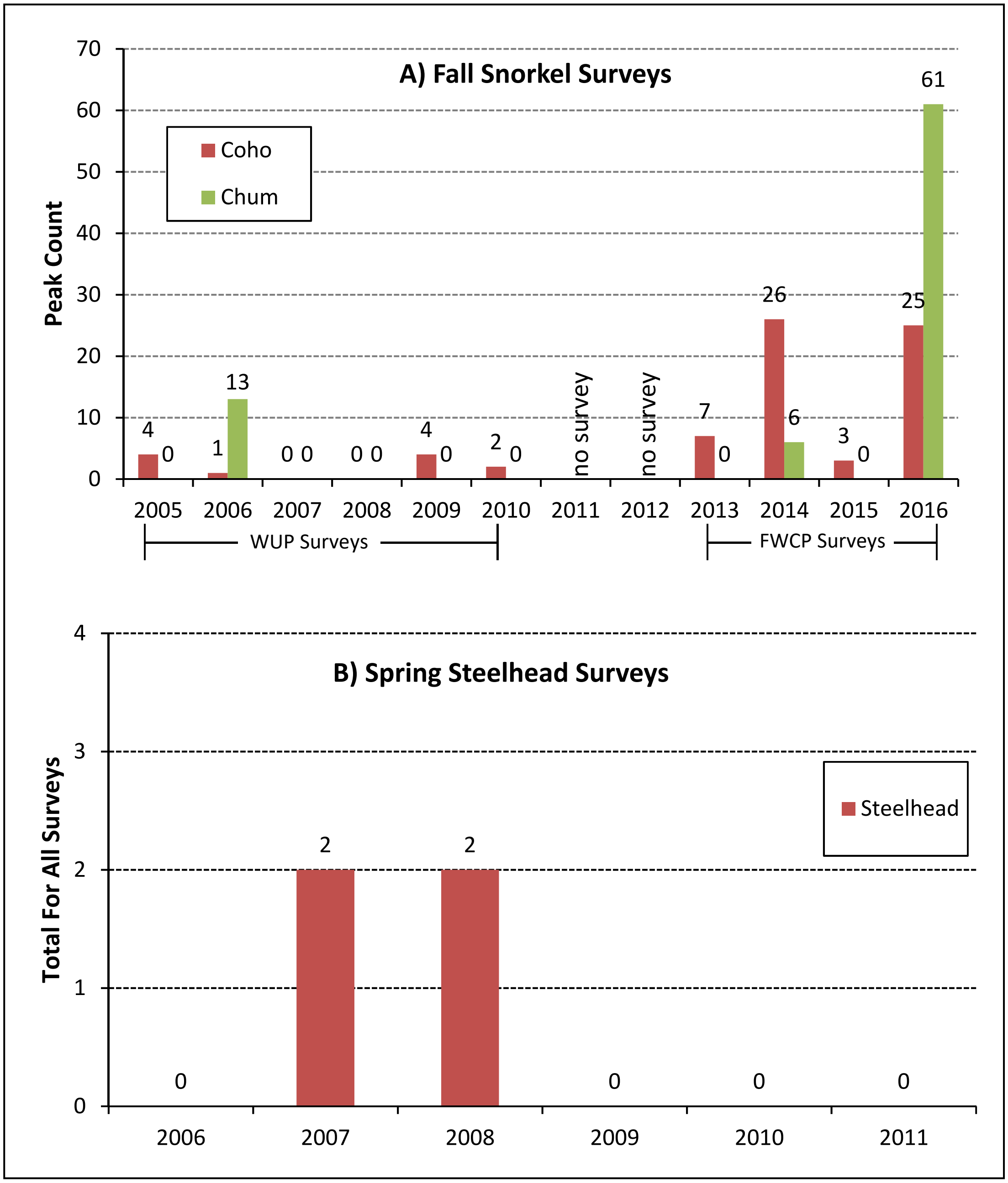


Figure 10. Summary of fall (Chart A) and spring (Chart B) snorkel survey enumerations conducted on Reach 2 of the Jordan River by Monitor 3 (adapted from Cascadia Biological Services 2013). Chart A also includes results from snorkel surveys conducted from 2013 to 2016 by Fish and Wildlife Compensation Program projects (Burt 2014, Northwest Hydraulic Consultants and D. Burt and Associates 2017).

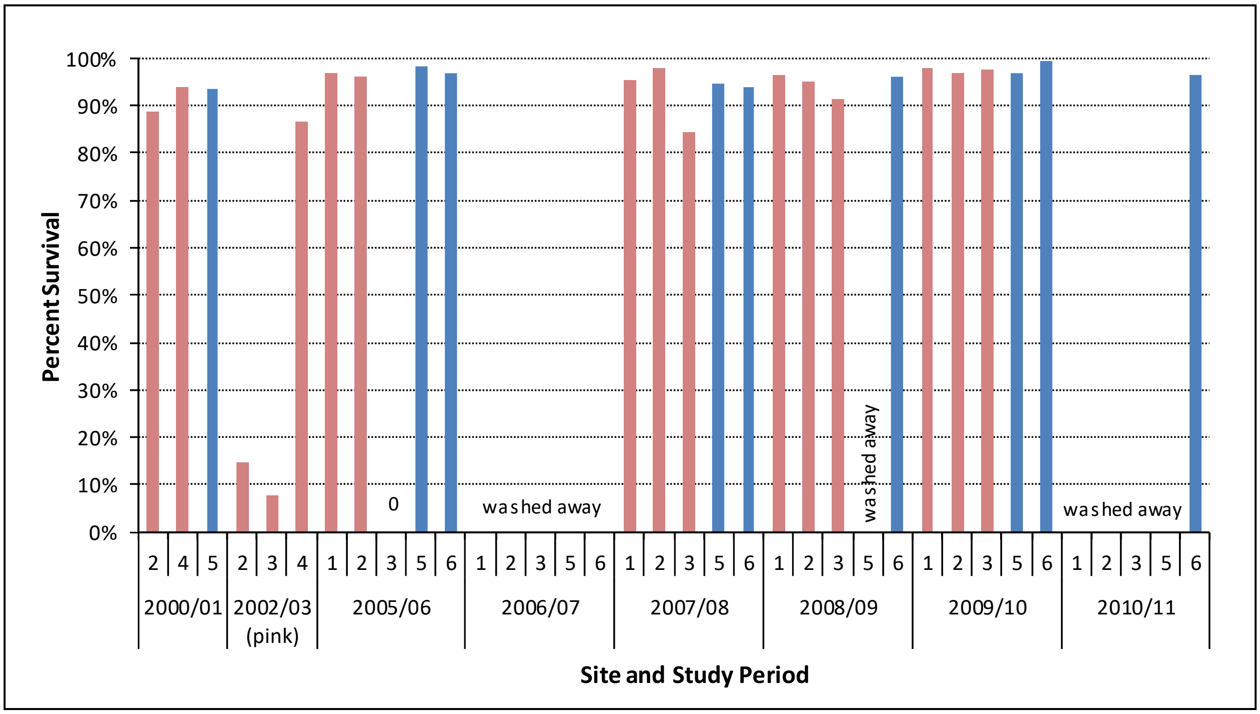


Figure 11. Egg-to-emergence survival from incubation studies conducted in Reaches 2 and 3 of the Lower Jordan River. Tan bars indicate sites in the copper affected zone while blue bars show sites upstream of this zone. Survival rates are for coho salmon eggs, with the exception of 2002/03, when pink salmon eggs were used. Data for 2005/06 to 2010/11 are from Monitor 3 (Cascadia Biological Services 2013), while 2000/01 data are from Lightly (2001), and 2002/03 from Wright and Guimond (2003).

Figure 12. Pre flow release view of the riffle leading from Reach 1 into Reach 2 (Sept. 4, 2006). Discharge at the M1 gauging station was 0.012 m^3/s. At these flows, salmon would not be able to ascend the riffle to gain access into Reach 2 and would be forced to remain in the tidal reach until the arrival of fall rains. This could increase their exposure to turbine flows.

Figure 13. Photo of potential spawning habitat just upstream of the previous photo (view is looking downstream, Sept. 4, 2006). Discharge at M1 was 0.012 m^3/s and statistics for the habitat unit in view included: wetted width 4.3 m, mean depth 8 cm, mean velocity 0.05 m/s.

Figure 14. Photo of the same location Figure 13 but after the flow release (looking downstream, Sept. 6, 2008). Discharge at M1 was 0.425 m^3/s and statistics for the same habitat unit included: wetted width 27.5 m, mean depth 15 cm, mean velocity 0.33 m/s.

Implications

The first management question asked whether the flow release would improve spawning success. Assessment of this question using adult enumeration as the performance measure showed no apparent increase in coho or steelhead spawners during the 2–3 years of monitoring after initiation of the flow release, however, more recent surveys undertaken by FWCP projects indicated that improvements in adult coho and chum returns may be beginning to occur (Figure 10, Chart A).

In terms of improvements to available spawning habitat, the flow release was deemed to have little effect since most spawning occurs after the arrival of fall rains. However, the flow release has visibly improved fish passage into Reach 2, which could assist adults in avoiding turbine flows and improve access to available spawning and rearing habitat.

The second management question asked whether the flow release would improve incubation conditions. The high survival rates found within *in situ* incubators before and after the flow release suggests that a) the flow release had no apparent benefit to incubation success, b) that egg survival was unaffected by ambient copper concentrations, and c) that existing intergravel flows and gravel porosity are favourable for incubation.

The third management question related to whether the flow release would reduce the effects of copper toxicity proximal and downstream of the mine deposit located at the upstream end of Reach 2. As indicated by the incubation trials, coho egg survival appeared unaffected by ambient levels of copper. In contrast, the fish index study (JORMON-2), found that salmonid rearing could not occur in the copper affected zone prior to the flow release, but could occur in this zone after the flow release (see Figure 9). This means that rearing was the critical life stage impacted by copper toxicity prior to the flow release, and that the release has provided sufficient dilution of copper to allow for successful completion of this life stage. The implication is that anadromous species such as coho and steelhead now have the ability to produce smolts from the Jordan River. Further details on changes in copper concentration and associated biological response are described in Burt (2012).

As mentioned in the introduction to this Monitor, management decisions for the minimum flow release from Elliott Dam were focussed on providing improvements to resident fish communities as opposed to anadromous species. However, the CC agreed that “increased anadromous salmonid success associated with the base flow release will influence future water allocation decisions” (BC Hydro 2002, Table 8-1). Results from snorkel surveys suggest benefits of the flow release may be starting to show in the number of adult salmon returning to the river. Similarly, results from JORMON-2 indicate that the current flow release has restored salmonid rearing function to a major portion of anadromous habitat through the dilution of copper and increased summer base flows. These findings suggest that the needs of anadromous fish may require review in the future Water Use Plan Order Review process.

4.5 Monitor 4 – Diversion Reservoir Fish Indexing

Prior to the Jordan WUP, the operating range of Diversion Reservoir was approximately 370 to 386.2 m (BC Hydro 2002). With implementation of the WUP, daily and seasonal constraints were Ordered by the CWR on the extent of drawdown of Diversion Reservoir (BC Hydro 2004). These included:

• 1 July – 30 September	Minimum normal elevation of 376 m
• 1 October – 30 June	Minimum normal elevation of 372 m

The decision to implement a minimum summer elevation of 376 m was based on a biophysical assessment by Griffith (1996) who suggested that excessive drawdown was contributing to low dissolved oxygen conditions in bottom waters of the reservoir, poor water quality conditions in surface waters, and overcrowding of the resident trout population. The Jordan WUP Fisheries Technical Committee (FTC) recognized that data supporting Griffith's assessment were not conclusive, but opted for a risk averse approach (implementation of drawdown minimums), along with a monitoring program to provide more conclusive evidence of the effects of drawdown on the resident trout population.

The hypothesis behind the FTC's recommendation was that a decrease in daily and seasonal reservoir fluctuation, and the overall increase in pelagic volume, would allow establishment of an effective littoral zone, and provide more favorable rearing conditions for resident rainbow trout. Benefits to trout were anticipated to manifest in terms of increased fish condition factor (weight to length ratio). It was assumed that trout condition factor was adversely affected by high temperatures and low oxygen associated with drawdown during the summer.

The primary management questions from the study terms of reference were:

1) What are the benefits to rainbow trout condition associated with a reduced allowable drawdown?
2) What are the impacts on rainbow trout condition associated with a prolonged extensive drawdown?

The objectives of the monitoring program were to evaluate the effects of extensive drawdown on lentic trout using fish condition factor as the performance measure, with collection of limnological data to assist in understanding underlying mechanisms. The study design called for 5 years of monitoring under the WUP drawdown regime (baseline years), followed by a final year with extensive drawdown (treatment year).

Methods

The 6-year field program consisted of 1) the collection of limnology data, and 2) biological sampling of the resident trout population. For the limnology component, two stations were established: Station 1, located in the deepest part of the West Basin and Station 2, located in the deepest part of the East Basin (Figure 15). Activities completed at each station included the collection of water samples from a depth of 1 – 2 m, measurement of Secchi depth, and measurement of water temperature/dissolved oxygen profiles of the water column. Water samples were analysed in the lab for total phosphorous, dissolved phosphorous, and chlorophyll *a*.

For the biological component, fish were captured by floating and sinking gillnets (4 index sites), and by minnow trapping (12 index sites). Locations of gillnet and minnow trap index sites are shown in Figure 15. Sampling performed on captured fish included measurement of fork length and weight, and collection of scales and otoliths for age analysis.

Results

Key results of the Diversion Reservoir Fish Index Study were as follows:

- The first order productivity indicators (Secchi depth, total phosphorous, dissolved phosphorous and chlorophyll a levels) showed significant changes over the course of the 6 study years. Correlation analysis on pooled data suggested an increasing trend in Secchi depth, dissolved phosphorus, and chlorophyll a, while a decreasing trend was found for total phosphorous (Figure 16). Values were generally within the range typical of oligotrophic lakes on Vancouver Island.
- In terms of mean trout condition factor, no significant difference was found between any of the 6 study years (Figure 17). Correlation analysis on pooled condition factor detected a declining trend, but this change was very slight. Thus, the study concluded that there was no significant increase in trout condition in the 6 years with reduced drawdown.
- Trout abundance increased significantly over the 6 study years (Figure 18). It was concluded that trout abundance was a more appropriate gauge of fish response to reduced drawdown than condition factor.
- Despite the lack of a planned experimental drawdown in the final year of study, monitoring of reservoir drawdowns in 2005 and 2008 revealed that excessive reservoir drafting had the potential to directly impinge on critical trout habitat. In 2005 and 2008, the limnological conditions in the reservoir resulted in the trout being "sandwiched" between warm, stress-inducing temperatures near the surface, and an uninhabitable anoxic layer near the bottom. Excessive drawdown under these conditions, can place the habitable layer of water at the level as the hollow cone valve (HCV) intake, potentially drawing off the layer of water upon which the trout are dependent (illustrated in Figure 19).

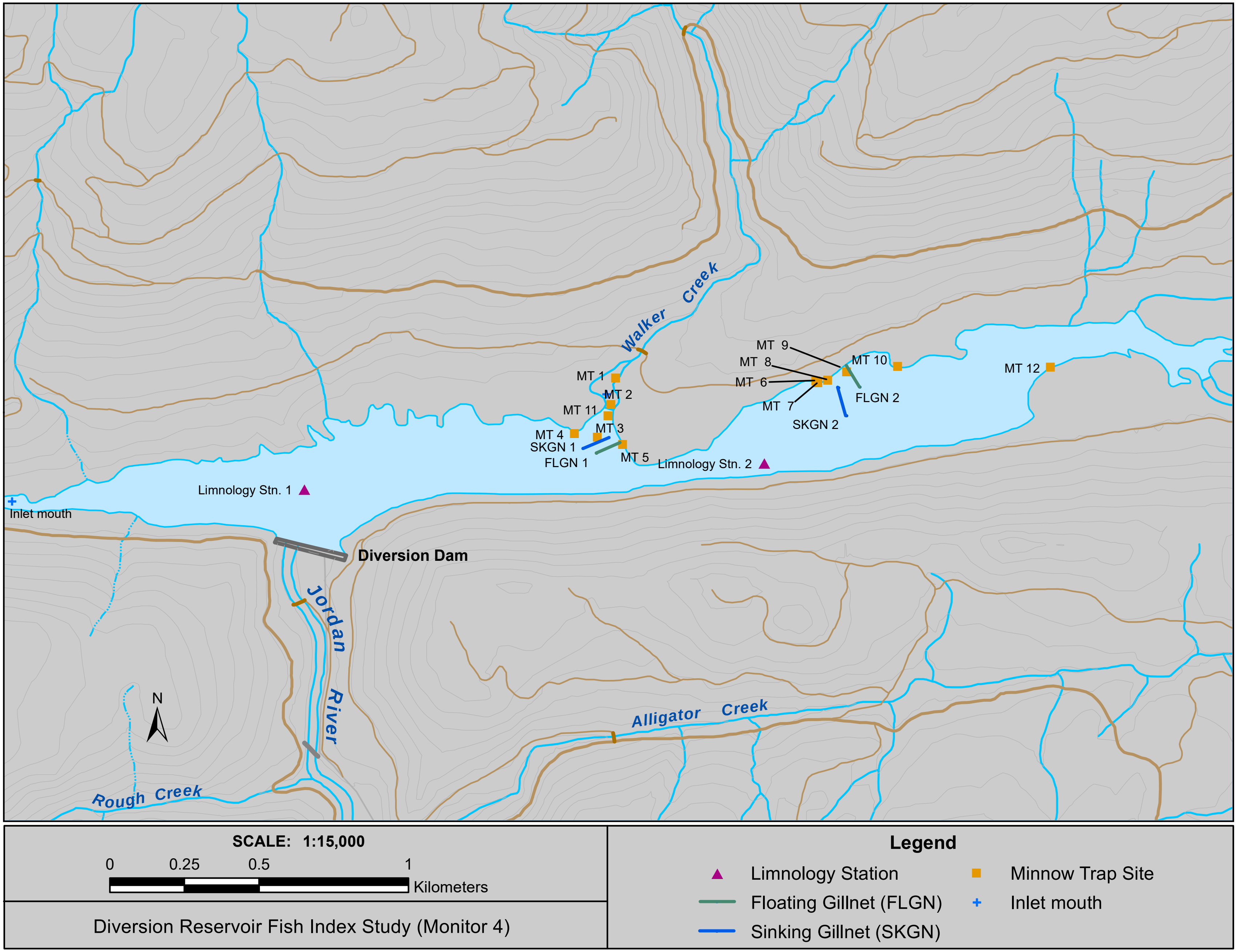


Figure 15. Monitor 4 map showing locations of the 2 Limnology stations, the 4 gillnet sites, and the 12 minnow trap sites sampled annually from 2005 to 2010. Site UTM coordinates were provide by Mike Lough, MJ Lough Environmental Consultants.

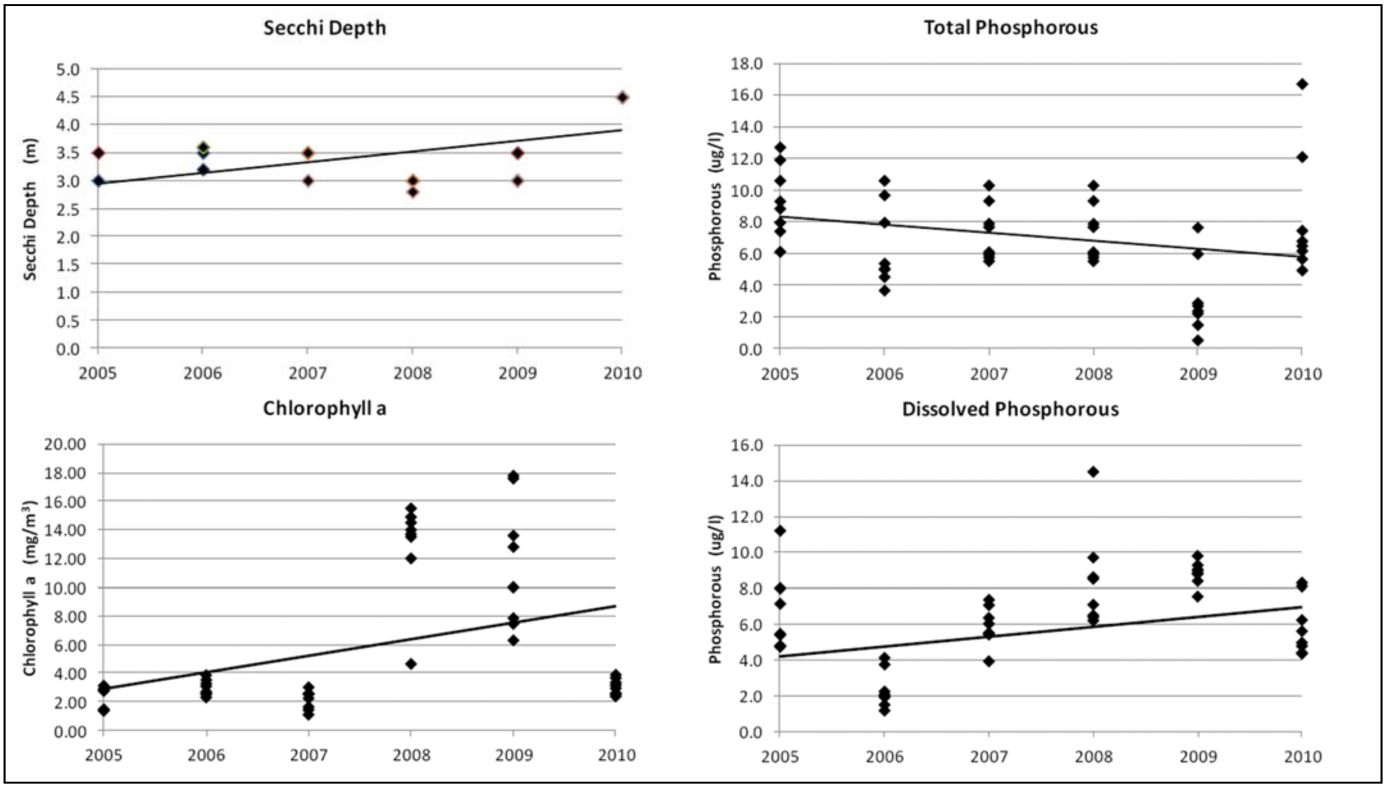


Figure 16. Results for Diversion Reservoir productivity indicators (Secchi depth, total P, dissolved P, and chlorophyll a) over the 6 years of Monitor 4. The fitted trend lines are based on correlation analysis on pooled data. Data are from MJ Lough Enviromental Consultants (2010).

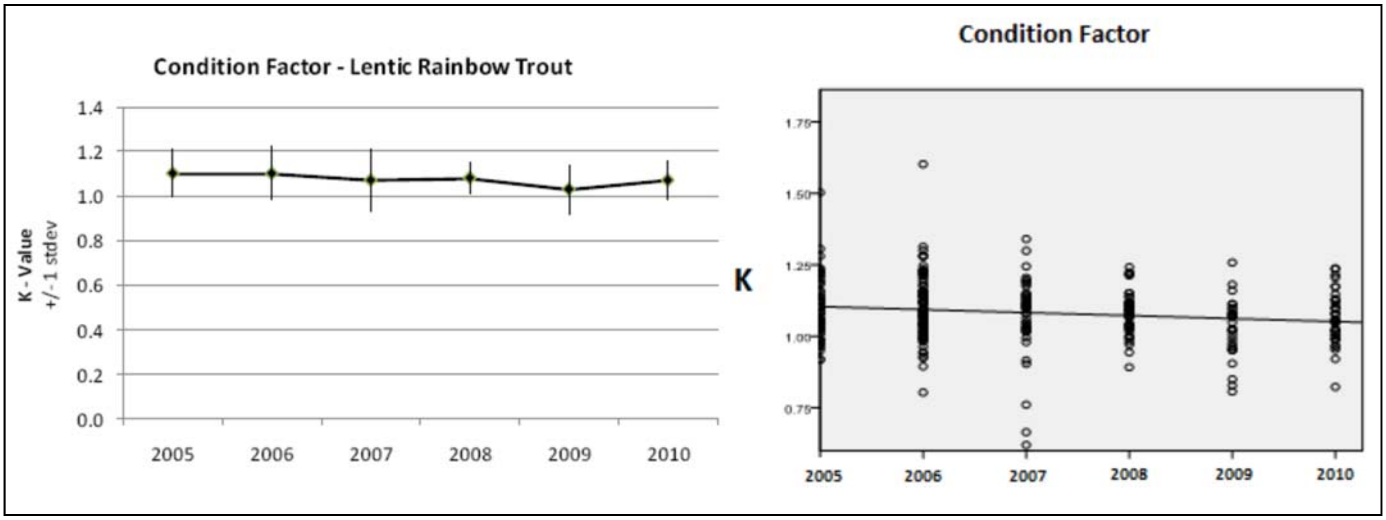


Figure 17. Left: mean annual condition factor (K) for captured rainbow trout, 2005 – 2010. Right: correlation trend in pooled condition factor over the 6-year study period. From MJ Lough Enviromental Consultants (2010).

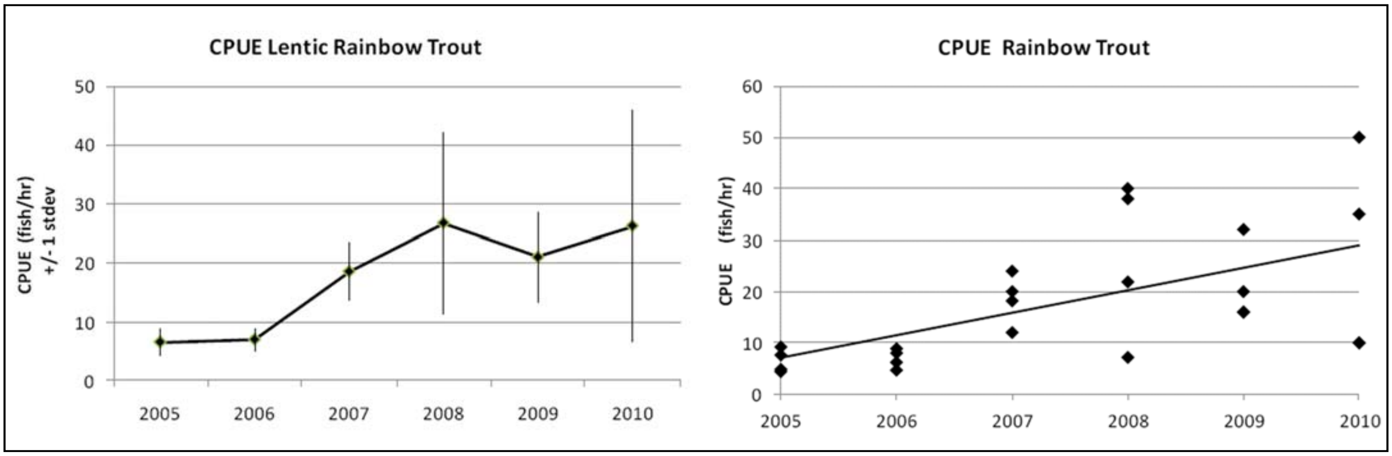


Figure 18. Left: mean catch per effort (CPUE) of floating and sinking gillnets combined. Right: correlation trend for pooled CPUE over the years 2005 to 2010. From MJ Lough Enviromental Consultants (2010).

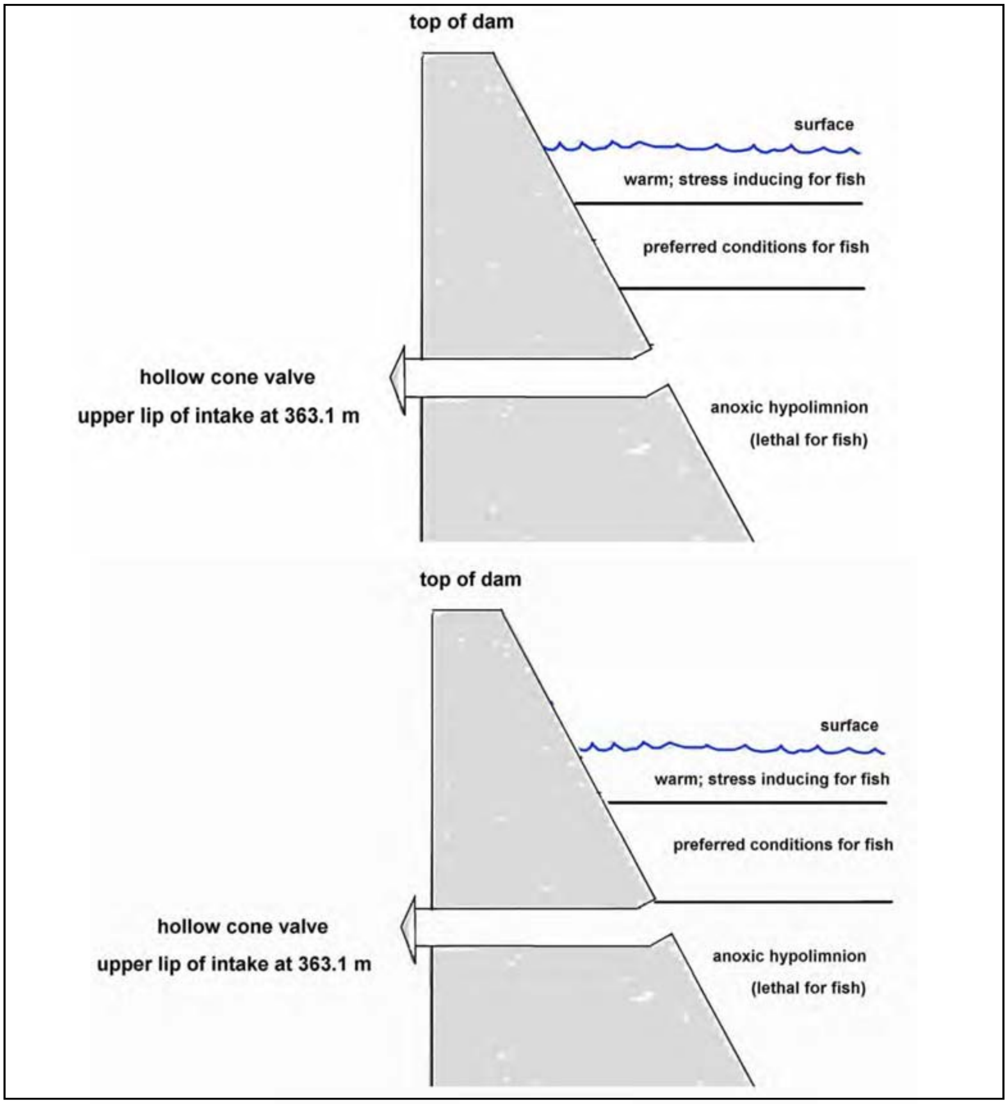


Figure 19. Section view of Diversion Reservoir showing conditions before and after an unscheduled drafting event (Sept. 12–13, 2008).

Implications

This monitor provided 2 important findings that have implications for management of Diversion Reservoir:

- The increase in abundance of rainbow trout (as measured by CPUE) over the 6 years of the study suggests a positive response to the reduced drawdown regime.
- Surveys during drafting events in 2005 and 2008 revealed that severe drawdown during the summer months can lower the mid-water layer of crucial fish habitat to the point where it is drawn off by hollow cone valve releases.

The terms of reference for Monitor 4 indicated that, should trout show no benefit from the drawdown constraints, the restrictions could be revisited for consideration of more flexible operating options. Given the positive response in trout abundance, and the potential for extraction of the critical rearing zone during severe drawdown, study findings do not support revisiting the WUP drawdown restrictions.

4.6 Monitor 5 – Surf Quality Study

The area around the mouth the Jordan River is one of the most popular surf locations on Vancouver Island. Greatest use occurs from October to March. During this “surfing season”, the quality of the surfing experience is variable, and highly dependent on ocean and weather conditions. A surfing survey conducted during the WUP process (Recreation Resources Ltd 2001b), indicated that discharges from Jordan River Generating Station can also affect surfing experience, with high discharges having a negative effect. The survey suggested that high outflows may flatten waves and make it more difficult for surfers to catch a wave. To address this potential issue, the consultative committee recommended that discharges from the generating station be limited to 30 m^3/s or less during the day for 4 weekend days during the month of March, and that a monitoring program (Monitor 5) be implemented to evaluate the effectiveness of the reduced discharge on surf quality (BC Hydro 2004).

As per the study terms of reference, the management question to be addressed by Monitor 5 was:

- How do constraints on generation benefit surf quality at Jordan River?

The objective of Monitor 5 was to assess potential benefits of the generation discharge constraint (30 m^3/s) on surf quality (performance measure). Surf quality was to be based on the response of experienced surfers to a surfing survey questionnaire, which was to be conducted under both constrained and unconstrained generation discharges.

Methods

Surveys were conducted by in-person interviews generally during the month of March when surfer use of the Jordan River tends to be high. A surf questionnaire was used and questions were read aloud and responses recorded. In addition to the surf user survey, number of surfers in the water and their locations were recorded at approximately half hour intervals, along with weather observations at the same intervals. Generation flows for survey periods were acquired from BC Hydro, while hourly weather and tide data were obtained from the internet (www.bigwavedave.ca).

Results

Over the 2006 – 2011 study period, 232 in-person surveys were conducted capturing both constrained and unconstrained generation flows from Jordan River Generating Station. Constrained flows ranged from 0 generation discharge to the 30 m^3/s prescribed by the WUP. Unconstrained generation flows were generally around 51 m^3/s. Fully unconstrained flows (70 m^3/s) did not occur during any of the survey windows and so the study was unable to test surfer response to discharges of this magnitude.

Figure 20 summarises responses to the survey question pertaining to whether Jordan River flows had an effect on surfing quality. The data are the aggregate of all 6 study years and are grouped according to discharge scenario. The bars show response percentages that reported an effect or no effect from Jordan River flows under each discharge scenario.

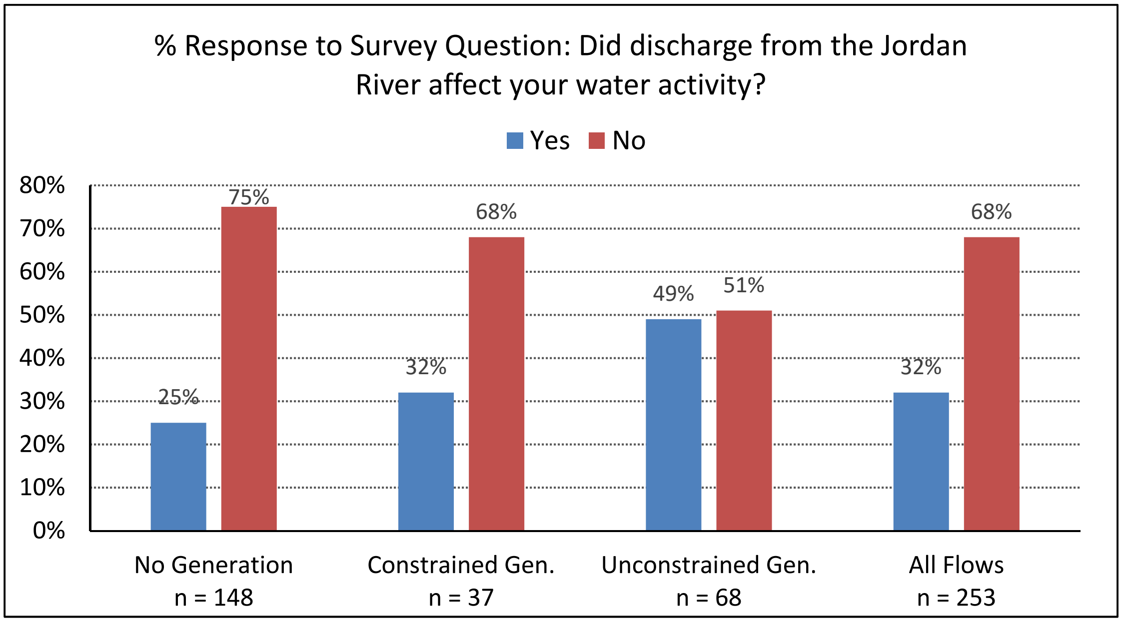


Figure 20. Combined response (2006 – 2011) to the survey question regarding an effect of river flows on surf quality under conditions of no generation, constrained generation, and unconstrained generation. Adapted from Recreation Resources Ltd (2013).

These data suggest a relationship between the magnitude of Jordan River flows and the number of surfers reporting and effect on surf quality. Number of surfers reporting an effect increased from 25% at no generation flows to 49% at unconstrained generation flows (~ 51 m^3/s).

It was concluded from response results that constrained flows can provide more favourable surf conditions but this was generally only detected by experienced surfers familiar with the conditions of the site, and when surf quality was not overridden by other environmental variables (weather, tides, wind, wave height, etc.). As a whole, the majority of users did not report Jordan River discharge to be a factor in their surfing experience, but pointed to other environmental variables as factors affecting surf quality.

Implications

The authors of the study concluded that, while it would be desirable to maintain constraints at times when it contributes to surf quality, the range of environmental conditions that occur at the Jordan River site, and the variability in their nature and occurrence, limit the ability to predict when flow constraints would successfully provide improved surf conditions. Continuation of generation curtailment over weekends during the surf season would need to consider the costs and benefits of the operation in the context of the effects of non-operational variables on surf quality.

5. SYNOPSIS OF MONITOR IMPLICATIONS

For the most part, the 5 studies successfully answered their management questions. In turn, the knowledge acquired from the monitors has implications for future operation of Jordan River facilities. Table 2 summarises key results from the 5 WUP monitors and implications the results have on facility operation.

Table 2. Summary of the 5 monitors and operational implications for the Jordan River facility.

Study	Objectives	Performance Measures	Study Results	Operational Implications
Monitor 1: Lower Jordan River Inflow Monitoring	The release of 0.25 m^3/s at Elliott Dam combined with modelled inflows were predicted to provide a certain level of rainbow trout rearing habitat (WUA). The objectives of this monitor were to assess the accuracy of the modelled inflows and the performance of the fish flow release in delivering the anticipated discharge and additional wetted stream length.	The PM was measured instream flows relative to modelled flows. August was selected as the critical month (month of summer base flows).	1) Flows used in the WUP overestimated August inflows between Elliott Dam and the generating station by 0.105 m^3/s. 2) There was a loss of 0.03 – 0.05 m^3/s of the flow release to groundwater conveyances. 3) Due to control valve issues, releases were greater than the proposed flow; generally from 0.3 – 0.4 m^3/s depending on headpond elevation.	1) Study results estimated that a release of 0.395 m^3/s would be required to achieve the target flow and associated rearing WUA for rainbow trout. 2) The target flow and associated WUA was largely achieved under the existing flow release of ~0.3 – 0.4 m^3/s.

Study	Objectives	Performance Measures	Study Results	Operational Implications
Monitor 2: Lower Jordan R. Fish Index Study	There was uncertainty as to whether theoretical benefits (WUA) predicted during the WUP would translate into actual biological benefits. The objective of this monitor was to assess for measureable benefits to rearing salmonids and their habitat. Additional objective: assess water quality before/after the flow release (including copper).	1) Standing stock (density) of rainbow trout at index sites. 2) Condition factor (weight: length ratio) of rainbow trout at index sites. 3) Habitat continuity in index sections. The above assessed in 3 pre-release and 3 post-release years.	1) Density of age 1^+ and 2^+ rainbow trout increased after the flow release; the increase in 2^+ was statistically significant. 2) No change in condition factor. 3) Habitat continuity was greatly improved; wetted channel right up to Elliott Dam; sufficient depths in riffles for fish to freely disperse between habitat units. 4) After the flow release juvenile trout, and in some years coho fry, repopulated the copper affected zone in Reach 2.	The flow release was successful in providing measureable biological and habitat benefits for resident rainbow trout. The flow release provided sufficient dilution of copper that rearing stages can now occur in the anadromous region; coho and steelhead can now complete their freshwater life cycle. Benefits were achieved under a ~ 0.3 – 0.4 m^3/s release; it is unknown whether benefits would be sustained if the release is reduced to the original intent of 0.25 m^3/s.
Monitor 3: Assessment of spawning and incubation success, anadromous reaches	Assess whether the flow release improves spawning and incubation success in the anadromous reaches. Quantify spawning habitat and assess the influence of the flow release on available spawning habitat. Assess the effects of copper on incubation and rearing of anadromous species, and whether the flow release mitigates effects.	1) Number of adult salmon and steelhead observed by snorkel surveys. 2) Survival rate of coho eggs within incubator planted in gravel sites in the lower river. Above assessed under pre- and post-release flows.	1) Counts of adult salmon and steelhead were low within the study years, but subsequent surveys show a notable increase in adult coho and chum salmon. 2) Survival rate of coho eggs was high throughout the study, both before and after the flow release; no apparent effects on survival from copper issues. 3) The flow release was estimated to have little effect on available spawning habitat as spawning tends to occur after the arrival of fall rains; however, the flow release appears to have improved fish access into Reach 2	The flow release appears to have little effect on Incubation survival rates. The flow release does not appear to influence the quantity of available spawning habitat, but does appear to be important in providing access to that habitat. Flow release has had a significant benefit to anadromous rearing through dilution of copper – the river now has the potential to produce smolts. Benefits of the flow release on adult returns were not found within the Monitor 3 study period; however, recent FWCP surveys have observed greater adult salmon returns. Successful salmon rearing and increased adult returns suggest the needs of anadromous fish may warrant inclusion in the future WUP Order Review.
Monitor 4: Diversion Reservoir Fish Index Study	Monitor lentic trout populations for potential benefits from reduced drawdown and evaluate the effects of extensive drawdown on these fish. The study called for 5 years with reduced drawdown and a 6th year with extensive drawdown.	Condition factor of lentic rainbow trout (weight: length ratio). Collection of limnological data to assist in understanding underlying mechanisms.	No significant increase was found in trout condition factor under reduced drawdown However, abundance increased significantly and was concluded to be a better indicator of drawdown performance.	Increased abundance of lentic trout suggests a positive response to reduced drawdown. Thus, the reduced drawdown operating protocol should be maintained. Consideration should be given to avoiding HCV releases during periods when critical mid-water

Study	Objectives	Performance Measures	Study Results	Operational Implications
			Limnological conditions can develop where trout become sandwiched between warm surface waters, and an anoxic bottom layer. Extensive drawdown at these times can result in the HCV drawing off water from the crucial mid-water layer.	layer is at the level of the HCV intake.
Monitor 5: Surf Quality Survey	Assess the benefits of constrained generation discharge (≤ 30 m^3/s) on the quality of the surfing experience off the mouth of the Jordan River.	Surf quality; gauged by the response of surfers to a questionnaire; conducted under both constrained and unconstrained generation discharges.	25% of surfers reported an effect of generation on surf quality when there was no generation flows; 32% at constrained flows; and 49% at unconstrained generation flows.	It was concluded that, while maintaining constraints at times when it contributes to surf quality would be desirable, the range of environmental conditions at surfing sites, and the variability in their nature and occurrence, limit the ability to predict when flow constraints would successfully provide improved surf conditions.

6. CONCLUSIONS

The monitors that focused on the Lower Jordan River all demonstrated significant benefits to resident and anadromous species and their habitat under the current flow release (0.3 – 0.4 m^3/s). Also, this release inadvertently turned out to be close to what would be required to meet the WUP WUA and wetted habitat targets.

If through the WUP review, it is decided to revert to the originally planned 0.25 m^3/s, then additional studies would be required to determine whether benefits achieved to date are sustained at that flow. In order to satisfy statistical requirements, these studies would need to span 3 consecutive years. Relevant studies include: a) flow monitoring at the original M1 and M3 gauging stations, b) a repeat of the Fish Index Study (Monitor 2) at the original 15 index sites (which includes 4 sites in the anadromous section), c) monitoring of copper levels at previously established water quality monitoring sites (these include 1 control site just upstream of the mine deposit and 3 sites in the impacted zone). It is important to be aware that in the process of reducing flows to 0.25 m^3/s, that dilution of copper will be reduced, and toxicity effects may occur on salmonids rearing in Reaches 1 and 2, with potential adverse consequences on the health and survival of these fish.

Given the renewal of rearing capability for anadromous species in copper impacted reaches, and recent increases in the number of adult salmon returning to the river, inclusion of the needs of anadromous fish may be a warranted in future Water Use Plan Order Reviews. One of these considerations is potential stranding of fry and smolts in Reach 1 as they migrate from the river in the spring. The area of potential concern is a 200 m long perched bar on the river left between the tailrace and the log sort. During generation, tailrace discharges are thrust to the left side of the channel and then along the left bank where they wash over this bar. When the turbine is turned off, the bar dewaters, and the river switches to the river right as it recedes back to base flow conditions. If salmon fry and smolts are migrating from the river during such a scenario, they could become stranded on the perched bar. Based on the 2016 adult returns, roughly 6,000 chum fry and 500 coho smolts would be expected to emigrate from the river in 2017 and 2018, respectively.

7. REFERENCES

Anderson, R.O., and R.M. Neumann. 1996. Length, weight, and associated structural indices. *In* Fisheries techniques, 2nd edition. *Edited by* B.R. Murphy and D.W. Willis editors. American Fisheries Society, Bethesda. pp. 447-481.

BC Hydro. 2000. Bridge-Coastal Fish and Wildlife Restoration Program, Volume 2, Chapter 5: Jordan River Watershed. Available online at http://www.bchydro.com/bcrp/about/docs/ch05_final.pdf. 17 p.

BC Hydro. 2002. Consultative Committee Report, Jordan River Water Use Plan. BC Hydro, Burnaby, BC. 172 p.

BC Hydro. 2003. Jordan River Water Use Plan. BC Hydro, Burnaby, BC. 44 p.

BC Hydro. 2004. Jordan River Water Use Plan: monitoring terms of reference. BC Hydro, 6911 Southpoint Drive, Burnaby, BC. 35 p.

BC Hydro. 2006. Jordan River Water Use Plan: physical works terms of reference - water release mechanism at Elliott Dam. BC Hydro, 6911 Southpoint Drive, Burnaby, BC. 8 p.

BC Hydro. 2007. Lower Jordan River inflow monitoring - monitoring terms of reference (May 2007 revision). BC Hydro, Burnaby, BC. 6 p.

BC Hydro. 2008. Jordan River Water Use Plan, Jordan River Generating Station, Elliott Dam fish water release, Engineering completion report JOR06MTC. Available from BC Hydro, Burnaby, BC, or online at http://www.bchydro.com/content/dam/hydro/medialib/internet/documents/environment/pdf/wup_-_jordan_river8.pdf. 4 p.

Burt, D.W. 2006. Lower Jordan River fish index study - year 1 results (2005). BC Hydro, Water Use Planning, Burnaby, BC. 43 p.

Burt, D.W. 2012. Summary of water quality and biological data for anadromous reaches of the Jordan River. Prepared for BC Hydro, Fish and Wildlife Compensation Program, John Hart Generating Station, Campbell River, BC. 51 p.

Burt, D.W. 2013. Lower Jordan River fish index study - year 6 results (2010) and pre/post flow release comparisons. Prepared for BC Hydro, Water Use Planning, Burnaby, BC. 59 p.

Burt, D.W. 2014. Assessment of gravel quantity/quality/stability and stranding risks in reach 1 of the Jordan River. FWCP Seed Project 13.JOR.02 Prepared for the Fish and Wildlife Compensation Program. 32 p.

Burt, D.W., and G. Hill. 2015. A Restoration Plan for Fish and Fish Habitat within Anadromous Reaches of the Jordan River. FWCP Project 14.JOR.01 Prepared for the Fish and Wildlife Compensation Program. 65 p.

Burt, D.W., and R. Hudson. 2008. Lower Jordan River inflow monitoring: Year 2 results (2007-2008). Prepared for BC Hydro, Water Use Planning, Burnaby, BC. 44 p.

Burt, D.W., and R. Hudson. 2009. Lower Jordan River inflow monitoring: Year 3 results (2008-2009). BC Hydro, Water Use Planning, Burnaby, BC. 40 p.

Cascadia Biological Services. 2001. Lower Jordan River transect survey and biophysical assessments. BC Hydro and Power Authority, 6911 Southpoint Drive, Burnaby, BC. 54 p.

Cascadia Biological Services. 2013. Jordan River spawning assessment and enumeration, Year 6 (Sept 2010 - May 2011). WUP Monitor JORMON#3. BC Hydro, Water Use Planning, Burnaby, BC. 54 p.

Comptroller of Water Rights. 2004. Section 39 Water Act Order for the Jordan River hydroelectric system. Issued to BC Hydro and prepared by the Ministry of Environment, Victoria, BC.

DFO. 2011. NuSEDS V2.0 Regional Adult Salmon Escapement Database, Jordan River. Retrieved September 18, 2012.

Griffith, R.P. 1996. Biophysical assessment of fish production within the Jordan River Drainage, 1994. BC Hydro and Power Authority, Burnaby, BC. 129 p.

Hirst, S.M. 1991. Impacts of the operation of existing hydroelectric developments on fishery resources in British Columbia, volume 1: anadromous salmon. Can. MS Rep. Fish. Aquat. Sci. **2093**: 153 p.

Hudson, R., and J. Fraser. 2005. Introduction to salt dilution gauging for streamflow measurement. Part IV: the mass balance (or dry injection) method. Streamline Water Management Bulletin **9**(1): 6-12.

Lightly, M. 2001. Jordan River coho salmon bioassay. Memorandum report to Mel Sheng (June 11, 2001). Fisheries and Oceans, Nanaimo, BC. 7 pp. + appendices.

MJ Lough Enviromental Consultants. 2010. Jordan River Diversion Reservoir fish indexing - Implementation Year 6. Prepared for BC Hydro, Vancouver Island Generation, Campbell River, BC. 39 p.

Northwest Hydraulic Consultants, and D. Burt and Associates. 2017. Jordan River, design and work plan for gravel placement in reach 1 (draft). Fish and Wildlife Compensation Program Report COA-F17-F-1379. 46 p.

Province of British Columbia. 1998. Water Use Plan Guidelines. Ministry of Environment, Victoria, BC. 65 p. Available online at http://www.env.gov.bc.ca/wsd/plan_protect_sustain/water_use_planning/cabinet/wup.pdf.

Recreation Resources Ltd. 2001a. Jordan River historical salmonid survey. Prepared for BC Hydro, Burnaby, BC. 35 p.

Recreation Resources Ltd. 2001b. Jordan River surf users final report. Prepared for BC Hydro, Water Use Planning, Burnaby, BC.

Recreation Resources Ltd. 2013. Monitoring surfing quality below the Jordan River Generating Station, Summary Report (2006 - 2011). Prepared for BC Hydro, Burnaby, BC. 15 p.

Sit, V. 1994. Catalogue of curves for curve fitting. Biometrics information handbook #4. Ministry of Forests, Victoria, BC.

SNC-Lavalin Inc. 2016. Supplemental stage 1 and limited stage 2 preliminary site investigation and preliminary risk opinion, Sunro Mine, Jordan River, BC. Pepared for Teck Metals Ltd. 407 p.

Wright, M.C., and E. Guimond. 2003. Jordan River pink salmon incubation study. BC Hydro Bridge Coastal Fish and Wildlife Restoration Program report (02.Jo.64). 31 p.