Wahleach Water Use Plan

Monitoring and Physical Works Program Synthesis Report

- **WAHMON-1 Lower Jones Creek Fish Productivity Indices**
- **WAHMON-2 Channel Stability Assessment**
- **WAHMON-3 Herrling Island Side-Channel Chum Spawning Success Monitoring**
- **WAHWORKS-1 Boulder Creek Diversion Bypass**
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- **WAHWORKS-3 Lower Jones Creek Channel Enhancement Project**

Draft Report

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Executive Summary

The Wahleach Water Use Plan (WUP) was initiated by BC Hydro in 2000 and finalized in 2002. In January 2005, the Comptroller of Water Rights (CWR) issued an Order (the "WUP Order") under the *Water Act*[1] in response to the Wahleach WUP submission that included implementing three monitoring projects and three physical works projects.

This document was prepared as a part of the WUP Order Review process. It summarizes the outcomes from the monitoring projects and outlines whether the management questions have been addressed (Table E-1). The draft MPSR will be shared with government agencies, First Nations and key stakeholders for review and comment.

Below is a summary of key findings from the Wahleach Water Use Plan:

Egg-to-fry survival and outmigration totals for Chum (*Oncorhynchus keta*) and Pink Salmon (*Oncorhynchus gorbuscha*) were measurably higher following implementation of the WUP Order.

Though egg-to-fry survival was higher (WAHMON-1), no correlation was concluded (WAHMON-2) between Chum and Pink spawning success and key channel changes or substrate quality indicators in Lower Jones Creek even with continued substantial lateral movement, scour and fill within the channel.

Two-hour generation shutdowns did not mitigate stranding, though exclusion fencing did limit spawner access and stranding.

While the prescribed two hour generation shutdowns every 24 hours were effective at reducing the amount of spawning in areas affected by operational flow changes, adult stranding remained a concern (WAHMON-3). After the Pink Salmon adult stranding event in 2009, exclusion fencing was installed in 2010 and was deemed successful at reducing stranding. As a result, BC Hydro continues to install exclusion fencing annually to limit stranding events.

Constructed weir to maintain Boulder Creek bypass intake and enable upstream passage functioning as intended.

Two different weirs were constructed to increase water elevations in Boulder Creek at the bypass intake while maintaining fish passage (WAHWORKS-1). A concrete lock-block weir failed after a storm event and was subsequently replaced by a Newbury style boulder weir. The weir was designed and maintained so that the upstream passage of Kokanee (*Oncorhynchus nerka*) would be sustained at flows of 0.14 m^3/s and above. The Newbury style weir was inspected in 2010 and 2015 and was found to be functioning as designed (BC Hydro 2016), though regular inspections and maintenance will be required.

[1] The *Water Act* was replaced by the *Water Sustainability Act* in February 2016; however Orders and Water Licences continue to be valid and are governed by the new *Water Sustainability Act*.

Fertilization has enhanced Kokanee spawner abudance, reservoir fish populations and zooplankton production.

The Kokanee population in Wahleach Reservoir appears well supported by the fertilization program (WAHWORKS-2), with significant spawner numbers observed annually, particularly since 2013. Reservoir fish populations appear to be healthy and the zooplankton population enhancement has been very successful with a seven fold increase in densities. *Daphnia,* a preferred food source of Kokanee, were also well represented in the increase of food availability.

Off-channel rearing habitat initially functional became non-functional after infilling. Enhanced spawning habitat continues to be functional.

Off-channel habitats in Lower Jones Creek and enhanced spawning riffles in Lorenzetta Creek were constructed (WAHWORKS-3). The rearing habitat was available and used until it was completely infilled with fine sediments by 2010. Fisheries and Oceans Canada (DFO) and the CWR supported the BC Hydro decision to not reinstate or reconstruct the rearing habitats due to channel instabilities and high likelihood that it would infill again. Spawning riffles constructed in Lorenzetta Creek were stable and functional when last checked in 2014 and are presumed to still be functional.

Table E 1. Summary of objectives, management questions, outcomes, and implications for the Wahleach WUP Monitoring projects.

Project	Objectives	Management Questions	Response
WAHMON-1 Lower Jones Creek Fish Productivity Indices	To determine the fisheries benefits associated with the flow provisions outlined in the Wahleach WUP.	1. Will the recommended operational changes in the Wahleach Water Use Plan result in increased productivity for anadromous and resident fish populations in Lower Jones Creek as predicted from the flow-habitat relationships generated from the empirical study? a) Is salmon fry survival improved through the operational changes recommended in the WAH WUP? b) Is juvenile steelhead productivity improved through the operational changes recommended in the WAH WUP?	1. a) Egg-to-fry survival and outmigration totals for Chum and Pink salmon were over two fold and 11-fold higher during WUP operations than during prior years respectively. Increases were also recorded for Coho Salmon, though the increases were uncertain due to very limited data. b) No Steelhead Trout were encountered during the study, so their productivity was not assessed, and the question remains unresolved.
WAHMON-2 Channel Stability Assessment	To determine if channel stability and substrate quality are limiting fish productivity in Lower Jones Creek.	1. Is channel stability in Lower Jones Creek limiting fish productivity? 2. Is substrate quality in Lower Jones Creek limiting fish productivity?	1. Results of the monitoring study indicated that Lower Jones Creek undergoes significant scour, fill and channel migration annually, and that there was no correlation between indices of channel stability in Lower Jones Creek and egg-to-fry survival of Pink and Chum Salmon. 2. Correlation analysis suggested that none of the grain size metrics (D16, D50, D84, % <1 mm, % <2 mm, % <8 mm) for substrate condition were correlated with egg-to-fry survival, but the analysis limited the ability to support conclusive results.
WAHMON-3 Herrling Island Side-Channel Chum Spawning Success Monitoring	To assess the effectiveness of Wahleach Generating Station operations to minimize salmon fry stranding and assess stranding risk of adult spawners associated with the operations.	1. Will the recommended operational measures keep spawning away from marginal areas? 2. Do the operational measures in the fall result in minimal fry stranding in the spring? 3. Will the operational measures in the fall result in stranding of adult spawners?	1. Observations of higher numbers of Pink Salmon embryos in non-marginal areas indicates that spawners are more likely to spawn in areas that do not become dewatered. However, in 2009, numerous adult Pink Salmon were stranded, and in 2010 as a corrective action, exclusion fencing was installed and has been effective at preventing stranding events. 2. As per the above, the operational measures reduced the likelihood of embryos being found in marginal spawning habitats by approximately two-thirds. While these benefits are

Project	Objectives	Management Questions	Response
			substantive, an adult pink spawning stranding incident in 2009 resulted in additional mitigation measures to be recommended. 3. The two hour shutdown operational measure significantly reduced the likelihood of spawning in marginal areas, but adult stranding still occurred. Exclusion fencing has proven to be effective in reducing adult stranding and subsequent redd stranding.

Table E 2. Summary of objectives, source requirements and completion timeline for the Wahleach WUP physical Works projects.

Project	Objectives	Source Requirements	Completion
WAHWORKS-1 Boulder Creek Diversion Bypass	To construct an in-channel weir to increase water level elevations in Boulder Creek sufficiently to provide a consistent water supply to the Boulder Creek Diversion bypass above $0.14 m^3/s$ while providing Kokanee access.	*Water Act* Order Section 88	Boulder Creek Diversion Upgrade was first started in 2005 and eventually resulted in the installation of a Newbury style weir in 2007. Engineering assessments in 2010 and 2015 concluded that the weir was in stable condition but should be monitored and maintained as needed. The Boulder Creek diversion dam, channel and bypass intake continues to be inspected weekly and semi-annually by BC Hydro Dam Safety. The November 2021 storm impacted the bypass intake and Newbury style weir, so maintenance works will be required in the near future.
WAHWORKS-2 Wahleach Reservoir Fertilization Program	To restore and maintain Kokanee abundance in Wahleach Reservoir.	*Water Act* Order Section 88	Nutrient additions to Wahleach Reservoir commenced in 1995 and have continued annually except when road access or equipment issues prevented program operations. Typically, nutrient additions occur over a 20-week period or once the reservoir water levels turned over, whichever came first. During this 20-week period, monthly limnology sampling was conducted to monitor chemical, physical and biological parameters within the reservoir and the ratio of fertilizer blends, timing of the additions, and the total amounts added to the reservoir were adjusted based on these monitoring results.

Project	Objectives	Source Requirements	Completion
			Fish sampling was also conducted annually or biannually and included nearshore gillnetting and minnow trapping, Kokanee spawner surveys, hydro-acoustics, trawl netting (in earlier years) and pelagic gillnetting. The fertilization program has been successful in achieving the objectives of enhancing primary productivity and maintaining the Kokanee population in Wahleach Reservoir.
WAHWORKS-3 Lower Jones Creek Channel Enhancement Project	Improve fish productivity in Lower Jones Creek through habitat enhancement.	*Water Act* Order Section 88	Enhancement works were completed in September 2006 and resulted in the construction of 722 m^2 of rearing and spawning habitat in Lower Jones and Lorenzetta Creeks. Due to the significant movement of substrate and channel instability in Lower Jones Creek, the created off-channel rearing habitats became infilled and no-longer functional. Only the 288 m^2 of spawning habitat remains functional. As further confirmed by the recent avulsion in Lower Jones during the November 2021 flood event, any future fish habitat enhancement works in Lower Jones should consider the instability in the watershed.

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BC Hydro would like to acknowledge that these projects were conducted on the traditional territory of the following First Nations:

Chawathil, Cheam, Cowichan, Halalt, Kwaw-kwaw-apilt, Lake Cowichan, Lyackson, Nooaitch, Penelakut, Peters, Popkum, Seabird Island, Shxw'owhamel, Skawahlook, Skwah, Soowahlie, Sto:lo Nation, Sto:lo TC, Stz'uminus, and Union Bar.

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List of Abbreviations

CC	Consultative Committee
CWR	Comptroller of Water Rights
DFO	Department of Fisheries and Oceans, Canada
EFO	Environmental Field Operations, BC Hydro
BC ENV	BC Ministry of Environment and Climate Change Strategy
GS	Generating Station
TOR	Terms of Reference
WAH	Wahleach
WLR	Water License Requirements
WUP	Water Use Plan

Glossary of Terms

Hyporheic Through gravel or other substrate flow.

Reservoir Turnover The seasonal change in water layers within the reservoir become exchanged. In the fall, the warm surface water cools, becomes more dense, and sinks. This denser water forces the water of the lower level to rise, "turning over" the water layers.

Wahleach Water Use Plan
Monitoring and Physical Works Program Synthesis Report

1.0 CONTEXT

The Wahleach Water Use Plan (WUP) was accepted by the Comptroller of Water Rights (CWR) in 2004. In January 2005, the CWR issued an Order (the "WUP Order") under the *Water Act*[2] in response to the Wahleach WUP. The Order included operating requirements and requirements to implement three monitoring projects and three physical works projects.

This document was prepared as a part of the WUP Order Review process. It summarizes the outcomes from the monitoring projects and outlines whether the management questions have been addressed (Table E-1).

The purpose of the WUP Order Review is to determine whether the ordered facility operational constraints and the physical works in lieu of operation changes are achieving the specific environmental and social objectives identified in the WUP.

The draft MPSR will be shared with government agencies, First Nations and key stakeholders for review and comment.

The specific objectives of the Monitoring and Physical Works Program Synthesis Report are to:

1. Provide a summary of the objectives, activities, and results for each of the three monitoring projects and three physical works;
2. Relate monitoring project findings to the objectives of the Wahleach WUP and provide any updates to these project findings from other work conducted after the projects were completed;
3. Where management questions were not addressed, identify the data gaps that persist.

2.0 PROJECT BACKGROUND

2.1 Hydroelectric Facilities

The Wahleach hydroelectric facility is situated in the Lower Mainland approximately 25 km west of Hope and 100 km east of Vancouver. An area map of the Wahleach hydroelectric facility is provided in Figure 2.1 and Table 2.1 provides an overview of the general facility. The key features of the facility are summarized in the following sections.

[2] The BC *Water Act* was replaced by the *Water Sustainability Act* in February 2016. Orders and Water Licences continue to be valid and are governed now through the new *Water Sustainability Act*.

2.1.1 Wahleach Dam

The Wahleach Dam is situated at the outlet of Wahleach Reservoir (also known as Jones Lake), which was a natural lake prior to impoundment. The Wahleach Dam raised the lake level post impoundment. It is an earth fill dam with a crest length of 418 m and a crest elevation of 646.3 m. A free-crest overflow spillway is located on the east abutment of the dam. The spillway discharges into an excavated rip-rap lined channel, which then carries water into Wahleach Creek (also known as Jones Creek), approximately 400 m downstream of the dam. A fish water release siphon was added to the top of the dam near the west abutment in 1969 and can divert up to 0.85 m^3/s of flow from Jones Lake Reservoir into Jones Creek. The invert of the siphon is at 634.81 m elevation.

2.1.2 Wahleach (Jones Lake) Reservoir

Jones Lake Reservoir is the storage reservoir in the Wahleach hydroelectric facility. It is an ultra-oligotrophic lake with a surface area of 490 ha, a maximum depth of 29.0 m and a mean depth of 13.4 m. As noted above, Jones Lake Reservoir was a natural lake prior to impoundment with Upper Jones Creek (also known as Wahleach Creek) as its primary inflow source. From its headwaters in the Cheam Ridge, the creek flows approximately 3 km north and enters Jones Lake Reservoir at its southern most end. Additional water is supplied to the reservoir by smaller tributaries and the diversion of Boulder Creek into the reservoir post-impoundment. The Boulder Creek Diversion Dam is located approximately 400 m east of the Wahleach Dam.

2.1.3 Boulder Creek Diversion

The Boulder Creek Diversion comprises of a diversion dam and channel, and fish valve and water bypass gate. The Dam is an earth fill dam with a crest length of 180 m. The Dam diverts flow from Boulder Creek into the Boulder Creek Diversion Channel which flows into Jones Lake. The Boulder Creek Diversion Dam was built with a release bypass gate capable of diverting up to 2.0 m^3/s of Boulder Creek flow to continue into Jones Creek to provide flows for fish downstream of the dam. Over time, erosion in the diversion channel at the intake of the bypass gate had resulted in reduced water levels so that the bypass gate became dewatered during lower flows. An in-channel Boulder Creek Diversion weir was initially constructed in 2005 as WAHWORKS-1 to elevate water levels in Boulder Creek at the bypass gate so that it would remain functional during lower flows.

2.1.4 Penstock and Wahleach Generating Station

Water is drawn from the west side of the reservoir through the Four Brothers Mountain via a tunnel and penstock. Water from Wahleach Reservoir enters an intake structure on the west side of the reservoir and is carried through a 4.2 km tunnel and a 500 m penstock to the generating station situated on the south bank of the Fraser River. The generating station has a maximum sustained generating capacity of 61 MW. The generated station discharges into Herrling Side Channel of the Fraser River approximately 10.5 km downstream of the Lower Jones Creek confluence and is typically operated to meet local peak electricity demand. This can result in daily fluctuations in discharge to Herrling Side Channel.

2.1.5 Lower Wahleach (Jones) Creek

Most flow from Upper Jones Creek watershed is diverted through the power tunnel and into the Wahleach Generating Station before being discharged into Herrling Side Channel. The Boulder Creek diversion water and the water released from the Wahleach Dam (siphon and spillway) flows north into Lower Jones Creek, which then passes under the Trans-Canada Highway and the Canadian National Railway to the creek's confluence with the Fraser River near Laidlaw. The section of the creek is referred to as Lower Jones Creek. The total length of Lower Jones Creek is approximately nine km, of which ~1.2 km is accessible to anadromous salmonid species due to a natural barrier located about 100 m above the Laidlaw Bridge crossing. This lower section of the creek is referred to as the anadromous reach of Lower Jones Creek. The remainder is referred to as the non-anadromous reach.

Figure 2.1. Site map of Wahleach Facility.

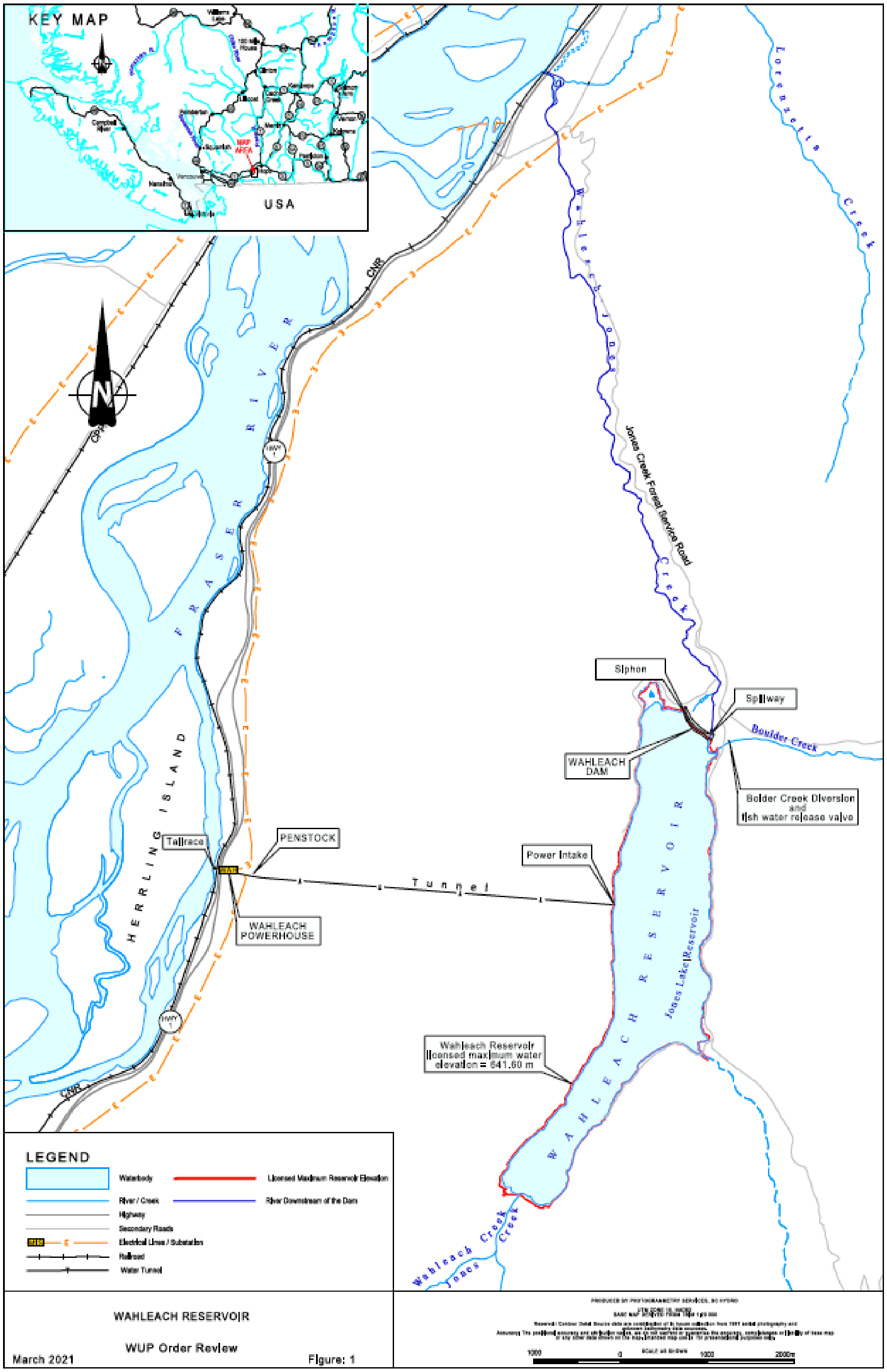


Table 2.1. Wahleach Project General Information.

Dam Name	Wahleach Dam
Year of Completion	1952
Dam Type	Earthfill dam
Dam Use	Diversion for Electrical Generation
Dam Height	22 m
Spillway Type	Free overflow weir with chute, impact block stilling basin and rip-rap lined discharge channel
Max. Discharge Capacity of Spillway	616 m^3/s and 300 m^3/s for the discharge channel
Generating Station	Wahleach
Nameplate Capacity	66 MW, but dependable capacity is 61 MW
Active Storage	61 Mm^3 (surface area = 490 Hectares)
Reservoir Name	Jones Lake/Wahleach Reservoir
Reservoir Area at Max. Normal Level	500 ha
Water Course	Wahleach/Jones Creek
Drainage Area	88 km^2
Reservoir Operating Range	621.8 to 641.6 metres
Upstream Project	None
Downstream Project	None
Nearest City	Hope, B.C.

3.0 WAHLEACH WUP PROCESS

The Wahleach WUP process conducted from 2000 through 2002 followed the Water Use Guidelines developed by the province (Province of British Columbia 1998). The WUP was accepted by the CWR in 2004, and an Order based on the WUP was issued in January 2005. The WUP Order has now been implemented for 16 years, with the WUP Order Review (WUPOR) scheduled to start in early 2022. The WUP process created the following outputs (in chronological order):

- Wahleach WUP Consultative Committee Report (BC Hydro 2003) – documentation of the structured decision-making process which identified objectives, evaluated operating alternatives against those objectives, and documented uncertainties.
- Wahleach WUP (BC Hydro 2004) – submitted by BC Hydro to the CWR as the summary of operating constraints and implementation commitments to form the basis for an Order. The implementation commitments included monitoring projects to address uncertainties identified by the Consultative Committee, and physical works projects to support key objectives.
- Wahleach Facility Order (Comptroller of Water Rights 2005) – the *Water Sustainability Act* Order issued by the CWR to implement the WUP as a

condition of the three licences associated with the Wahleach project. The 2009 Amendment to the 2005 Order amended Clause 2 of Schedule A.

- Water Licence Requirements (WLR) Terms of Reference (TOR; BC Hydro 2005 and BC Hydro 2006) – for monitoring and physical works projects ordered by the CWR; management questions and methodologies were prepared to address uncertainties identified in the WUP process and submitted to the CWR for Leave to Commence project implementation.
- Project progress and annual watershed reports – reports summarizing results for ordered projects, and a report summarizing watershed activities were submitted to the CWR each year.

All reports are available on BC Hydro's WUP website at:

https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/wahleach.html.

The WUP CC identified uncertainty of the benefits associated with the following operating conditions (Table 3.1):

- Wahleach Reservoir levels;
- Minimum and excess flows in the Boulder Creek Diversion and bypass gate;
- Minimum flows in Lower Wahleach Creek, and
- Generation and associated flows to Herrling Side Channel of the Fraser River.
    - To address these uncertainties, physical works and monitoring projects were recommended to:
- Assess expected outcomes of the operational change being recommended.
- Assess the effectiveness of the physical works; and
- Provide improved information for future operating conditions.

The monitoring projects were ordered to address the data gaps and uncertainties in the Wahleach WUP and to assess whether anticipated benefits from changes made under the WUP were achieved. Results from monitoring projects are reviewed upon completion as part of BC Hydro's WUP Order Review process, and the results are used and considered along with other values and information collected to support considerations and decisions during the WUP Order Review.

The following ordered projects were implemented under the BC Hydro's Water Licence Requirements program according to these terms of references and any associated addenda:

WAHMON-1 Lower Jones Creek Fish Productivity Indices: A ten-year study to determine the fisheries benefits associated with the flow provisions outlined in the Wahleach WUP.

WAHMON-2 Channel Stability Assessment: A nine-year study to determine if channel stability and substrate quality are limiting fish productivity in Lower Jones Creek.

WAHMON-3: Herrling Island Side-Channel Chum Spawning Success Monitoring: A five-year study to assess the effectiveness of Wahleach Generating Station operations to minimize salmon fry stranding and assess stranding risk of adult spawners associated with the operations.

WAHWORKS-1 Boulder Creek Diversion Bypass: Construct a weir to increase water elevations in Boulder Creek sufficiently to provide source water to the Boulder Creek Diversion bypass gate above $0.14 m^3/s$, while providing Kokanee access.

WAHWORKS-2 Wahleach Reservoir Fertilization Program: To implement a program to enhance primary productivity and to restore and maintain Kokanee abundance in Wahleach Reservoir.

WAHWORKS-3 Lower Jones Creek Channel Enhancement Project: To construct habitat enhancement works in Lower Jones Creek to improve fish productivity.

All WUP Terms of Reference, including any significant revisions and addenda, are circulated to agencies and First Nations for review and comment prior to submission to the Comptroller of Water Rights.

The operating conditions under the Wahleach WUP Order issued by the CWR are shown in Table 3-1.

Table 3.1. Operating conditions of the WUP Order for the Wahleach Hydroelectric system (Comptroller of Water Rights 2004).

System Component	Constraint	Time of Year	Purpose
Wahleach Reservoir	Minimum operating elevation of 628 m.	All year	Improve reservoir productivity and Kokanee production.
Boulder Creek Diversion	BC Hydro will provide a minimum flow of 0.14 m^3/s from Boulder Creek to Wahleach Reservoir via the Boulder Creek Diversion Channel to the extent that Boulder Creek inflows are available. It is expected that there will be times when the minimum flow will not be available.	All year	Boulder Creek fish productivity.
Boulder Creek Diversion	Flows from Boulder Creek in excess of 0.14 m^3/s can be diverted at the Boulder Creek Diversion Dam through the bypass gate into the original Boulder Creek channel to meet minimum flow obligations downstream in Lower Wahleach Creek to the extent that Boulder Creek inflows are available. This condition would require a capital investment to undertake structural modifications to the discharge facilities at the Boulder Creek Diversion Dam and/or the construction of a weir downstream of the intake structure to elevate water levels at the intake.	All year	To assist with meeting minimum flow targets in Lower Jones Creek.
Lower Jones Creek	When the Wahleach Reservoir elevation level is at or above 637.6 m and/or Boulder Creek inflows in excess of 0.14 m^3/s are available: - BC Hydro will maintain a minimum flow of 1.1 m^3/s in Wahleach Creek measured at a staff gauge installed in Jones Creek near Laidlaw. - BC Hydro will maintain a minimum flow of 0.6 m^3/s in Wahleach Creek measured at a staff gauge to be installed in Wahleach Creek near the Laidlaw Bridge. The 2009 Amendment to the 2005 Water Order (Clause 2 of Schedule A) changed the required minimum flows into Lower Jones Creek as follows: If during the Sept 15 to Nov 30 period the following conditions exist, the diversion at Boulder Creek Diversion bypass gate (PD 42969) will be reduced to provide a minimum flow of 0.6 m^3/s in Wahleach Creek, as measured at the gauge near Laidlaw, for as long as both conditions persist: I. Kokanee are utilizing Boulder Creek downstream of the fish-water by-pass gate for spawning and incubating, and; II. Spawning salmon are not utilizing lower Wahleach Creek habitats below Laidlaw Bridge."	15 September to 30 November 1 December to 14 September	Improve fish productivity in Lower Jones Creek Improve fish productivity in Lower Jones Creek

System Component	Constraint	Time of Year	Purpose
Wahleach Generation Station	BC Hydro will curtail generation to zero for a two-hour period every twenty-four hours. There is no time of day condition. At all other times, BC Hydro can generate at maximum capacity. There is no constraint on the rate of change of flow or ramping rate.	15 September to 30 November	To avoid salmon spawning in areas of Herrling Side Channel susceptible to dewatering during flow reductions and therefore increase egg-to-fry survival and salmon productivity in Herrling Side Channel.

4.0 ORDERED MONITORING PROJECT SUMMARY

4.1 WAHMON-1 Lower Jones Creek Fish Productivity Indices

4.1.1 Project Summary

Objectives	Management Questions[1]	Response
To determine the fisheries benefits associated with the flow provisions outlined in the Wahleach WUP.	1. Will the operational changes recommended in the Wahleach Water Use Plan result in increased productivity for anadromous and resident fish populations in Lower Jones Creek as predicted from the flow-habitat relationships generated from the empirical study? a) Is salmon fry survival improved through the operational changes recommended in the WAH WUP? b) Is juvenile steelhead productivity improved through the operational changes recommended in the WAH WUP?	1. a) Egg-to-fry survival and outmigration totals for Chum and Pink salmon were over 3-fold and 11-fold higher during WUP operations than during prior years. Increases were also recorded for Coho Salmon, though the increases were uncertain due to very limited data. b) No Steelhead Trout were encountered during the study, so their productivity was not assessed, and the question remains unresolved

[1]BC Hydro 2005a

4.1.2 Project Approach

The Lower Jones Creek Fish Productivity Indices monitoring project was conducted from 2005 to 2014. The monitoring project was completed by contractors Jeff Greenbank and Jason McNair. Reports were compiled each year following 2006. A mid-term summary report for the period 2005 to 2010 was completed in 2010 and the final annual report in 2014 summarized results for the entire study period. All reports are available on BC Hydro's WUP website:

https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/wahleach.html

This monitoring project consisted of four key components: smolt abundance monitoring, egg to fry survival studies, adult escapement monitoring, and hyporheic (or through substrate) flow measurements. All study components were carried out in the section of Lower Jones Creek that is accessible to anadromous salmon and trout. The section consists of the lower ~1.2 km section of the creek starting at its confluence with the Fraser River and ending at a cascade just upstream of the Laidlaw Road Bridge, which is a barrier to upstream fish passage.

4.1.3 Interpretation of Data

Monitoring results suggest that egg-to-fry survival totals for both Chum and Pink Salmon were higher post WUP (Table 4.1). The pre-WUP mean for Pink egg-to-fry survival was 0.34%, while the WUP mean was 2.42%, and for Chum it was 0.35% pre-WUP and 2.39% during WUP monitoring.

Table 4.1. Lower Jones Creek fry population and egg-to-fry estimates for Chum and Pink Salmon. There was no Chum population estimate for 2007 due to low Chum escapement and fry capture.

	Chum			Pink		
Brood Year	Fry Capture	Pop. Est	Egg-to-Fry	Fry Capture	Pop. Est	Egg-to-Fry
1999	170	5,049	0.37%	396	7,160	0.36%
2003	164	1,901	0.30%	470	5,702	0.32%
2004	108	1,027	0.39%			
2005	161	1,055	1.17%	493	3,570	2.56%
2006	1,572	16,733	1.07%			
2007		0	n/a	5,377	86,442	3.54%
2008	231	1,567	0.97%			
2009	3,965	16,711	3.13%	9,085	39,315	0.66%
2011	368	2,301	1.98%	20,149	119,249	2.24%
2013	6,447	24,750	6.01%	22,897	129,498	3.10%
Pre WUP Mean	147	2,659	0.35%	433	6,431	0.34%
Post WUP Mean	2,124	9,017	2.39%	11,600	75,615	2.42%

Answers to Management Questions

1. Will the operational changes recommended in the Wahleach Water Use Plan result in increased productivity for anadromous and resident populations in Lower Jones Creek as predicted from the flow-habitat relationships generated from the empirical study?

   To address the management question, the following two secondary management questions were also developed:

   ***a**) Is salmon fry survival improved through the operational changes recommended in the WAH WUP?*

   The data indicates that there may have been improvements to anadromous salmon productivity since WUP implementation, particularly for Pink and Chum Salmon egg-to-fry survival. Coho Salmon (*Oncorhynchus kisutch*) were also recorded using Lower Jones Creek during the study period but in very limited numbers, so no analysis could be completed on their use of Lower Jones Creek habitats.

   b) Is juvenile Steelhead productivity improved through the operational changes recommended in the WAH WUP?

This management question could not be addressed due to a lack of Steelhead (*Oncorhynchus mykiss*) adult and juvenile capture data. The lack of adult capture data was partly attributed to the timing of adult sampling. Steelhead typically require a stable stream to support their extended freshwater life history stage and the continued instability in the watershed will likely deter Steelhead use for decades.

Other Results

An in-situ egg incubation study conducted in Lower Jones Creek (Greenbank et al 2008) showed that hyporheic water quality was within the range considered suitable for salmon egg development and survival. Low hyporheic flow rates within the gravel sufficiently flushed away metabolic wastes and replenished depleted oxygen levels. The Lower Jones hyporheic flow study recorded that in-migration of fine sediments occurred within the first week of incubation, which was also observed by Beschta and Jackson (1979). However, as also reflected by Beschta and Jackson (1979), sediment composition did not appear to be fine enough to severely inhibit hyporheic flow.

4.2 WAHMON-2 Channel Stability Assessment

4.2.1 Project Summary

Objectives	Management Questions[1]	Response
To determine if channel stability and substrate quality are limiting fish productivity in Lower Jones Creek.	1. Is channel stability in the Lower Jones Creek limiting fish productivity? 2. Is substrate quality in Lower Jones Creek limiting fish productivity?	1. Results of the monitoring study indicated that Lower Jones Creek undergoes significant scour, fill and channel migration annually, and that there was no correlation between indices of channel stability in Lower Jones Creek and egg-to-fry survival of Pink and Chum Salmon. 2. Correlation analysis suggested that none of the grain size metrics (D16, D50, D84, % <1 mm, % <2 mm, % <8 mm) for substrate condition were correlated with egg-to-fry survival, but the analysis limited the ability to support conclusive results.

[1]BC Hydro 2005b

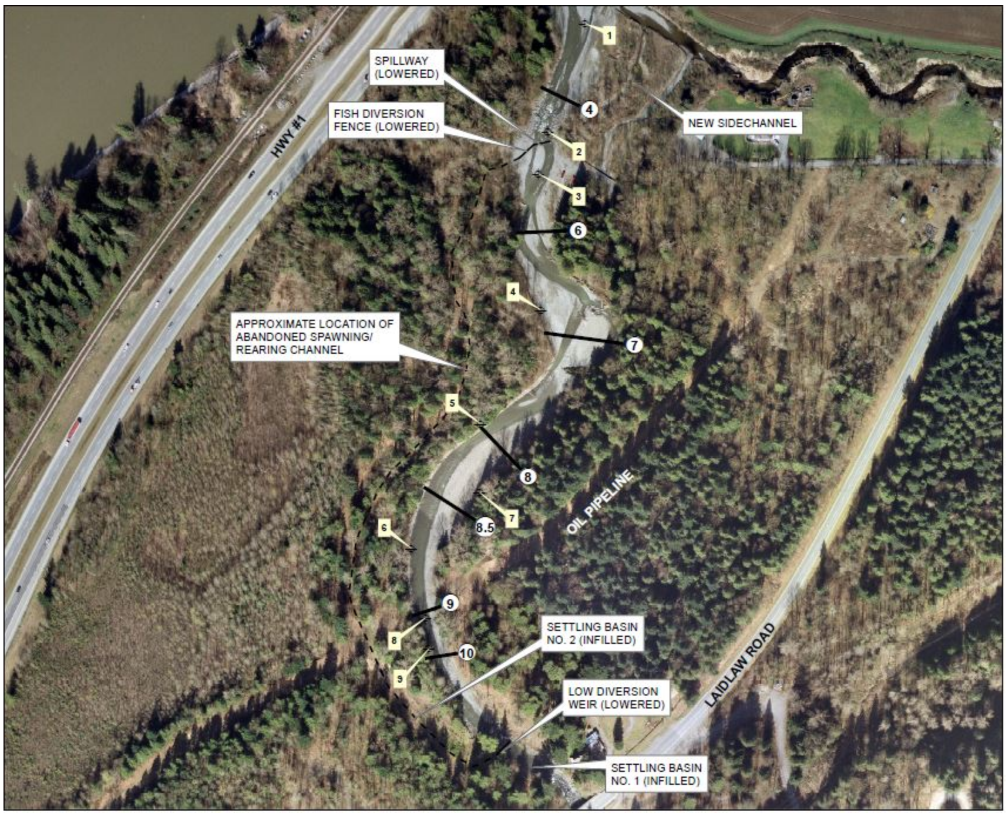
4.2.2 Project Approach

The Channel Stability Assessment monitoring project was conducted from 2005 to 2014. The monitoring project was completed by Northwest Hydraulic Consultants (NHC). Assessments were conducted on odd years consistent with Pink Salmon spawning and reporting was completed every second year following 2006. The final report summarized the results for the ten years of monitoring and provided a comparison of data collected during Years one (2005/2006), three (2007/2008), five (2009/10), seven (2011/2012) and nine (2013/2014). All reports are available at the following BC Hydro WUP website:

https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/wahleach.html.

The general approach to this monitoring project was to complete topographic surveys, site photography, and photographic substrate sampling at six established transect locations and nine points (points 1 through 9 and transects 4, 6, 7, 8, 8.5, 9, and 10, Figure 4.2.a) along Lower Jones Creek. Surveys were conducted during the relevant Pink Salmon spawning year at incubation midpoint and incubation endpoint time periods. These changes were compared with Pink Salmon productivity assessment results from WAHMON-1 to determine if there was a link between habitat stability or substrate condition and Pink Salmon productivity.

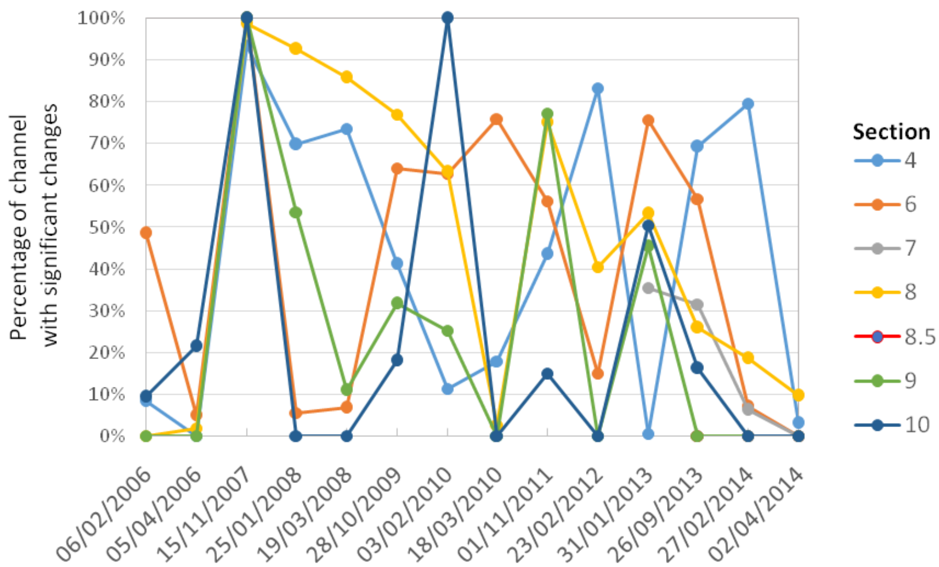
Figure 4.2.a. Lower Jones Creek sections showing transect locations and notable features (from NHC 2015). Numbers with white circles reflect transects and numbers with yellow boxes reflect photo documentation points.



4.2.3 Interpretation of Data

There was significant lateral movement of the wetted channel over the period of the monitor as determined by orthophoto analysis. Significant fill, scour, and lateral movement were also observed annually at each of the surveyed transect sites (Figure 4.2.b). The most significant changes were recorded in sections 4, 6 and 8 which experienced more than 15 cm of scour or fill each year across more than 40% of the wetted channel. No correlations were found between the stability metrics and Pink Salmon egg-to-fry survival.

Figure 4.2.b. Percentage of channel width at each transect that experienced more than 15 cm of fill, scour and total change during each survey (from NHC 2015).



Assessments of the surface substrate quality found no correlation between egg-to-fry survival and grain size metrics (D16, D50, D84, % < 1 mm, % < 2 mm, % < 8 mm). However, as surface rather than sub-surface grain size was assessed, results shouldn't be considered conclusive, as there was likely to be a higher content of fines in the unassessed subsurface substrates.

Answers to Management Questions

1. **Is channel stability in the Lower Jones Creek limiting fish productivity?**

Two hypotheses were developed in order to address this management question:

H_{1a}: Fish Productivity is not correlated to channel instability as measured by cross sectional areas of scour and fill in the anadromous reach.

The maximum discharge, and weighted scour, fill, and change metrics for the spawning and incubation period did not correlate with the egg-to-fry survival ratio.

H_{1b}: Fish productivity is not correlated to channel instability as measured by lateral channel migration involving abandonment of spawning habitat in the anadromous reach.

To determine if lateral stability of the channel is correlated with egg-to-fry survival, the proportion of the wetted channel that was not wetted during the previous survey was determined and weighted based on fish use data for each cross-section. This metric did not correlate with the egg-to-fry survival ratio. However, lateral change metrics and orthophoto wetted channel mapping indicate that the channel is consistently unstable laterally and this condition likely effects fish productivity.

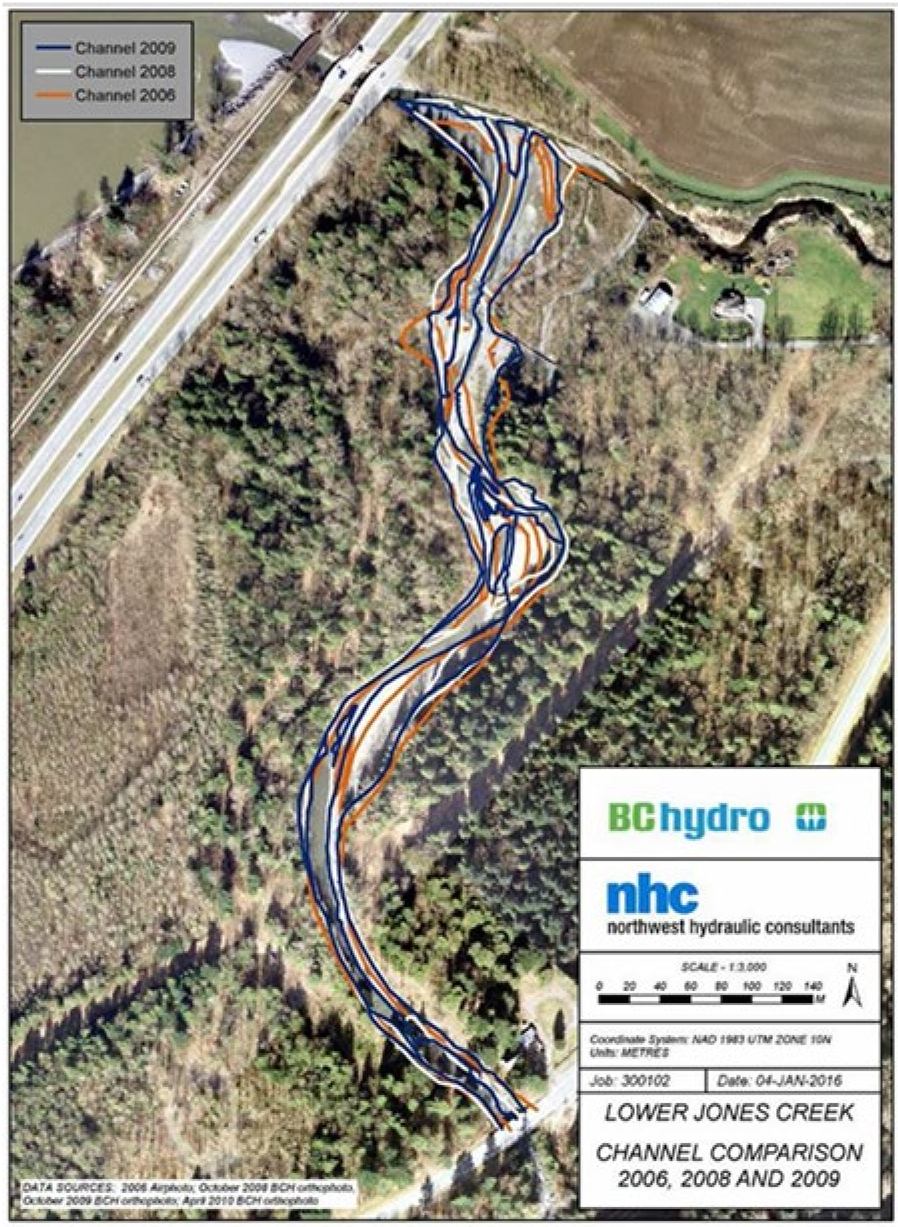
2. **Is substrate quality in the Lower Jones Creek limiting fish productivity?**

To answer this management question, the following hypothesis was developed:

H_2: In consideration of improvements to spawning habitat through increased spawning and incubation flows, fish productivity is not correlated to substrate quality as measured by substrate particle size in the anadromous reach of Lower Jones Creek.

To determine whether substrate quality is related to egg-to-fry survival, the proportion of bed substrate that is sand (< 2 mm) and the proportion that is fine gravel or smaller (< 8 mm) were correlated with egg-to-fry survival. These metrics were specified in the WUP monitoring program based on metrics in Tappel and Bjornn (1983) who related large amounts of sand and fine gravel in the substrate with poor egg-to-fry survival. The correlation analysis revealed that none of the grain size metrics (D16, D50, D84, % <1 mm, % < 2 mm, % < 8 mm) were correlated with egg-to-fry survival. However, it should be noted that the bioassays completed by Tappel and Bjorn (1983) were based on subsurface grain size distribution while the results of this work are based on the photographic analysis of surface grain size only. Inherently, surface grain size would be coarser due to surface erosion of fine particles, so this analysis should not be relied upon as providing conclusive results.

Figure 4.1.c. Results of orthophoto overlay showing lateral channel movement over time (from NHC 2015).



Other Results

NHC also reviewed the occurrences of high tributary inflow events between the survey periods and found that maximum instantaneous flows were above 20 m^3/s during 11 of the 14 survey periods. The bankfull discharge for Lower Jones Creek is approximately 20 m^3/s (Newberry 2004), above which flows can change channel morphology and substrate quality. This indicates that the conditions thought to cause changes in Lower Jones Creek morphology and substrate quality have been well represented during the program period.

Table 4.2. Summary of data gaps and flows below instream flow targets (ITF; Table from NHC 2015).

Year	Proportion of year with missing data	Proportion of year with flow < IFT or missing data	Proportion of spawning period with missing data	Proportion of spawning period with flow < IFT or missing data	Proportion of incubation period with missing data	Proportion of incubation period with flow < IFT or missing data
2005	2%	46%	4%	37%	0%	58%
2006	2%	21%	8%	61%	1%	22%
2007	32%	46%	0%	16%	4%	38%
2008	29%	48%	100%	100%	8%	48%
2009	54%	62%	0%	35%	59%	59%
2010	0%	0%	0%	2%	0%	0%
2011	0%	2%	0%	8%	0%	0%
2012	1%	11%	3%	42%	2%	7%
2013	5%	10%	16%	35%	3%	6%
2014	1%	6%	0%	20%	1%	3%
2015	0%	28%	0%	40%	0%	9%

4.3 WAHMON-3 Herrling Island Side-Channel Chum Spawning Success Monitoring

4.3.1 Project Summary

Objectives	Management Questions[1]	Response
To assess the effectiveness of Wahleach Generating Stations operations to minimize salmon fry stranding and assess stranding risk of adult spawners associated with the operations.	1. Will the recommended operational measures keep spawning away from marginal areas? 2. Do the operational measures in the fall result in minimal fry stranding in the spring? 3. Will the operational measures in the fall result in stranding of adult spawners?	1. Spawning and redd stranding still occurred in marginal areas with the operational measures. However, observations of higher numbers of Pink Salmon embryos in non-marginal areas indicates that spawners are more likely to spawn in areas that do not become dewatered. In 2009, numerous adult Pink Salmon were stranded, and in 2010 as a corrective action, exclusion fencing was installed and continues to be installed annually to prevent adult stranding events. 2. Redd stranding was found in all years except in 2007 when high Fraser River mainstem flows supplemented side channel flows. Incidences of both fry and redd stranding were encountered. 3. The 2-hour shutdown operational measure did not mitigate all adult stranding. Adult stranding was observed in all years except 2007and 2008 when flows were above and below average respectively. Since 2010, exclusion fences have been effective in reducing adult stranding and subsequent redd stranding.

[1]BC Hydro 2005c

4.3.2 Project Approach

The Wahleach Generating Station is typically operated to meet local peak electricity demand. This can result in daily fluctuations in discharges to the Herrling Island Side Channel of the Fraser River. These changes in discharge aren’t as noticeable during the Fraser freshet. However, between August and early May of each year, when Fraser River flows are not directly connected to and have little influence on side channel flows, the change in generating station discharge can result in a larger effect on the availability of wetted habitat within the side channel.

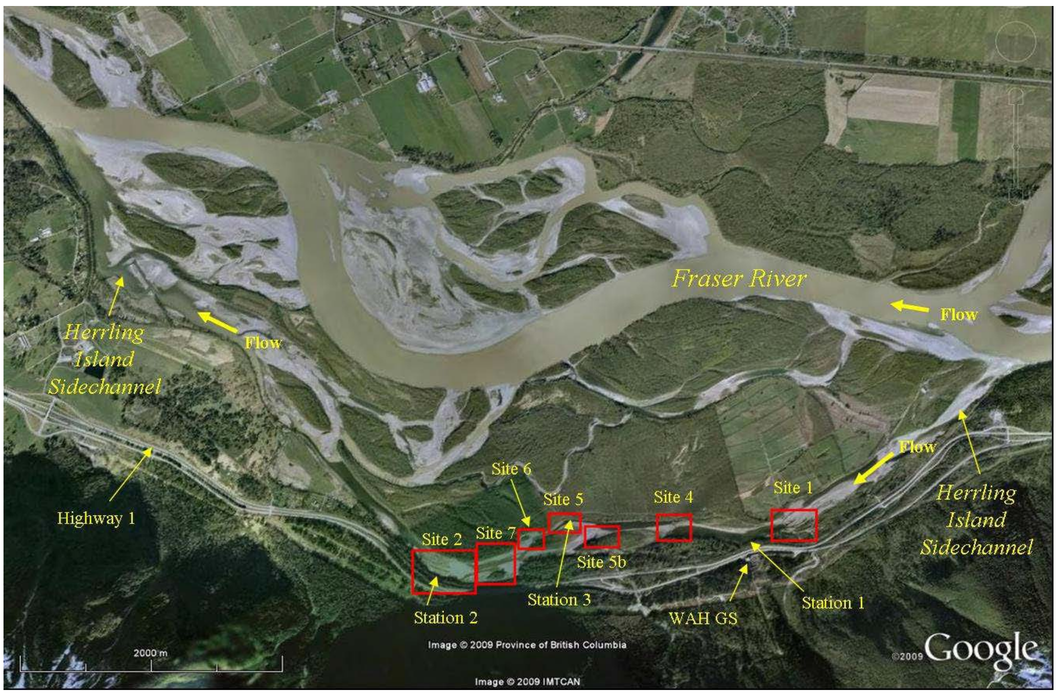
The Herrling Island Side Channel Chum Spawning Success Monitoring Program was conducted from 2005 to 2009 to assess the efficacy of the WUP prescribed operational changes to mitigate salmon adult spawners, redd and fry stranding. The monitoring program was completed by LGL Ltd., and reports were compiled each year following 2006. The final 2010 report summarized results for the study period. All reports are available at the following BC Hydro’s WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/wahleach.html).

The general approach to this monitoring program was to carry out adult stranding and redd dewatering assessments from 2005 to 2009. This represented five years of Chum and two years of odd-year Pink Salmon monitoring as the 2005 Pink spawning year was missed. Adult counts were completed over a portion of the spawning run period. Stranded fish were counted as either being alive or as a mortality. Crews also enumerated dewatered redds and the total number of spawners.

The project team determined that it was difficult to assess responses to spawning site selection in relation to operational changes due to observer limitations, variable or turbid water conditions and high spawning adult densities, particularly during the 2009 Pink spawning year when there was a large Fraser River Pink Salmon escapement. An addendum to the TOR was made in December 2007 to include the mapping of Pink Salmon egg distribution after the peak spawning period using hydraulic sampling to better assess spawning site selection.

Figure 4.3.a. Aerial photograph of the Herrling Island Side Channel showing the Wahleach Generating Station (WAH GS), three hydrometric stations, and index sites used to monitor Pink and Chum Salmon spawning activity in 2009-10 (from LGL 2010).



4.3.3 Interpretation of Data

Spawner stranding assessments showed variable results over the monitor but were often confounded by environmental conditions such as high or low and turbid water conditions.

The three key management questions relating to the operational change of the Wahleach Generating Station (GS) and its effects on fish stranding are discussed below.

Answers to Management Questions

1. **Will the recommended operational measures keep spawning away from marginal areas?**

The following hypothesis was developed to address this management question:

H_1: Suspending Wahleach generation for two hours daily during the spawning period does not deter spawning from marginal areas.

Spawning occurred in marginal areas in most years. Hydraulic redd sampling of the 2009 brood year for Pink Salmon found significantly higher numbers of embryos per sampling effort in the non-marginal sites indicating that spawners are more likely to spawn in the areas that do not become dewatered. Fewer viable redds were found in the marginal sites compared to the non-marginal sites, but there was no significant difference between the percent of live embryos between them. Though the redd distribution data suggest a higher concentration of redds in continuously submerged habitats, it is unclear whether this is the result of Wahleach GS operations, or the natural distribution of spawning.

The study was unable to assess the efficacy of the Wahleach GS two hour daily shut downs with only one year of redd sampling. Ideally, the study would need to assess years with and without the daily two hour GS shutdowns.

2. **Will the operational measures in the fall result in stranding of adult spawners?**

The following hypothesis was developed to address this management question:

H_3: Suspending Wahleach generation for two hours daily during the spawning period does not result in stranding of spawning adults.

Stranding of spawners was observed in all years except 2007 and 2008. Results were confounded by very high flows in 2007 that tended to flush stranded fish away, and by very low flows in 2008, which prevented fish from accessing the marginal sites during operations. Since adult stranding was observed in most years during average Fraser River flow conditions using the shutdown operations, this hypothesis was rejected.

3. **Do the operational measures in the fall result in minimal fry stranding in the spring?**

The following hypothesis was developed to address this management question:

H_2: Suspending Wahleach generation for two hours daily during the spawning period does not eliminate fry or redd stranding caused by operations.

Redd stranding was found in all years except in 2007 when Fraser River flows were high and Herrling Side Channel flows were connected with and influenced by the mainstem Fraser. A complete elimination of redd stranding with this operation is not likely to occur in any year. Only one successful assessment of salmon fry stranding was completed as part of this study on 14 April 2008 when approximately 50 live and two dead salmon fry were found stranded. Incidences of both fry and redd standing were encountered and therefore were not ‘eliminated’ by the operation. As such, this hypothesis was not rejected.

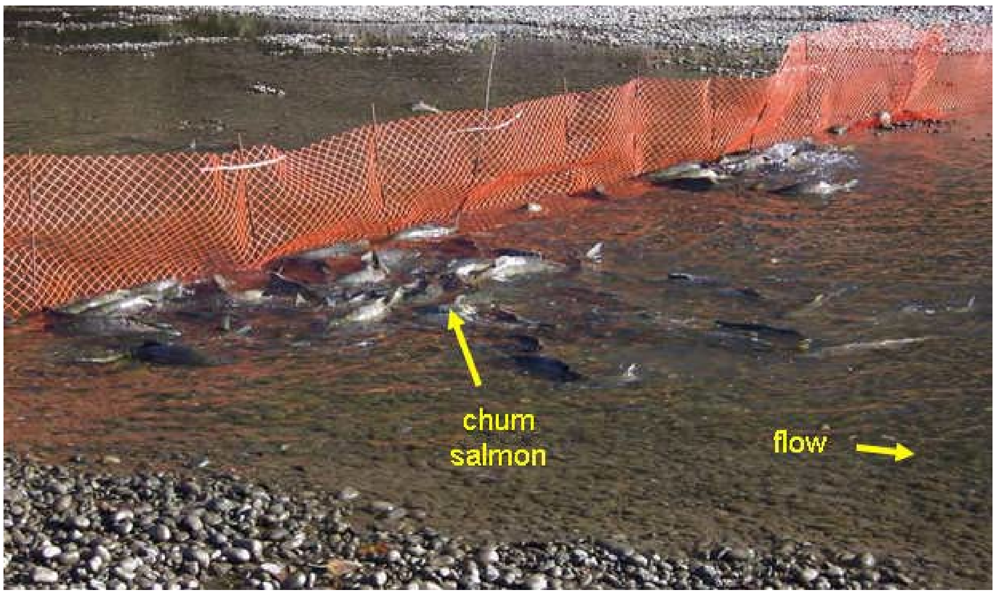
Table 4.3. Summary of Pink and Chum Salmon stranding assessment in the Wahleach side-channel. Note the percentage of the run covered each year is low (≤ 20%). The 2007 results are confounded by Fraser River inundation eliminating the effect of the operational changes.

		2005	2006	2007	2008	2009
Pink	Percentage of run covered (%)	-	-	11	-	11
	Max daily count (N)	-	-	1,185	-	3,000
	Stranded (N)	-	-	15	-	30
	Mortality (N)	-	-	0	-	200
	N or % of redds dewatered	-	-	0	-	192
Chum	Percentage of run covered (%)	20	20	5	20	10
	Max daily count (N)	286	349	281	360	
	Stranded (N)	29	2	0	0	15
	Mortality (N)	0	0	0	0	16
	N or % of redds dewatered	35 or 46%	88%	0	75%	3

Other Results

BC Hydro directed the installation of adult spawner exclusion fencing in the Herrling Island Side-Channel starting in 2010 to limit fish access and reduce spawning in marginal areas after a large stranding event in 2009. The installation of exclusion fencing has continued each fall since then. This mitigation measure was found previously to be successful at managing spawning activities (Moore et al 2004). Though effective, fish exclusion fences are temporary in nature and can be breached by high flows, bears, and high densities of spawners. As such, future deployments will require sturdy installation, regular monitoring and maintenance.

Figure 4.3.b. Chum Salmon trying to pass an exclusion fence installed in site 1, November 2009. Photo by Living Streams Environmental Services, West Vancouver.



5.0 ORDERED PHYSICAL WORKS SUMMARY

5.1 WAHWORKS-1 Boulder Creek Diversion Bypass

5.1.1 Project Summary

Boulder Creek is a tributary of Lower Jones Creek. During the development of the Wahleach hydroelectric project, the Boulder Creek Diversion was constructed to divert the flows into Jones Lake to increase reservoir inflows and generation potential. The diversion structure included the installation of a gated culvert bypass intake structure through the diversion dike which allowed some flow to bypass the diversion facility and spill into the original Boulder Creek channel, which in turn discharged into Lower Jones Creek downstream of the reservoir. Due to erosion and channel degradation in Boulder Creek adjacent to the bypass intake, the intake became inoperable and was eventually abandoned (BC Hydro 2016b).

The Wahleach WUP Order required that flows be reinstated through the bypass intake for Lower Jones Creek. This project consisted of installing a weir on Boulder Creek immediately downstream of the bypass intake structure to increase water elevations in the creek channel at the intake. This would enable the bypass intake gate to be sufficiently inundated so that it could provide augmented flows when needed to meet the minimum flow requirements for Lower Jones Creek.

Objectives	Source of Requirement	Outcome
The fish-water bypass gate on Boulder Creek must be operated such that the first 0.14 m^3/s of water flowing in Boulder Creek at the point of the fish-water bypass gate is divered through the diversion channel into Wahleach Lake Reservoir. For a period of five years from the issuance of this order, BC Hydro shall operate the existing works and necessary temporary works to provide the required flow.	Schedule A of *Water Act* Order Section 88 dated January 18th, 2005, Clause 2	First construction: 2005 Modification 1: 2007

5.1.2 Project Approach

The following were key phases and activities of the project:

1. Feasibility phase:
2. Design phase:
    - Confirmed CWR budget and approval to proceed to design and costing;
    - Prepared detailed design drawings; and
    - Acquired permits and regulatory approvals.
3. Implementation / Construction phase:
    - Development of environmental management, safety plans; and
    - Constructed the project to design specifications ensuring appropriate safety and environmental management.
4. Completion phase:
    - Developed record drawings, construction report, and added to the facility operating orders.

5.1.3 Project Outcomes

5.1.4 Identification / Feasibility Phase

Originally, a lock-block weir was constructed in 2005. As per the Order, it was intended as a temporary structure to allow partial diversion of flows from Boulder Creek to Lower Jones Creek and permit the collection of monitoring data to assess the effectiveness of enhancing Jones Creek flows with Boulder Creek flows. At the conclusion of the monitoring study data collection period, a decision would be made whether to install a permanent structure in Boulder Creek for flow diversion, or to decommission the structure.

This original weir design was completed by BC Hydro Engineering staff and consisted of a headpond and lock-block weir structure on Boulder Creek, for the purpose of maintaining flows on the right bank of the creek and to promote sediment accumulation on the left. The original lock-block structure constructed in 2005 failed in November 2006 after a significant storm event, providing limited data for the decision making process. A subsequent Newbury style rock weir was built in summer 2007 (BCH Hydro Engineering, 2007).

5.1.5 Design

Following the lock-block weir failure, the Newbury style weir was designed to withstand a one in 50-year flood event (BC Hydro 2016b). As with the lock-block weir, a low-flow channel on the right bank was incorporated into the weir design to manage sedimentation and to provide fish access to habitats upstream of the weir during lower base flow conditions.

The replacement Newbury style rock weir was based on multiple considerations (e.g. high energy nature of Boulder Creek, minimizing disturbance, two-week work window) and an analysis of the failure mechanism of the original lock-block weir. It was proposed that the new weir extend downstream to dissipate energy and protect the toe under high flows and be constructed so that the upstream crest elevation would consistently backwater the intake. The weir was to have a wedge shape to minimize energy loss and be constructed from appropriately sized and graded materials larger than the observed bedload in Boulder Creek. Providing a low flow channel and tapering the downstream face of the weir would promote fish access by eliminating over-steepened sections (WAHWORKS 1 – 2007 TOR).

Figure 5.1.a. Boulder Creek lock-block weir, August 2005 (BC Hydro 2006)

Figure 5.1.b. Replacement Boulder Creek Newbury style weir, October 2015 (BC Hydro 2016).

5.1.6 Implementation / Construction

The original lock-block structure constructed in 2005 failed in November 2006 during a high flow event. Construction of the Newbury weir was completed during August and September of 2007 and was undertaken in the following sequence: site preparation, base placement, weir construction, grade lifting, and low-flow channel construction. An Environmental Management Plan was prepared, and an environmental monitor was onsite throughout construction.

5.1.7 Sustainment / Ongoing Maintenance

As the current Newbury style weir was initially considered to be a temporary structure, it was only designed to withstand moderate flow events (<30 m3s), however surveys completed in 2010 and 2015 determined that the weir was in stable condition, was performing as designed, and had remained passable to fish (BC Hydro 2010b and 2016). Anecdotal observation information confirmed that the low-flow channel remained passable to upstream migrating Kokanee.

Recommendations were made to continue monitoring the efficacy of the structure and to conduct an Engineering inspection after any in-flow events greater than 20 m^3s. BC Hydro Dam Safety conducts inspections on the Boulder Creek diversion dam, channel and bypass intake semi-annually and ensures any necessary maintenance is undertaken (BC Hydro 2020). Maintenance works were conducted on the toe of the diversion dam during the summer of 2021 (Andrew Walter, EFO pers comm).

5.1.8 Completion

Until the recent November 2021 storm event, the Newbury style weir and associated Boulder Creek intake operated successfully since the 2007 construction. However, during the 2021 event, the weir became damaged (Figure 5.1d), and as a consequence, the intake became infilled with sediment and made non-functional (Figure 5.1e). Subsequently, the intake and weir will require maintenance in the near future. Since 2007, Kokanee (*Oncorhynchus nerka*) spawning in Boulder Creek has been limited with the majority of Kokanee spawning now occurring in other reservoir tributaries (Jones and Flat Creeks), which are also more suitable for Kokanee spawning and early rearing (WAHWORKS-2), future weir designs and flow requirements should consider this change in preferred Kokanee spawning habitat.

Deliverables on project completion included record drawings which are stored in BC Hydro's McLaren system and in the supplied operations and maintenance manual for the site works.

Figure 5.1.c. Boulder Creek Newbury weir, June 2021 (photo taken by Andrew Walter, EFO)

Figure 5.1.d. Boulder Creek Newbury weir, post November 2021 storm (photo taken by Frank Weber)

Figure 5.1.e. Boulder Creek intake, post November 2021 storm (photo taken by Frank Weber)

5.2 WAHWORKS-2 Wahleach Reservoir Fertilization Program

5.2.1 Project Summary

BC Hydro initially funded a reservoir fertilization and Kokanee restoration program in Wahleach Reservoir from 1995 to 2001 to support the re-establishment of the Kokanee (*Oncorhynchus nerka*) population and to offset project construction impacts prior to initiation of the Wahleach WUP.

After the WUP, the BC Ministry of Environment and Climate Change Authority (BC ENV) implemented the program in partnership with BC Hydro which was intended to provide long term fertilization of the reservoir, re-establishment of the Kokanee population, and reduction of the competing Three-spine Stickleback (*Gasterosteus aculeatus*) population by stocking predatory sterile Cutthroat Trout (*Oncorhynchus clarkii*).

The terms of reference (TOR) for the works project prescribed an annual fertilization program with the intent to mitigate the impacts of reservoir fluctuations within the operating range that was prescribed by the Order. The objective of the fertilization program is to enhance reservoir productivity in order to restore and maintain Kokanee abundance in Wahleach Reservoir. The following performance measures were evaluated over the course of the review period to determine if the objective was being met:

- *Spawners Abundance:* Annual assessments of tributary spawning by Kokanee;
- *Reservoir Fish Population:* Annual and biannual estimates of

population all fish species; and

- *Phytoplankton and Zooplankton Production:* Regular limnology assessments throughout the fertilization application period each year to assess the physical, chemical and biological characteristics of the reservoir and nutrient loading. This included detailed assessments of species composition and annual estimates of phytoplankton and zooplankton production in the reservoir.

The key uncertainty related to the WUP Consultative Committee recommendation is whether the fertilization program would be necessary to maintain the Kokanee population in Wahleach Reservoir.

The synopsis of this works program is based primarily on the 2009-2015 program review report (Sarchuk et al 2019) and the 2019–2020 study report (Vainionpaa, H.E. et al 2021) but is also based on reports from additional years of the program. All the study reports including the 2009-2015 and 2019-2020 monitoring reports provide summaries of the findings from each of the program years, and comparisons to the pre-treatment years.

Consult the program reports (annual and multi-year) and their detailed analysis for additional information, which are available at the following website: https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/wahleach.html

Objectives	Source of Requirement
To restore and maintain Kokanee abundance in Wahleach Reservoir	*Water Act* Order Section 88

5.2.2 Project Approach

BC Hydro and BC ENV confirmed the collapse of the Kokanee population in Wahleach Reservoir in the late 1990's. The collapse was attributed to reductions in productivity resulting from reservoir level fluctuations and associated reductions in littoral productivity as well as competition from introduced Three-spine Stickleback. To improve productivity conditions, a fertilization and fish management program was initially implemented between 1995 and 2000 by BC Hydro and BC ENV. The program also included restocking the reservoir with Kokanee between 1999 and 2004. The efficacy of the program with increasing primary productivity in the reservoir and with managing the fish populations was confirmed in these earlier studies (Perrin et al 2006). BC ENV continued the fertilization program with support from BC Hydro during the WUP process starting in 2002. The WUP would later prescribe continuing a fertilization program as an alternative to additional operational changes. The program was to focus on:

- Long-term fertilization of the reservoir to enhance primary productivity and food resources for fish in the reservoir;
- Limnology monitoring after the nutrient additions;
- Fish population and Kokanee spawners abundance monitoring; and Short-term stocking of sterile Cutthroat Trout to reduce Threespine Stickleback populations and reduce competition for food resources with Kokanee.

BC ENV continues to deliver the program in partnership with and support from BC Hydro. The program design has undergone minor changes through the years of implementation though the primary components of the program have not changed. Annual fertilization additions were to be supplemented by limnology and fish population monitoring programs designed to ensure program effectiveness and efficiencies, evaluate in-season progress and enable fine-tuning, as required. The Wahleach Reservoir fertilization program has several components:

- *Fertilizer Application/Nutrient Addition:* The application of agriculture grade fertilizer for nutrient enhancement. Conducted each year from early June through to late September.
- *Chemical/Physical Limnology Monitoring:* Sampling to be based on the fertilizer application schedule to be conducted from late May through to October. Limnology sampling to be completed at selected reservoir monitoring locations throughout the fertilization application period each year to confirm appropriate fertilizer application rates and to monitor project outcomes.
- *Fish Population and Kokanee Spawner Monitoring:* Will be conducted annually or biannually with timing dependent on the type of monitoring which will typically occur between late July and October.

5.2.3 Project Outcome

5.2.3.1 Interpretation of Data

Program implementation consisted of three components: nutrient addition, water quality and plankton monitoring, and fish population and Kokanee spawner monitoring. Each of these components and their associated results are summarized as follows:

Nutrient Addition and Monitoring

From 2005 to 2020, agricultural grade liquid ammonium polyphosphate (10-34-0: N-P_2O_5-K_2O; % by weight) and urea-ammonium nitrate (28-0-0: N-P_2O_5-K_2O; % by weight) fertilizers were added weekly to Wahleach Reservoir from early June to late September.

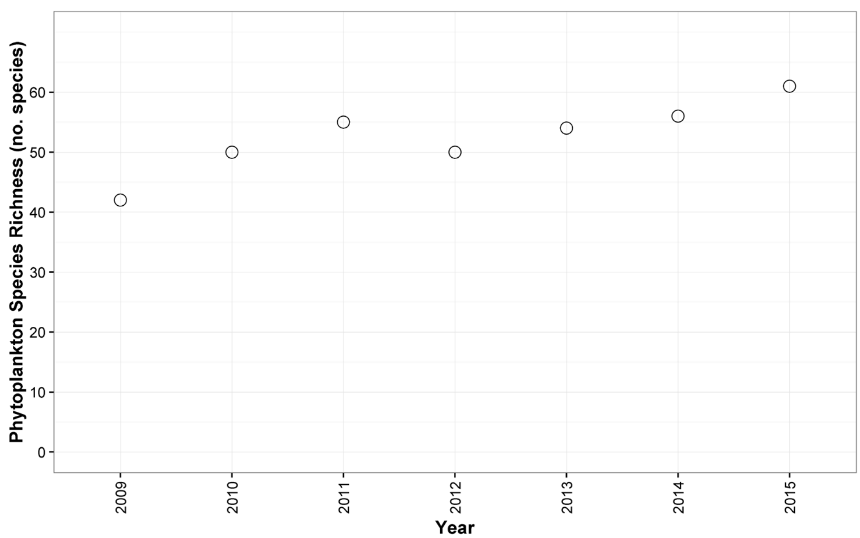
The annual nutrient additions ended each year after a 20-week period or once the reservoir turned over, whichever came first. During this nutrient addition period, the monthly monitoring of biological, physical and chemical parameters in the reservoir was completed and the ratio of fertilizer blends, timing of additions, and total amounts added to the reservoir were adjusted based on the monitoring results.

Plankton Monitoring

Phytoplankton

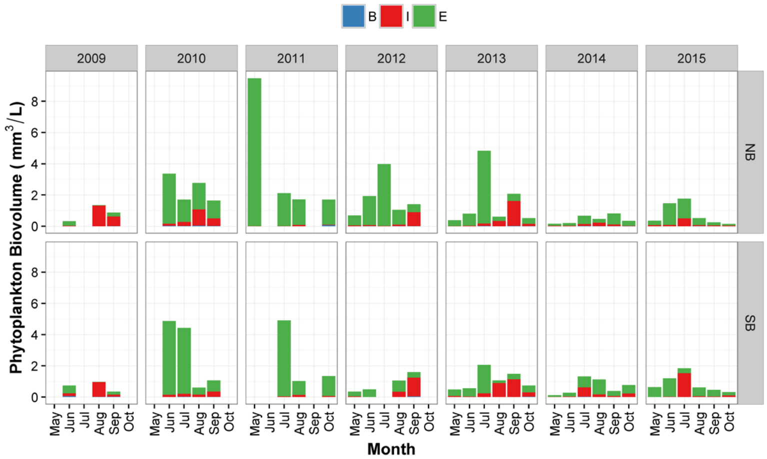
Plankton sampling was conducted through the limnology sampling and was important for recording the effect of the nutrient enhancement in providing available food organisms for fish. Phytoplankton densities and composition change seasonally and are dependent on many factors including being flushed out of the reservoir, sinking to the bottom, and zooplankton grazing. No consistent trend was reported between the program years and pre-treatment years for density or bio-volume of phytoplankton, though there was a recorded increase in species richness (Figure 5.2a).

Figure 5.2.a. Phytoplankton species richness (number of species detected), 2009-2015, Wahleach Reservoir, BC (from Sarchuk 2019).



There were differences also recorded with species composition between the program years and pre-treatment years. Species composition in pre-treatment years was represented by diatoms and *dinophytes* while *chrysophytes* and *cryptophytes* were predominant in many later years. Species of *chrysophytes* and *cryptophytes* observed were also in the edible size range for zooplankton.

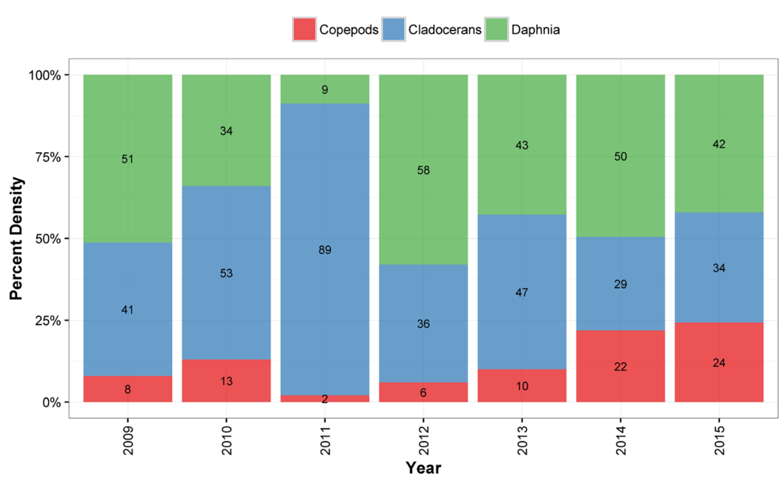
Figure 5.2.b. Seasonal phytoplankton biovolume ($mm^3 \cdot L^{-1}$) by edibility (I=inedible, B= both edible and inedible forms) at the north basin (NB) and south basin (SB) limnology station May to October, 2009-2015, Wahleach Reservoir BC.



Zooplankton

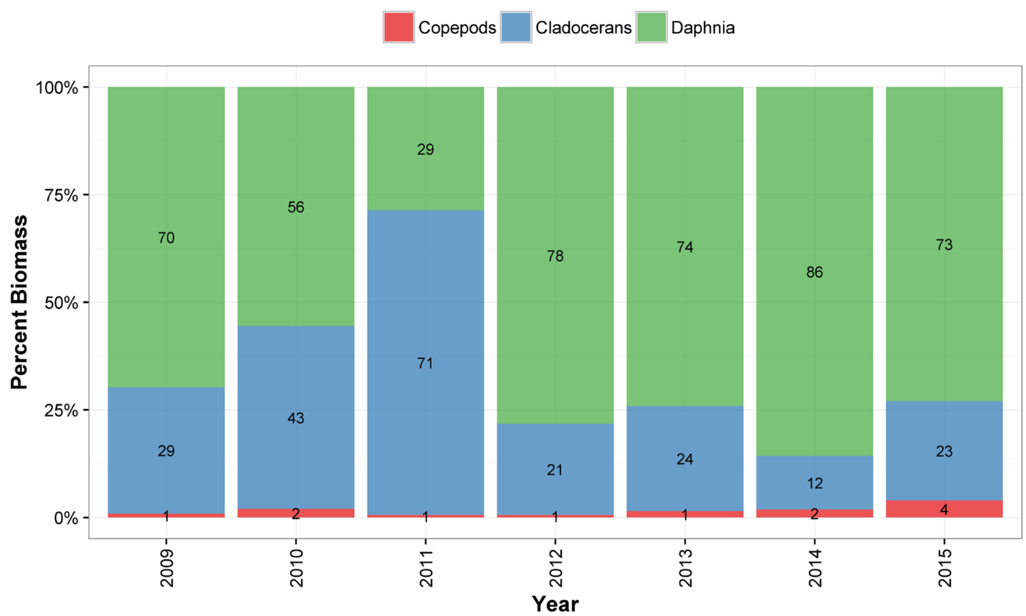
Zooplankton densities were significantly higher during the program years compared with 1993-94 pre-treatment years (Vainionpaa, H.E. et al 2021). Overall, the zooplankton community in Wahleach Reservoir during the program represented a significant increase in food availability for planktivores such as Kokanee relative to baseline years. Density of *Daphnia sp.* was consistently higher for the program compared to the pre-treatment years and represented nearly half of the total density.

Figure 5.2.c. Relative contribution (%) of each major group (Copepods, *Daphnia* and other Cladocerans) to annual (May-October) zooplankton density, 2009-2015, Wahleach Reservoir BC (from Sarchuk et al 2019).



Daphnia sp. are favoured by Kokanee and were absent from pre-treatment samples until 1997. The program results indicate that zooplankton density was largely driven by cladocerans other than Daphnia early in the season with a shift to Daphnia as the dominant in both density and biomass in July and August, and then a shift back to other cladocerans in October. Zooplankton populations varied amongst program years, but between 2009 and 2015 Daphnia made up to ~58% of the seasonal density and up to ~86% of biomass, while other cladocerans made up to ~89% of density and up to ~71% of the biomass (Figures 5.2c & d).

Figure 5.2.d. Relative contribution (%) of each major group (Copepods, *Daphnia* and other Cladocerans) to annual (May-October) zooplankton biomass, 2009-2015, Wahleach Reservoir BC (from Sarchuk et al 2019).



Fish Population Monitoring

Nearshore Gillnetting and Minnow Trap Sampling

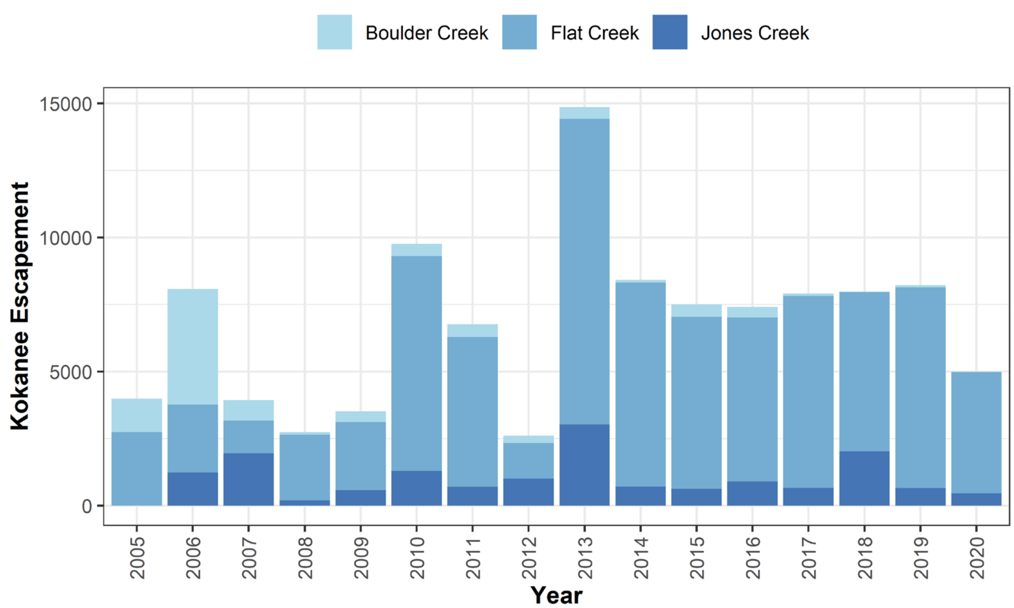
Fish sampling was completed in October of each program year using six provincial standard lake inventory nets. In each year, nets were set at six stations near dusk consisting of three floating nets and three sinking nets. Nets were fished overnight and retrieved the following morning. Each year, the nearshore gillnetting program captured a mix of Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout and Kokanee. The sizes and age classes of captured Rainbow Trout and Kokanee varied in length and weight during the 2009-2015 study period. Fulton's condition factor for Rainbow Trout was 1.0-1.1 and for Kokanee was 1.1-1.2 during this same period. Cutthroat Trout captures were also regularly monitored but no comparisons were made with pre-treatment years since sterile Cutthroat were first introduced in 1997 to control the Threespine Stickleback population. Minnow traps were also set in nearshore habitats to monitor

Threespine Stickleback abundance. Stickeback captures varied between years but were lower than pre-Cutthroat Trout stocking years.

Kokanee Spawner Surveys

Spawner surveys were completed annually in Boulder, Flat and Jones Creeks. Live spawners and carcasses were enumerated from the confluence with Wahleach Reservoir to 600 m upstream on Boulder Creek, 1,000 m upstream on Flat Creek, and 400 m upstream on Jones Creek. Escapement estimates were generated using an area-under-the-curve method (AUC; Irvine et al. 1993) with weekly live-counts completed through the peak spawning period. Challenges encountered with spawner counts included regular Black Bear (*Ursus americanus*) encounters and reduced visibility during high flow events. Kokanee spawner numbers varied between years of the program with a tendency towards the most abundance over time in Flat Creek followed by Jones and then Boulder Creek. Spawning in Boulder Creek has decreased significantly since the start of the program (Figure 5.2.e).

Figure 5.2.e. Annual Kokanee escapement estimates from 2005-2020, Wahleach Reservoir, BC (updated chart provided by J. Sarchuk 2021).

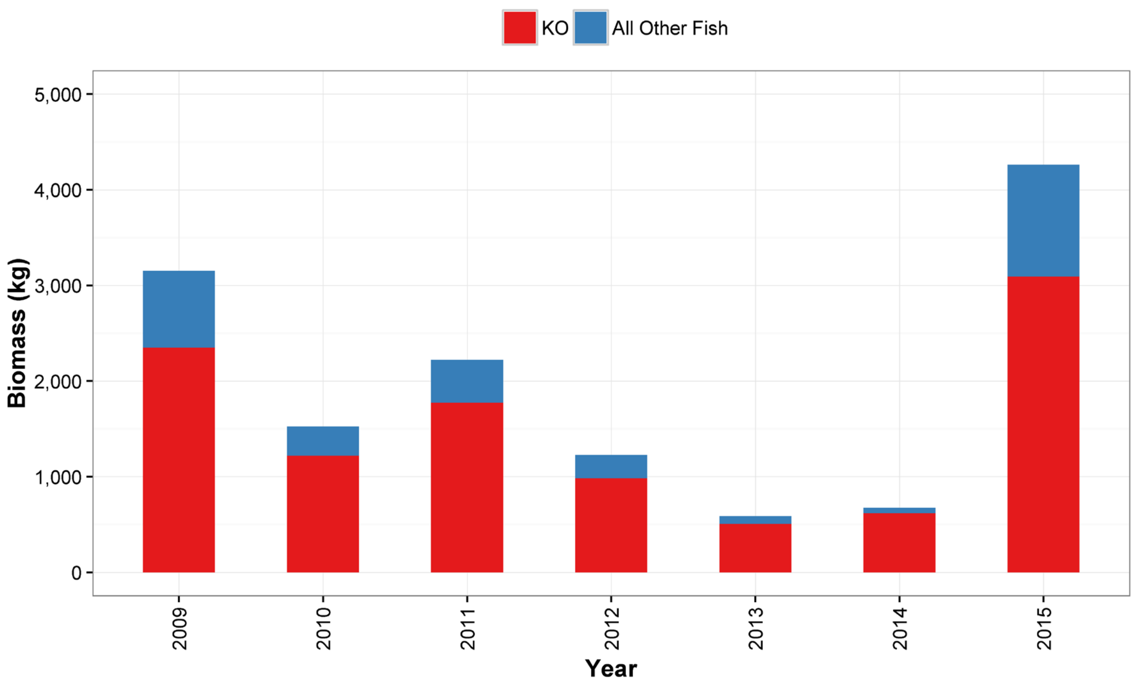


In 2019, the Kokanee escapement was estimated to be 9,599 fish (84 Boulder; 8,791 Flat; 719 Jones). The 2013 escapement was the highest on record since 2005 and hasn't been recorded since. The 2020 estimate was significantly lower than the previous seven years (Figure 5.2.e).

Hydroacoustics

Hydroacoustic surveys were completed during late July or August of each year along 11 transects in the reservoir. Surveys were completed about 1 hour before sunset during the new moon phase. The Kokanee population was calculated over a depth range of six to 30 m. Figure 5.2.f summarizes the results of the 2009-2015 surveys.

Figure 5.2.f. Total fish biomass by species group (as determined by depth analysis) in Wahleach Reservoir, 2009-2015 (from Sarchuk et al 2019).



Trawl and Pelagic Gillnet Sampling

To calibrate hydroacoustic surveys and to further inform population composition, trawl net sampling and pelagic gillnetting were completed during the hydroacoustic sampling period. However, trawl net sampling was eventually dropped from the program due to challenges with efficacy. For example, three trawls net sets in 2013 only caught 41 (86%) Kokanee and 5 (14%) Threespine Stickleback. In contrast, a total of 104 fish were caught during pelagic gillnetting, of which 94 (90%) were Kokanee, 6 (6%) Cutthroat Trout, 3 (3%) Rainbow Trout, and 1 (1%) Threespine Stickleback.

5.2.4 Conclusions

This fertilization program continues to mitigate reductions in productivity resulting from reservoir level fluctuations and associated reductions in littoral productivity. Program monitoring data and further evidence from multiple other systems across BC (i.e. Alouette Reservoir see Herbet et al. 2016), has shown that seasonal nutrient additions to Wahleach Reservoir have had a positive effect on primary productivity. The program has also confirmed that stocking sterile Cutthroat Trout continues to provide top-down pressure on the Threespine Stickleback population helping Kokanee to take advantage of the improved productivity with reduced competition for available food. The combined enhancement efforts of this program have worked to restore and maintain Wahleach Reservoir's Kokanee population.

Project Objectives/ Requirements	Completion
To restore and maintain Kokanee abundance in Wahleach Reservoir.	Nutrient additions to Wahleach Reservoir commenced in 1995 and have continued to date with the exception of 2000 when there were limited additions, and 2001 and 2002 where there were none. Since the start of the program, agricultural grade liquid ammonium polyphosphate and urea-ammonium nitrate were added weekly to Wahleach Reservoir from early June to late September annually. The nutrient additions ended each year after a 20-week period or once the reservoir turned over, whichever came first. During this 20-week period, monthly limnology sampling was conducted to monitor chemical, physical and biological parameters within the reservoir and the ratio of fertilizer blends, timing of the additions, and the total amounts added to the reservoir were adjusted based on these monitoring results. Fish sampling was also conducted annually or biannually and included nearshore gillnetting and minnow trapping, Kokanee spawner surveys, hydro-acoustics, trawl netting (in earlier years) and pelagic gillnetting. The fertilization program has been successful in achieving the objectives of enhancing primary productivity and maintaining the Kokanee population in Wahleach Reservoir.

5.3 WAHWORKS-3 Lower Jones Creek Channel Enhancement Project

5.3.1 Project Summary

A habitat enhancement program for Lower Jones Creek was agreed upon in 2006 through the WUP process. Of the alternatives proposed, the selected options included the excavation of an off-channel rearing habitat in Lower Jones Creek and the placement of spawning gravels and cobbles in Lorenzetta Creek near its confluence with Lower Jones Creek. Lorenzetta Creek was chosen for enhancement because of its stable flow regime and proximity to Lower Jones Creek.

Objective	Source of Requirement	Outcome
Improve fish productivity in Lower Jones Creek through habitat enhancement.	Schedule D of *Water Act* Order Section 88 dated January 18th, 2005	Completed First construction: 2006 Modification 1: 2008

5.3.2 Project Approach

The following were key phases and activities of the project:

1. Feasibility phase:
2. Design phase:
    - Confirmed CWR budget and approval to proceed to design and costing;
    - Prepared detailed design drawings; and
    - Acquired permits and regulatory approvals.
3. Implementation / Construction phase:
    - Development of environmental management, safety plans; and
    - Constructed the project to design specifications ensuring appropriate safety and environmental management.
4. Completion phase:
    - Developed record drawings, construction report, and added to the facility operating orders.

5.3.3 Project Outcomes

5.3.3.1 *Identification / Feasibility Phase*

A spawning channel was constructed in 1953/54 to address fish productivity concerns by providing stable spawning, incubation and early rearing habitat for Chum and Pink Salmon. The channel was the first of its kind in western Canada, was productive and continued operation for nearly 40 years. Excessive substrate movement in Lower Jones Creek began in the 1990's with a large slide in a tributary in the upper Jones Creek watershed downstream from the dam (see Figure 6.3b). In 1993 and 1995, landslide events (see Figure 6.3a), in the upper non-anadromous reach of Jones Creek, approximately 4 km downstream of the dam damaged the spawning channel. The substrate instability and movement, which has not decreased in the past twenty plus years, is due to ongoing erosion of the tributary gully walls and slide paths at their confluences with Jones Creek.

A decision was made in 2002 to decommission the spawning channel and associated weirs due to these long-term watershed instability issues (WAHWORKS 3 – TOR). Decommissioning included the removal of an impassible steel sheet pile wall in Lower Jones Creek and an upstream weir. The works were completed in 2004 and the removals re-established access to the entire anadromous reach downstream of the Laidlaw Bridge. Several mitigative works were initiated during the summer of 2005 to increase channel stability.
An outcome of the WUP process was to once again provide spawning habitat improvements in Lower Jones Creek. As sediment loading remains an ongoing issue in the watershed, enhancement efforts also focussed on Lorenzetta Creek,

near its confluence with Lower Jones, as it provides a relatively clean water refuge for fish from Lower Jones Creek during flood.

Figure 6.3.a. Remnants of 1950's created Lower Jones Creek spawning channel. October 2014 (photo by Teri Neighbour).

Figure 6.3.b. Tributary slide track at confluence with Jone Creek (Google 2004 image).

5.3.3.2 *Design*

A design drawing of several proposed fish habitat enhancements was developed by consultants following a site visit with representatives of BC Hydro and DFO. The design was also later submitted to DFO for review. The supported fish habitat enhancements included constructed off-channel rearing habitats in Lower Jones Creek and enhanced spawning platforms in Lorenzetta Creek.

5.3.3.3 *Implementation / Construction*

Approvals and permits were obtained from the regulatory agencies for instream works in fall 2006. Proposed fish habitat improvements to Lower Jones Creek and Lorenzetta Creek were completed in September 2006. An Environmental Management Plan was prepared, and an environmental monitor was onsite throughout construction.

The enhancement works completed in September 2006 resulted in the construction of 722 m^2 of rearing and spawning habitat (Table 5.3.a, Greenbank 2006), via construction of two off-channel habitat areas (‘A’ and ‘B’) and two cobble/gravel riffles in Lorenzetta Creek (see Figure XX):

- Off-Channel A: a 1.5 to 2 m wide by 94 m long off-channel was constructed within a semi-protected island between two Lower Jones Creek channels upstream of its confluence with Lorenzetta Creek. It included an over-widened section midway and several over-excavated pools, all with added wood debris for shade and cover. An estimated 226 m^2 was created by this off-channel feature (see Table 5.3.a).
- Off-Channel B: a short channel through the previously constructed downstream-most rock groyne, connecting an existing pond to the Lorenzetta Creek channel. Excavated material was used to fill in a low area between the

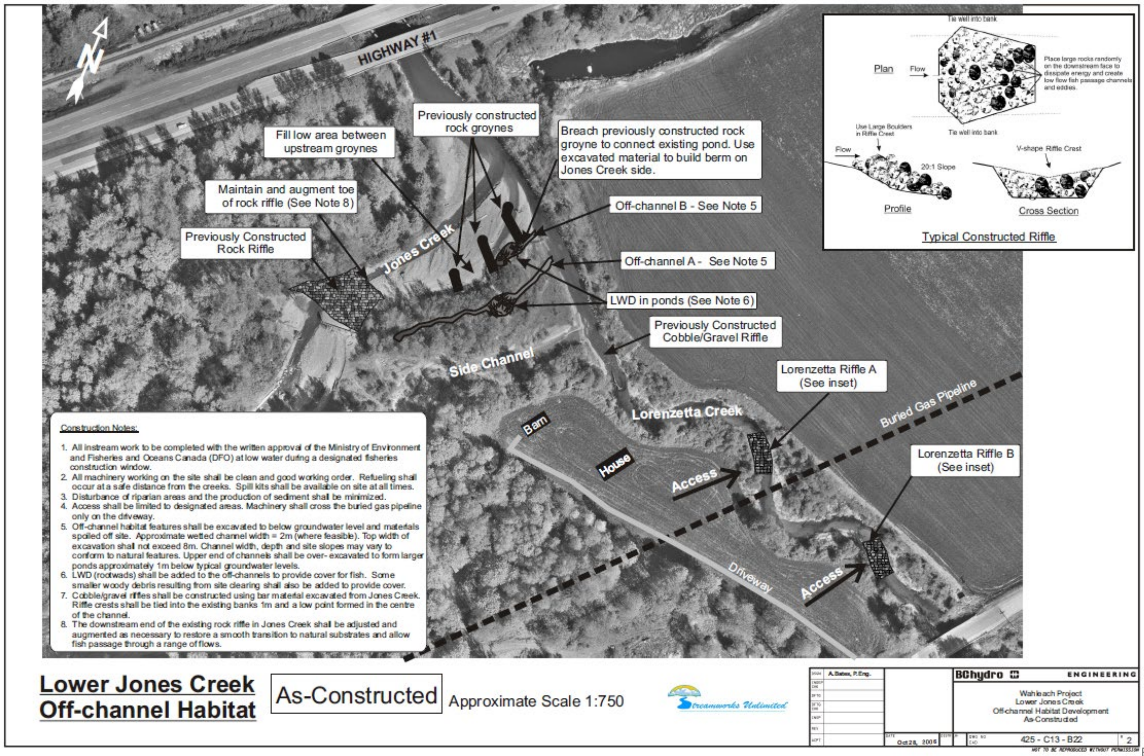
upper groynes and protect the newly connected pond. An estimated 208 m^2 was created by this off-channel feature (see Table 5.3.a).

- Two cobble/gravel riffles were constructed in Lorenzetta Creek, upstream of the previously constructed riffle and downstream of Laidlaw Road Bridge. An estimated 288 m^2 was created by these spawning riffles (See Table 5.3.a).
- Additional large rock was placed at the lower end of the existing rock riffle in Jones Creek to ensure continued fish passage and riffle stability.
- Large logs were placed over the newly excavated channels near Lorenzetta Creek to serve as foot bridges.
- A recently constructed beaver dam on Lorenzetta Creek upstream of the Jones Creek confluence was breached to maintain fish passage.

Table 6.3. Summary of habitat enhancements in Lower Jones Creek completed in September 2006 (From Greenbank, 2006).

Habitat Feature	**Dimensions** (length x width in meters)	**Area** (m^2)
Off-Channel A		
Upper	52 x 1.75(avg)	91
Mid-Pond	12 x 7.5	90
Lower	30 x 1.5	45
Subtotal		**226**
Off-Channel B	26 x 8	208
Lorenzetta Riffle A	13.5 x 8.5	115
Lorenzetta Riffle B	16.5 x 10.5	173
Total		**722**

Figure 6.3.c. As constructed habitat enhancements



In September 2008, modifications were completed after the initial enhancement works to improve through-flows in the off-channels. Sediment loading and channel movement continued to be an issue in Lower Jones Creek, as well as in the adjacent constructed off-channels, so a surface water connection was ruled out. An infiltration gallery designed to increase groundwater recruitment was installed in hopes that this would bring clean water into the off-channel habitats regardless of the condition of Lower Jones Creek. Despite the infiltration gallery installation, constant channel shifting resulted in a variable supply of clean water. Further maintenance work was considered but was dismissed based on the considerable instability of the adjacent channel.

5.3.3.4 *Sustainment / Ongoing Maintenance*

During the 2010 freshet, fine sediment accumulation infilled a large portion of the off-channel rearing habitat making it unusable (see Figure 5.3c). During the 2010 Wahleach WUP Interim Review, it was decided to continue ongoing monitoring of the fish use and stability of the off-channel works. Future maintenance was to be confirmed annually based on condition assessments. In December 2012, the off-channel habitats were reported to be damaged and in-filled with sand.

A site visit and assessment by BC Hydro and DFO in August 2013 confirmed that further maintenance of the off-channel habitats was not warranted or cost effective due to the repeated and substantial infilling of the channels due to significant sediment loading from Upper Jones Creek.

An October 2014 site visit and assessment by BC Hydro and DFO further confirmed that the enhanced riffle habitats in Lorenzetta Creek were still functioning and were being used by spawning salmon (see Figure 6.3d).

Consequently, BC Hydro discontinued monitoring and maintenance of the off-channel rearing habitat. The spawning habitat constructed in Lorenzetta Creek was unaffected by the 2010 freshet or the Lower Jones substrate instability and has been used annually by adult spawners according to the last inspection, which was completed in October 2014. The total habitat created as such is limited to the enhanced spawning riffles in Lorenzetta Creek, totalling 288 m^2.

Figure 6.3.d. Infilling of constructed off-channel habitat. October 2014 (photo by Teri Neighbour).

Figure 6.3.e. Lorenzetta Creek spawning pad. October 2014 (photo by Teri Neighbour).

5.3.4 Completion – Compliance Requirements

Approximately 722 m^2 of fish habitat improvements were constructed near the downstream reach of Lower Jones Creek in 2006, including off-channel rearing habitat in Lower Jones Creek and riffle spawning habitat in Lorenzetta Creek. The rearing habitat was completely infilled in 2010 (Figure 6.3c) due to sediment movement from storms and the 2010 freshet and reduced the amount of enhanced habitat to 288 m^2. Following agreement from DFO (email dated July 8, 2014) that continued excavation of the off-channel habitats was unreasonable due to the continued unstable substrate movement in the upper watershed, BC Hydro applied for and received relief from completing additional works on the off-channel habitats in a letter from the CWR dated November 26, 2014. Any future discussions of habitat enhancement work for Lower Jones Creek should seriously consider the significant instability of the watershed downstream of the dam, as well as the space limitations within the fan and lower floodplain. The recent November 2021 flood event and resulting avulsion of the Lower Jones Creek channel have demonstrated this need (Figure 6.3.f).

The spawning riffles constructed in Lorenzetta Creek upstream from its' confluence with Lower Jones Creek have been used by spawners and were found to be in good condition during the last formal inspection completed by BC Hydro Environment and DFO staff in October 2014, and during a subsequent site visit by Jason McNair in December 2021.

Deliverables on project completion included record drawings which are stored in BC Hydro's McLaren system and in the supplied operations and maintenance manual for the site works.

Figure 6.3.f. Lower Jones Creek avulsion. The infilled historical channel is on the right bank. November 2021 (photo by Jason McNair).

6.0 REFERENCES

Arnason, A.N., Kirby, C.W., Schwarz, C.J., and Irvine, J.R. 1996. Computer analysis of data from stratified mark–recovery experiments for estimation of salmon escapement and other populations. Can.Tech. Rep. Fish. Aquat. Sci. No. 2106.

BC Hydro. 2016. Internal memo from Derek Sakamoto (Engineering) to Teri Neighbour (Water License Requirements) on the status of the Boulder Creek Weir. May 19, 2016.

BC Hydro. 2010a. Wahleach Water Use Plan. Monitoring Program and Physical Work Program Terms of Reference Addendum. Addendum to WAHMON#1– Lower Jones Creek Fish Productivity Index. 11 August 2010.

BC Hydro. 2010b. Internal memo from Derek Sakamoto (Engineering) to Dave Hunter (Fish and Aquatics) on the status of the Boulder Creek Weir. July 8, 2010.

BC Hydro. 2020. Wahleach Dam. Operation, Maintenance and Surveillance Manual for Dam Safety.

BC Hydro. 2006. Internal memo from Derek Sakamoto (Engineering) to Darren Sherbot on the status of the Boulder Creek Weir. November 23, 2006.BC Hydro. 2005a. Wahleach Project Water Use Plan Monitoring Program Terms of Reference. WAHMON-1 Lower Jones Creek Fish Productivity Indices. 17 August 2005.

BC Hydro. 2005b. Wahleach Project Water Use Plan Monitoring Program Terms of Reference. WAHMON-2 Channel Stability Assessment. 17 August 2005.

BC Hydro. 2005c. Wahleach Project Water Use Plan Monitoring Program Terms of Reference. WAHMON-3 Herrling Island Side-Channel Chum Spawning Success Monitoring. 17 August 2005.

BC Hydro. 2005d. Wahleach Water Use Plan Physical Works Terms of Reference. WAHWORKS-1 Boulder Creek Flow Bypass Facility Rehabilitation. July 2005.

BC Hydro. 2005e. Wahleach Water Use Plan Physical Works Terms of Reference. WAHWORKS-2 Wahleach Reservoir Fertilization Program. July 2005.

BC Hydro. 2005f. Wahleach Water Use Plan Physical Works Terms of Reference. WAHWORKS-3 Lower Wahleach Creek Channel Enhancement Project. June 2006.

BC Hydro. 2002. Consulative Committee Report, Wahleach Water Use Plan. BC Hydro, Burnaby, BC. 172 p.

Beschta, R.L., and W. L. Jackson. 1979. The Intrusion of Fine Sediments into a Stable Gravel Bed. J. Fish. Res. Bd. Can. 36(2): 204-210.

Boulton, A.J., S. Findlay, P. Marmonier, E. H. Stanley, and H. M. Valett. 1998. The Functional Significance of the Hyporheic Zone in Streams and Rivers. Annu. Rev. Ecol. Syst. 29:59–81.

Collett D (1994) Modeling Survival Data in Medical Research. Chapman & Hall: London

Comptroller of Water Rights. 2005. Section 88 Water Act Order for the Wahleach hydroelectric system. Issued to BC Hydro and prepared by the Ministry of Environment, Victoria, BC. 6 p.

Cooper, A.C. 1965. The Effect of Transported Stream Sediments on the Survival of Sockeye and Pink Salmon Eggs and Alevin. International Pacific Salmon Fisheries Commission, Bulletin XVIII. New Westminster, BC Canada. 71 p.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117, 1–21.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48: 241 – 261

Decker, S., J. Macnair, and G. Lewis. 2011. Coquitlam River Fish Monitoring Program: 2010 Results. Unpublished report prepared for B.C. Hydro Power Facilities, Burnaby, B.C., June 2011. 134 p.

English, K.K., R.C. Bocking and J.R. Irvine. 1992. A Robust Procedure for Estimating Salmon Escapement Based on the Are-Under-the-Curve Method. Can. J. Fish. Aquat. Sci. V. 49 No. 10 pp. 1982-1989

Greenbank J. and J.C. Macnair. 2010. Lower Jones Creek Fish Productivity Monitoring: Year 5 interim review. Prepared for BC Hydro Generation and Aboriginal Relations. pp. 50

Greenbank J. and J.C. Macnair. 2008. Lower Jones Creek Pink Fry Incubation: Year 1. Prepared for BC Hydro Generation and Aboriginal Relations. pp. 34

Hebert, A.S., G.F. Andrusak, S.L. Harris, H. Andrusak and T. Weir. 2016. Alouette Reservoir Nutrient Restoration Project, 2014-2015. RD 154. Ecosystems Protection & Sustainability Branch, BC Ministry of Environment and Climate Change Startegy.

Hilborn, R., Bue, B.G. and S. Sharr. 1999. Estimating spawning escapements form periodic counts: a comparion of methods. Can. J. Fish. Aqaut. Sci. 56:888-896.

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.

Jensena, D. W., E. A. Steela; A. H. Fullertona and G. R. Pessa. 2009. Impact of Fine Sediment on Egg-To- Fry Survival of Pacific Salmon: A Meta-Analysis of

Published Studies. Reviews in Fisheries Science, 17: 3, 348 — 359.

Kalbus E., F. Reinstorf and M. Schirmer. 2006. Measuring methods for groundwater – surface water interactions: a review. Hydrol. Earth Syst. Sci., 10, 873–887.

Living Resources. 2020. Herrling Island Adult Salmon Stranding Monitoring. September 2020 to December 2020. Prepared for BC Hydro by Living Resources Environmental. December 2020.

Marion, A., M. Zaramella and A.I. Packman. 2003. Parameter Estimate of the Transient Storage Model for Stream – Subsurface Exchange. J. Environ. Eng. 5:456 – 463.

Mills, M. 2011. Introducing Survival analysis and Event History Analysis. SAGE Publications. London UK. 288 p.

Millar, R.B., S. McKechnie and C.E. Jordan. 2012. Simple estimators of salmonid escapement and its variance using a new area-under-the-curve method. Can. J. of Fish. and Aquat. Sci. 69:1002-1015.

Millar, R.B. and C.E. Jordan. 2013. A simple variance estimator for the trapezoidal area-under-the-curve estimator of the spawner abundance of Pacific salmon. Can. J. of Fish. and Aquat. Sci. 70(8): 1231-1239.

Moore, J.W, D.E. Schindler and M.D. Scheuerell. 2004. Disturbance of freshwater habitats by anadromous salmon. Oecologia (2004) 139:298-308.

Nelson, J., and A. Messmer, 2008. Genetic Analysis of Pink Salmon in and adjacent to Jones Creek, prepared for BC Hydro Generation Sustainability and Aboriginal Relations, SeaStar Biotech, 8pp.

Newbury Hydraulics (2004), Lower Jones Creek Fish Fence Removal and Stream Restoration, Prepared by Newbury Hydraulics for British Columbia Hydro & Power Authority, Okanagan Centre, BC, pp. 10.

Northwest Hydraulic Consultants Ltd (NHC). 2015. Wahleach Project Water Use Plan Lower Jones Creek Stability Assessment Draft Final Report. Prepared for BC hydro. 43 p.

Perrin, C, M.L. Rosenau, T.B. Stables and K.E. Ashley. 2006. Restoration of a montane reservoir fishery via biomanipulation and nutrient addition. North American Journal of FIsheries Management 26: 391-407. 2006.

Plante, N. 1990. Estimation de la taille d'une population animale a l'aide d'une modele de capture- recapture avec stratification. MSc thesis. Universite Laval.

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

Salehin, M., A. I. Packman and M. Paradis. 2004. Hyporheic Exchange with Heterogeneous Streambeds: Laboratory Experiments and Modeling. Water Resources Research, Vol. 40, W11504 (16p.)

Sarchuk, J.A. A.S. Hebert, H. Andrusak, S.L. Harris, T. Weir, and D. Sebastian. 2019. Wahleach reservoir nutrient restoration project review report for years 2009-2015. Ecosystems Branch, BC Ministry of Environment and Climate Change Strategy. Fisheries Project Report No. RD 159 January 2021.

Sickbert, T. and E. W. Peterson. 2014. The Effects of Surface Water Velocity on Hyporheic Interchange. Journal of Water Resource and Protection, 6: 327-336.

Tappel, P. D., and T. C. Bjornn (1983), A new method of relating size of spawning gravel to salmonid embryo survival, North American Journal of Fisheries Management, 3, 123–135.

Vainionpaa, H.E., J.A. Sarchuk, T. Weir and S.L. Harris. 2021. Wahleach reservoir nutrient restoration project report 2019. Ecosystems Branch, BC Ministry of Environment and Climate Change Strategy. Fisheries Project Report No. RD 169 January 2021.

Von Reth, E.A., M.J.F.P. Plyum, A.A. von Steenhoven, J. Poulis, and A. Versprille. 1987. Estimation of Instantaneous Flow from the indicator-dilution curve after bolus injection of indicator. Med. & Biol. Eng. & Computing 25: 51-56.

Wilson, B. 2014. WAHWORKS-3 Lower Jones Creek Channel Enhancements Inspection. Internal BC Hydro memo. 1 p.

Zar, J.H. 1979. Biostatistical Analysis. Princeton Hall Inc. Englwood cliffs N.J. 620 p.

Zimmermann, A. E. and M. Lapointe. 2005a. Sediment infiltration traps: their use to monitor salmonid spawning habitat in headwater tributaries of the Cascapedia River, Quebec. Hydrol. Process. 19, 4161–4177.

Zimmermann, A. E. and M. Lapointe. 2005b. Inter-granular Flow Velocity through Salmonid Redds: Sensitivity to Fines Infiltration from Low Intensity Sediment Transport Events. River Res. Applic. 21: 865–881.