Stave River Water Use Plan
Monitoring Program Synthesis Report

- **SFLMON 1 Pelagic Monitor (Nutrient Load/Total Carbon Levels)**
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Draft Report

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EXECUTIVE SUMMARY

The Stave River Water Use Plan (WUP) was initiated in 1997 and finalized in 2003. The Stave River WUP was initiated as a result of Condition 14 of the Stave Falls Powerplant Replacement Energy Project Certificate, which allowed BC Hydro to construct and operate the power facilities at Stave Falls in Mission, BC. This condition required BC Hydro to undertake a water use planning process for both Alouette River and Stave River systems, including Alouette, Stave Falls and Ruskin dams and Generating Stations. Two separate consultation processes were conducted to complete the Alouette and Stave River Water Use Plans. The initial Alouette Water Use Plan was submitted to the Comptroller of Water Rights in September 1996, with the current Alouette WUP submitted in April 2009 and summarized in a separate report.

In 2004, the Comptroller of Water Rights (CWR) issued Orders under the *Water Act* in response to the Stave River WUP (BCH 2003). The requirements of the Order included the undertaking of ten monitoring projects (“studies”) to assess the anticipated benefits to fish, fish habitat, water quality, and archaeological resources. The Ordered operating conditions were expected to result in improved water levels in Stave Lake Reservoir for fish productivity, industry and recreation, and enhanced archaeological site protection and investigation opportunities. They also allowed for improved flexibility on power operations at Ruskin generating station.

At the conclusion of the WUP consultation process, the Stave WUP Consultative Committee (CC) was able to identify four general areas of uncertainty:

1. The first was the extent to which the productivity levels in both Stave and Hayward Reservoirs would change when operations specified in the WUP were implemented.
2. The second area of uncertainty dealt with the potential impacts of flow fluctuations on the reproductive cycle of anadromous salmonids downstream of Ruskin Dam.
3. The third area of uncertainty arose because of concerns regarding the quality of drinking water extracted from Hayward Reservoir by local residents, and how it may change because of more frequent and larger fluctuations in reservoir water levels.
4. The last area of uncertainty included the impacts of erosion and operational strategies on archaeological sites, whether there were additional sites in the area and if sites could be protected or salvaged.

Terms of Reference (TOR) were developed for ten studies with monitoring conducted between 2004 and 2014.

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 outcomes anticipated by the Stave WUP CC are being realized under the current operating regime.

The ten studies were as follows:

Reservoir Productivity Projects (Stave and Hayward):

- **SFLMON 1: Pelagic Monitor (Nutrient Load/Total Carbon Levels).** The objective of this ten-year study was to assess the influence of reservoir management on pelagic productivity in Stave Reservoir. This study focused on primary production (the annual production of phytoplankton) in the pelagic zone, with some analysis on zooplankton.
- **SFLMON 2: Littoral Productivity Assessment.** The objective of this ten-year study was to examine the relationship between littoral productivity in relation to reservoir operations in Stave and Hayward Reservoirs. This monitor developed an ELZ (Effective Littoral Zone) performance measure to track relative differences in littoral productivity as operating constraints were varied at both the Stave Falls and Ruskin dams. The adopted metric was derived based on a simple conceptual model of periphyton growth on fixed substrate, quantifying the area of aquatic shoreline habitat that received adequate light to promote photosynthesis for periphyton growth and at the same time, remained continuously wetted.
- **SFLMON 3**: **Fish Biomass Assessment**. The objective of this ten-year study was to study assess the likelihood that an increase in overall fish biomass occurs as a result of increased littoral and pelagic productivity due to greater stability in reservoir water levels in Stave Lake Reservoir.

Lower Stave River Projects (Downstream of Ruskin Dam):

- **SFLMON 4: Limited Block Loading as a Deterrent to Spawning**. The objective of this monitoring project was to monitor the success of the fall limited block loading strategy adopted in the WUP aimed at minimizing redd stranding by deterring spawning activity in shoreline areas that lie above the 100 m^3s^{-1} water level downstream of Ruskin Dam. From October 15 to November 30 (the spawning period for Chum and Coho), Ruskin output is subject to block loading. Block loading is when a generating plant is operated at a set output for a specific period of time. The intent is to maintain relatively constant water flow from Ruskin Generating Station during the block load period.
- **SFLMON 5: Risk of Adult Stranding.** The objective of this monitoring project was to verify that adult stranding, especially unspawned females, did not increase downstream after implementing the fall limited block loading operation downstream of Ruskin Dam and that the adult stranding was not biologically important.
- **SFLMON 6: Risk of Fry Stranding**. The objective of this two-year study was to assess the rate of fry stranding in relation to the spring limited block loading operation downstream of Ruskin Dam. From February 15 to May 15 (the emergence period for salmon fry), Ruskin is subject to limited daily block loading of a maximum of one plant load change each day. The intent is to maintain relatively constant water flow from the Ruskin Generating Station during the block load period to minimize the risk of stranding fry in the river.
- **SFLMON 7: Diel Pattern of Fry Out-migration.** The objective of this monitoring project was to assess the daily pattern of fry migration, as well as

their behavioral response to rapid flow changes downstream of Ruskin Dam in the Lower Stave River.

- **SFLMON 8: Seasonal Timing and Assemblage of Resident Fish**. The objective of this monitoring project was to assess the impact of Ruskin Dam releases (limited block loading and minimum tailwater), that were chosen to provide a potential benefit to anadromous species, on the seasonal habitat use of resident fish species, particularly non-salmonid species downstream of Ruskin Dam.

Water Quality Assessment (Hayward Reservoir):

- **SFLMON 9: Turbidity Levels in Hayward Reservoir.** The objective of this monitoring project was to collect turbidity data in Hayward Reservoir to confirm that the quality of drinking water drawn from Hayward Reservoir remained within provincial standards following the change in the minimum operating level as introduced in the Stave River WUP. Additional operational flexibility of Hayward Lake Reservoir was provided allowing an elevation reduction to 39.5 m during spring and fall block loading generation conditions below Ruskin Dam (October 15 to November 30, and February 15 to May 15). Prior to the 2004 order the minimum operating elevation was restricted to 41.08 m. To assess potential impacts of increased drawdown zone exposure on the quality of water entering the District of Mission domestic water distribution system a decision was made to monitor the level of turbidity in the reservoir over a five-year WUP review period (McNair 2010).

Archaeological Project:

- **SFLMON 10: Archaeological Management.** The objective of this monitoring project was to inventory, assess, and mitigate impacts to archaeological remains in the Stave River Watershed.

The ten Stave River WUP studies are complete and have predominantly answered the management questions. Individual studies have determined the benefits, if any, achieved by WUP operations and have provided information that may or may not have operational implications and can be used for decision making during the WUP Order review process.

Out of the nine aquatic studies, three studies (SFLMON-1, 3 and 8) showed no biological response linked to operations. Three studies (SFLMON-2, 6 and 7) did display a biological response. SFLMON-2 found that littoral productivity was directly influenced by reservoir operations. SFLMON-6 and SFLMON-7 both support the positive biological response to the fall and spring limited block loading operations in the Lower Stave River but suggest restricting flow changes to only daylight hours to reduce potential fry stranding. SFLMON-4 and SFLMON-5 also support the continuation of the spring and fall limited block loading operations in the Lower Stave River. SFLMON-9 showed no evidence of impacts on mean reservoir turbidity by normal fluctuations of reservoir level and no variation between block and non-block loading periods was observed, suggesting changes made to the operating strategy to accommodate downstream fisheries issues have not negatively impacted the drinking water resource in Hayward Reservoir.

The final study, SFLMON-10, was an Archaeological Assessment study with investigations throughout the Stave River watershed. This study inventoried several new archaeological sites with a total of 78 sites throughout the watershed and provided recommendations for operations that may reduce effects to archaeological sites. These operational implications will be considered in the WUP Order review. Any recommendations, aside from operational changes, that involve direct archaeological site management were provided to BC Hydro's Reservoir Archaeology Program (RAP)[1], as these activities fall under the purview of the *Heritage Conservation Act*.

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[1] Through the RAP, BC Hydro works with the Archaeology Branch of the B.C. Ministry of Forests, Lands and Natural Resource Operations and affected First Nations to assess and manage impacts to protected archaeological sites in the active erosion zone of the reservoir.

Table E1. Summary of objectives, management questions, outcomes, and implications for the Stave River WUP monitoring projects.

Study name	Objectives	Management Questions	Response	Implications
SFLMON-1 Pelagic Monitor (Nutrient Load/Total Carbon Levels	Assess the influence of reservoir management on pelagic productivity in Stave Reservoir.	1. What is the current level of pelagic productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical and biological processes, including the effect of reservoir fluctuation? 2. If changes in pelagic productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor? 3. To what extent would reservoir operations have to change to 1) illicit a pelagic productivity response; and 2) improve or worsen the current pelagic state of productivity? 4. Given the answers to the management questions above, to what extent does the WUP (Combo 6) operating alternative improve reservoir productivity in pelagic waters, and what can be done to make improvements, whether they be operations based or not?	1. Both Stave Lake and Hayward reservoirs are nutrient poor (ultra-oligotrophic). Seasonal variation of pelagic primary production was strongly correlated with availability of light experienced and coincidentally correlated with water temperature, indicating environmental conditions early in the growth period had a large effect on the final phytoplankton population size Reservoir fluctuation, water retention and outflow discharge weren’t strongly correlated with primary production. 2. Inter-annual variation in pelagic primary production was not correlated with reservoir hydrology suggesting productivity was independent of reservoir operations. Annual variation was likely driven by other environmental factors (e.g. nutrient loading, availability of light, water temperature). 3. There are no indications on how to improve productivity by altering reservoir operations. Production in Stave Lake and Hayward reservoirs are nutrient limited (i.e., phosphorus concentration). 4. Results determined WUP (Combo 6) operations had little to no impact on pelagic productivity. Stave Lake and Hayward reservoirs are ultra-oligotrophic; nutrient supplementation may be the only management action capable of increasing pelagic productivity.	Both Stave Lake and Hayward reservoirs are nutrient poor and are considered ultra-oligotrophic. Pelagic productivity was found to be independent of reservoir operations, it is considered unlikely that any kind of change to WUP (Combo 6) operation would lead to measurable changes in pelagic productivity.

Study name	Objectives	Management Questions	Response	Implications
SFLMON-2 Littoral Productivity Assessment	Examine the relationship between littoral productivity and reservoir operations in Stave and Hayward Reservoirs.	1. What is the current level of littoral productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical and biological processes, including the effect of reservoir fluctuation? 2. If changes in littoral productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor? 3. A performance measure was created during the WUP process to predict potential changes in littoral productivity based on a simple conceptual model. The Effective Littoral Zone (ELZ) performance measure was used extensively in the WUP decision making process, but its validity is unknown. Is the ELZ performance measure accurate and precise, and if not, what other environmental factors should be included (if any) to improve its reliability? 4. To what extent would reservoir operations have to change to 1) illicit a littoral productivity response; and 2) improve/worsen the current littoral and overall productivity levels? 5. Does the WUP (Combo 6) operating alternative improve reservoir littoral productivity as was expected in the WUP? Is there anything that can be done to improve the response, whether it is operations-based or not?	1. Both Stave Lake and Hayward Reservoirs are nutrient poor (ultra-oligotrophic). 2. Low nutrient levels limit productivity of littoral habitats in both reservoirs. However, inter-annual differences in mean nutrient concentration did not appear to have a significant impact on littoral growth rates despite the empirical WUP ELZ modeling to the contrary. Seasonal changes in littoral development appeared to be influenced by availability of light and prevailing water temperature. Reservoir operations were the most influential variable driving inter-annual differences in total littoral productivity. Availability of light and prevailing water temperatures had an effect on seasonal changes. 3. The conceptual ELZ metric used through the WUP decision making process failed to account for exponential growth, the importance of early growing conditions, and the effect of varying light intensity on growth as a function of water depth. An alternative empirically derived ELZ model was developed and is recommended to be used for future predictions. 4. The empirical ELZ model predicted a linear increase in productivity as the range of reservoir elevations narrowed from 8 to 4 m; with all littoral productivity lost at ranges above 8 m. The relationship between littoral and pelagic productivity was not addressed in this study; therefore, the response of overall productivity remains uncertain. Studies in other ultra-oligotrophic systems suggest	Littoral productivity in Stave and Hayward Reservoirs was found to be directly influenced by reservoir operations: WUP (Combo 6) operations produced slightly reduced littoral production compared to pre-WUP operations. a) Littoral productivity decreased linearly as fluctuations in reservoir elevation increased between 4 and 8 m, while fluctuations greater than 8 m tended to eliminate littoral productivity altogether b) Delaying the Stave Reservoir September drawdown until late September-early October would likely increase productivity. c) Reducing the Stave Reservoir mean summer elevation may provide increased littoral area, but could significantly impact other objectives.

Study name	Objectives	Management Questions	Response	Implications
			an increase in littoral productivity can play a significant role in increasing overall productivity levels. 5. The empirical ELZ model suggested that the average annual littoral productivity likely declines with the WUP (Combo 6) operating strategy. While littoral development was higher during the summer months compared to the pre-WUP operational strategy, the current-WUP operation to draft the reservoir in early September, combined with higher reservoir elevations thought to be less productive than lower elevations, likely contributed to the observed decline. Delaying the September drawdown for several weeks would allow the littoral zone to continue functioning for a longer time period. Alternatively, a lower mean summer reservoir elevation would reduce the magnitude of fall reservoir drawdown and maximize shoreline area with a <15% gradient.	
SFLMON-3 Fish Biomass Assessment	Assess the likelihood that an increase in overall fish biomass occurs as a result of increased littoral productivity due to greater stability in reservoir levels.	1. Is the relationship between fish production and littoral production such that the expected increase in littoral productivity as a result of the WUP (Combo 6) - operating strategy leads to a measurable increase in fish biomass? 2. By what extent does littoral productivity have to change in order to elicit a fish biomass response?	1. No evidence was found to indicate the WUP (Combo 6) operation produced an increase in total fish abundance during the ten years of study. No relationship was observed between fish abundance and primary production. No trend was observed between condition factor of kokanee and other ordered reservoir operations. 2. It is unlikely that there is a feasible Stave Reservoir operation that could elicit a biomass response.	No benefits to fish population in Stave Lake Reservoir were observed as a result of the WUP (Combo 6) operation. It is unlikely that alterations to the WUP (Combo 6) operation would provide a benefit to fish populations in Stave Lake Reservoir

Study name	Objectives	Management Questions	Response	Implications
SFLMON-4 Limited Block Load as Deterrent to Spawning	Monitor the success of the limited block loading strategy adopted in the WUP in minimizing redd stranding downstream of Ruskin Dam.	1. Is the limited block loading strategy adopted in the WUP as successful in minimizing red stranding as was the pre-WUP 'full' block loading strategy? a) If successful, can the range of partial peaking be extended by lowering the base flow from the 100 m^3s^{-1} without impacting reproductive success (measured here in terms of escapement)? b) If unsuccessful, should the concept of limited block loading be continued, or should another modification be made to lessen the impact, such as impose an upper boundary to the daily fluctuations?	1. The limited block loading strategy was successful at reducing redd stranding by deterring high elevation spawning. Redd density was significantly lower and redds were 30-50% smaller above the 100 m^3s^{-1} discharge watermark compared to below the 100 m^3s^{-1} discharge watermark. a) Lowering the base flow of the limited Block Loading flow was not tested as the 100 m^3s^{-1} threshold proved to support mitigation of stranding and reproductive success analysis was not included in this study.	The adopted limited block loading strategy was successful in providing mitigation of high elevation redd stranding.
SFLMON-5 Risk of Adult Stranding	Verify adult stranding has not increased downstream of Ruskin Dam by implementing the fall limited block loading operation	1. What is the rate of gravid Chum salmon spawning during the limited block loading operations? 2. Is the level of stranding biologically important?	1. During limited block loading operations, where tail water elevations were <3.0 m, daily maximum stranding rate of unspawned females was 1.6 females/km representing 0.39% of total female escapement. 2. An estimated 0.40% of total egg production was lost to stranded females (partially spawned and unspawned) representing 0.36% of total yearly female escapement (assuming average fecundity of 2800 eggs/female).	Annual adult stranding is unlikely to have a population level effect assuming that observations were typical of annual operations. Further monitoring may be warranted to ensure adult stranding rates do not influence confirmed population levels.
SFLMON-6 Risk of Fry Stranding	Assess the rate of fry stranding downstream of Ruskin Dam in relation to the spring limited block loading operation	1. Is the stranding mortality caused by the spring, limited block loading strategy less than 1.5% of the total Chum fry population?	1. The percent of total fry production stranded was 0.19% and 0.92% in 2008 and 2009, respectively. 2. The stranding mortality caused by the spring limited block loading strategy was found to be less than 1.5% of the total	Limited block loading operations are successful in keeping fry stranding rates below accepted levels in the Lower Stave River.

Study name	**Objectives**	**Management Questions**	**Response**	**Implications**
			Chum fry population threshold established pre- WUP (Leake and MacLean 1998).	Restricting flow changes to daylight hours may further reduce the risk of potential stranding as found in SFNMON-7.
SFLMON-7 Diel Pattern of Fry Out-migration	Assess the daily pattern of fry migration, as well as their behavioural response to rapid flow changes, downstream of Ruskin Dam	1. Does out-migrating fry express a daily pattern of migration, and if so, is it primarily at night, crepuscular, or during the day? 2. Is the behavior of emerging fry influenced by rising, steady and falling water levels, and do these responses change with the time of day and/or transverse location in the channel?	1. A daily pattern of out-migration was observed with catch rates higher at night than during the day. Fry catches peaked soon after dusk, declining through the night and remaining negligible throughout the day. 2. Fry behaviour did not change relative to changes in flow. Mean peak capture time of fry did not vary significantly with flow. Fry exhibited heterogeneous spatial distribution during out-migration where horizontal movements were affected by flow conditions and vertical movements were effected by time of day. However, sampling method restrictions did reduce confidence in the spatial distribution results.	Results from this one-year study indicate: 1. Chum fry out-migration was distinctively higher at night indicating that any flow changes during this timeframe could potentially impact the out-migrants in terms of stranding risk; 2. Operational changes, to restrict load changes to daylight period should be considered; and 3. Neither timing of out-migration nor quantity of Chum fry dispersal downstream was significantly affected by daily fluctuating flow regimes.
SFLMON-8 Seasonal Timing and Assemblage of Fish Residence	Assess the impact of Ruskin Dam releases on the seasonal habitat use patterns of resident fish species, particularly non-	1. Are the assumptions below valid? i.e. (Do WUP (Combo 6) operations based on anadromous salmonid rearing and spawning criteria conflict with the seasonal habitat use patterns of other resident fish species?):	1. Despite significant difficulties in collecting empirical information describing seasonal resident fish use in the Stave River, information suggests that resident fish habitat is not limited by “limited block loading” operations or minimum flows	Despite difficulties implementing the study terms, in all three years, results indicate that resident fish use is dynamic and responsive

Study name	Objectives	Management Questions	Response	Implications
	salmonid species, downstream of Ruskin Dam	a. Water releases from Ruskin dam found to impact or benefit spawning and incubation activities similarly affect rearing conditions for resident fish species. For example, the 100 m^3s^{-1} base flow during the anadromous spawning and incubation periods (as per the Combo 6 strategy) would benefit resident species as well. b. During the summer, operations that minimize within-day and between-day variability in flows improve rearing conditions for juvenile salmonids and resident fish species. This includes access to and availability of side channel habitats.	defined for anadromous fish, for the following reasons: a. Diversity of resident fish use did not vary by sample location indicating that resident use is adaptive to a variety of habitat types and conditions.; and b. Sampling between high and low flows indicated a preference for side channel habitats during high flows, indicating that the variety of habitats available in the Stave River can accommodate resident requirements over a variety of flow conditions.	to flow conditions, and there was no evidence that WUP flows have negatively impacted resident fish use in the system.
SFLMON-9 Turbidity Levels in Hayward Reservoir	Collect turbidity data to confirm that the quality of drinking water drawn from Hayward Lake Reservoir remains within provincial standards following a change in the minimum operation level.	Does the quality of drinking water drawn from Hayward Lake reservoir remain within provincial standards following a change in the minimum operation level?	Results of this study provided no evidence of impacts on mean reservoir turbidity by normal fluctuations of reservoir level and no variation between block and non-block loading periods observed, suggesting changes made to the operating regime to accommodate downstream fisheries issues have not negatively impacted the drinking water resource in Hayward Reservoir.	Turbidity levels recorded throughout this study remained within the District of Mission's drinking water quality standards. Therefore, operational constraints on the reservoir elevations can be removed.

Study name	**Objectives**	**Management Questions**	**Response**	**Implications**
SFLMON-10 Archaeological Management	To study and implement strategies for mitigation of impacts to archaeological sites.	1. How are First Nation archaeological sites affected by erosion? 2. How would sites be affected by other operational strategies? 3. How can they be protected or salvaged? 4. Are there other sites in the area, including lands adjacent to the reservoir that are associated with reservoir operations? 5. How would these be affected by other operational strategies?	Fifteen archaeological sites were newly recorded during this study and 63 sites were recorded during the course of earlier projects undertaken in the area. At least 72 of the 78 archaeological sites located in the study area are indicated as being impacted by reservoir operations. Sixty-nine of these sites are located in the Stave watershed and 9 are located downstream of Ruskin dam.	Archaeological sites in the Lower Stave River Delta region and upper Hayward Reservoir are affected from spilling. The study results recommended limiting spill episodes and considering operational strategies that promote re-vegetation of the shoreline which may better protect sites in the upper part of the drawdown zone (e.g., keeping water levels low during prime growing seasons).

Glossary of Terms

Daily Block Loading: a constraint applied to a hydroelectric plant which permits plant load (and therefore discharge) to be changed only once per day

Effective Littoral Zone (ELZ): a performance measure created during the Stave WUP CC process used to quantify the area of aquatic shoreline habitat that received adequate photosynthetic active radiation (PAR) to promote photosynthesis for periphyton growth and at the same time, remained continuously wetted to prevent mortality from desiccation.

Limited Block Loading: a modification to block loading constraints which permits the plant to peak at times when the block load flow would be greater than a threshold value - provided that the threshold value is maintained as a minimum flow during the peaking operations

Littoral Zone: The near-shore region of lakes where the sediments lie within the photic zone, and where the shallow water flora is frequently dominated by macrophytes (Kalff 2002).

Pelagic Zone: The open water zone beyond the littoral zone (Kalff 2002).

Plankton: The microscopic community of the open water adapted to suspension and subject to passive movements imposed by wind and currents. Composed of phytoplankton (plant plankton), bacterioplankton, and zooplankton (animal plankton) (Kalff 2002).

Primary Production: The growth of phytoplankton and zooplankton

Operating strategy: a collection of operating constraints applied to the BC Hydro plants in the Stave River system

Peaking: a hydroelectric plant operating practice which involves adjusting turbine outputs to match daily variations in the demand for electricity

Weekly Block Loading: a constraint applied to a hydroelectric plant which permits plant load (and therefore discharge), during the 15 October to 30 November period, when discharge is less than 100 m^3s^{-1}

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1.0 CONTEXT

The Stave River Water Use Plan (WUP) was initiated in 1999 and finalized in 2003 with the approval of the Comptroller of Water Rights (CWR). In 2004, the CWR issued Orders in response to the Stave River WUP under the *Water Act*[2] that included implementation of the WUP operating regime ("WUP Combo 6 operations"), and the undertaking of ten monitoring projects to assess for anticipated benefits to fish, fish habitat, and water quality (CWR 2004).

These ten monitoring projects were conducted over the years 2000 to 2014.

This document was prepared as part of the WUP Order Review process. It summarizes results from the projects and outlines whether benefits anticipated by the Stave River WUP Consultative committee (CC) are being realized under the current operating regime. The specific objectives of this report are to:

1. Provide a summary of the objectives, activities, and results for each of the ten studies;
2. Relate study findings to the objectives and management questions of each the Stave WUP studies 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; and
4. Summarize the implications of study outcomes as they may pertain to future operating decisions in the WUP Order Review.

2.0 PROJECT BACKGROUND

2.1 Hydroelectric Facilities

The Alouette-Stave Falls-Ruskin generating complex includes four dams, a 1090 m long diversion tunnel and three powerhouses (Figure 2-1). The Alouette-Stave Falls-Ruskin hydroelectric facilities are located approximately 64 km east of Vancouver, north of the Fraser River between Haney and Mission BC.

The Alouette system consists of a dam on the Alouette River (Table 2-1Table 2-1). At the north end of the Alouette Lake Reservoir, there is an intake with diversion tunnel to a 9.0 MW powerhouse (out of service since Feb. 2010) which discharges into Stave Lake Reservoir. The WUP operations of the Alouette Hydroelectric Facilities, located on the edge of Stave Lake Reservoir, are covered in the Alouette WUP (BC Hydro 2009).

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[2] The Water Act was replaced by the Water Sustainability Act in February 2016; however Orders are issued against the water licences already held by BC Hydro are grandfathered under the former Water Act.

The Stave Falls Dam with the Old and New Stave Falls powerhouses are located at the south end of Stave Lake Reservoir, 6.4 km north of the Fraser River. The original 85-year old Stave Falls Generating Station (50 MW) was replaced in 1999 with a new station of two 45 MW generators for a total plant capacity of 90 MW (Table 2-2). Ruskin Dam and the 105.6 MW powerhouse is located at the south end of Hayward Reservoir on the Stave River, 3.0 km upstream of the confluence with the Fraser River (Table 2-3).

Figure 2-1 Site map of Alouette, Stave Lake, and Ruskin Facilities (BCH Stave WUP 2003).

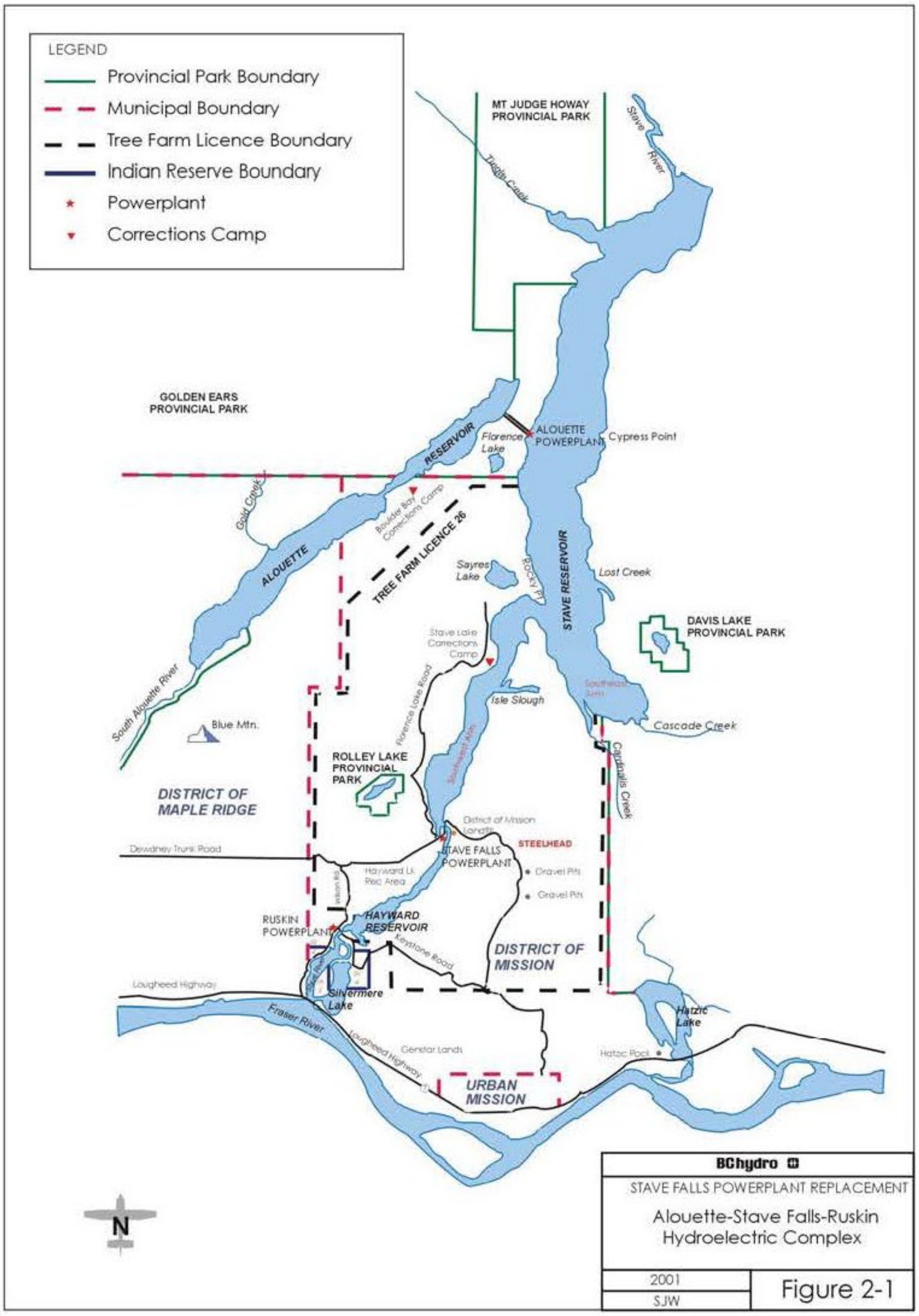


Table 2-1 Alouette Project general information. Referenced from BC Hydro website (August 2017) and BC Hydro (2003).

Dam Name	Alouette
Year of Completion	1936; rebuilt 1983
Dam Type	Earthfill embankment
Dam Use	Storage
Dam Height	21 m
Spillway Type	Free overflow
Max. Discharge Capacity of Spillway	1257 m^3s^{-1}
Generating Station	Alouette
Nameplate Capacity	9 MW (currently out of service)
Storage	155 million m^3
Reservoir Name	Alouette Lake Reservoir
Reservoir Area at Max. Normal Level	1600 ha
Water Course	Alouette River
Drainage Area	200 km^2
Reservoir Operating Range	9.5 m
Upstream Project	n/a
Downstream Project	Stave Falls and Ruskin Dam
Nearest City	Mission, BC

Table 2-2 Stave Falls Project general information. Referenced from BC Hydro website (August 2017) and BC Hydro (2003).

Dam Name	Stave Falls
Year of Completion	1911; powerhouse replaced in 1999
Dam Type	Concrete gravity and rockfill
Dam Use	Storage and Generation
Dam Height	26 m
Spillway Type	Concrete gravity
Max. Discharge Capacity of Spillway	2100 m^3s^{-1}
Generating Station	Stave Falls New
Nameplate Capacity	90 MW
Storage	365 million m^3
Reservoir Name	Stave Lake Reservoir
Reservoir Area at Max. Normal Level	6200 ha

Water Course	Stave River
Drainage Area	1170.0 km^2
Reservoir Operating Range	9.1 m
Upstream Project	Alouette
Downstream Project	Ruskin Dam
Nearest City	Mission, BC

Table 2-3 Ruskin Project general information. Referenced from BC Hydro website (August 2017) and BC Hydro (2003).

Dam Name	Ruskin Dam and Generating Station
Year of Completion	1950; units, spillway, powerhouse redevelopment completed in 2018
Dam Type	Concrete gravity
Dam Use	Storage
Dam Height	59.4 m
Spillway Type	Gated ogee crest; 7 radial gates
Max. Discharge Capacity of Spillway	4430 m^{3}s^{-1}
Genertating Station	Ruskin
Nameplate Capacity	105 MW
Storage	24 million m^3
Reservoir Name	Hayward Reservoir
Reservoir Area at Max. Normal Level	300 ha
Water Course	Stave River
Drainage Area	953 km^2
Reservoir Operating Range	1 m
Upstream Project	Stave Falls
Downstream Project	n/a
Nearest City	Mission, BC

3.0 STAVE RIVER WUP PROCESS

The Stave River WUP process was implemented over four years beginning in 1999 and followed the Water Use Plan Guidelines developed by the province (Province of British Columbia 1998). The process created the following outputs (in chronological order):

- Stave River WUP: Report of the CC (BC Hydro 1999) – documentation of the structured decision-making process which evaluated operating alternatives against objectives represented by the CC, and documented uncertainties that would define the study program for implementation following WUP approval.
- Stave River WUP (BC Hydro 2003) – submitted by BC Hydro to the CWR as the summary of operating constraints and implementation commitments (studies) to be appended to its Water Licences.
- Stave River Facility Order (CWR 2004) – the *Water Act* Order issued by the CWR to implement the WUP as a condition of the 7 licences associated with the Stave River projects.
- Water Licence Requirements (WLR) Terms of Reference (monitoring; BC Hydro 2004) – for studies ordered by the CWR; management questions and methodologies were prepared to address uncertainties defined in the WUP consultative process and submitted to the CWR for Leave to Commence.
- Study progress and annual watershed reports – reports summarizing annual data collection results for ordered studies were prepared and watershed activities were summarized each year in a watershed report and submitted to the CWR. All reports are available on BC Hydro's WUP website:
- (https://www.bchydro.com/about/sustainability/conservation/water_use_planning/lower_mainland/stave_river.html).
- The Stave CC recommended the establishment of a Stave Management Committee (later re-named the Stave Monitoring Committee) with members to include District of Mission, BCH, DFO, MoE and Kwantlen FN and local stakeholders. This group would meet annually to review findings from the 10 monitoring projects.

The operating conditions for the Stave River Hydroelectric System ordered by the CWR are shown in Table 3-1. The CC felt there was uncertainty of the benefits associated with the following operating conditions (BC Hydro 2004):

- Modifying minimum reservoir elevations;
- Changes in flows downstream of Ruskin Dam;
- Water quality response; and
- Archaeological investigations.

The Ordered Stave WUP operating conditions were expected to result in enhanced habitat for fish in the Stave River watershed, improved water levels in Stave Lake Reservoir for industry and recreation and enhanced archaeological site protection and investigation opportunities. They also allowed for improved peaking flexibility on power operations at Ruskin generating station.

Table 3-1 Operating conditions ordered by the Comptroller of Water Rights (CWR) for the Stave River Hydroelectric system* (CWR 2004).

System Component	Constraint	Time of Year	Purpose
Ruskin Dam and Generating Station	Discharge sufficient water from the Ruskin Generating Station:		
	To maintain a minimum tailwater level of 1.8 m	Oct. 15 – Nov. 30	Fisheries habitat
	To maintain a minimum tailwater level of 1.7 m	At all other times	Fisheries habitat
	When the discharge is less than 100 m^3s^{-1}, change the rate of discharge through the Ruskin Powerhouse only once over a seven-day period (weekly block loading). After each change the discharge must be greater than that of the previous seven-day period. Changes to discharge are to be conducted within a period of four hours or less.	Oct. 15 – Nov. 30 (Fall Block Loading)	Fisheries habitat
	When the Ruskin Powerhouse discharge exceeds 100 m^3s^{-1} changing the rate of discharge is permitted on the condition that a minimum discharge of 100 m^3s^{-1} is maintained and the duration of each peaking event is less than 12 hours.		
	When the discharge is less than 100 m^3s^{-1}, change the rate of discharge through the Ruskin Powerhouse only once over a twenty-four-hour period (daily block loading). Changes to discharge are to be conducted within a period of four hours or less.	Feb. 15 – May 15 (Spring Block Loading)	Fisheries habitat
	When the Ruskin plant discharge exceeds 100 m^3s^{-1} changing the rate of discharge is permitted on the condition that a minimum discharge of 100 cubic metres per second is maintained.		
	In the event of a forced outage, re-establish the pre-outage flow as soon as possible, by spilling water if necessary, to maintain the block load flow or 100 cubic metres per second, whichever is lower.	While block loading	Fisheries habitat
	During fall and spring block loading time periods, decrease the rate of discharge at a rate not to exceed:	Oct. 15 – Nov. 30; Feb. 15 – May 15	
	35 m^3s^{-1} per ten minutes, when discharge is 100 m^3s^{-1} or less; and		Fisheries habitat
	113 m^3s^{-1} per thirty minutes when discharge exceeds 100 100 m^3s^{-1}.		
Hayward Reservoir	Operate the works such that the:		
	Minimum elevation of 39.5 m.	Feb. 15 – May 15 and Oct. 15 – Nov. 30	Fish
	Minimum elevation of 41.08 m.	May 16 – Oct. 14 and Dec. 1 – Feb. 14	Fish
	Provide priority to the flow conditions downstream from Ruskin in accordance with the conditions above. In the event that insufficient water is available from Stave Lake Reservoir to maintain those flow conditions (above), Hayward Lake Reservoir may be operated to a	All year if not specified above.	Flow conditions

	minimum elevation of 33 m		
Stave Falls Dam and Generating Station	No conditions in the WUP Order	-	-
Stave Lake Reservoir	Operate the Stave Falls Generating Station to achieve water levels in Stave Lake Reservoir of 76 m or higher and be within an elevation band of 80 to 81.5 m for 53 days for more. In the case of a conflict between the target elevations for Stave Lake Reservoir described above, and the flow constraints downstream of the Ruskin generating station, give higher precedence to the flow constraints downstream from Ruskin.	May 15 – Sept. 7	Recreation
	For purposes of the Stave River Archaeology Management Plan (June, 2002) developed by BC Hydro with the Kwantlen First Nation, not draft the reservoir below the minimum operating elevation stated in clause e) of Conditional Water Licence 117536 (73.0 metres) prior to receiving leave in writing from the Comptroller of Water Rights.	All year	Archaeology

*As Hayward Lake Reservoir has limited storage, Ruskin generating station is operated in close hydraulic balance with the Stave Falls generating station.

To address the data gaps and uncertainties in the Stave River WUP and to assess whether anticipated benefits from changes to operations were achieved, monitoring and physical works projects were ordered. Results from these projects are reviewed upon completion and considered along with other values to support future decisions during the WUP Order Review. The Ordered projects were implemented under BC Hydro's Water Licence Requirements program according to the following terms of references:

SLFMON-1 - Pelagic Monitor (Nutrient Load/Total Carbon Levels): An assessment of the influence of reservoir management on pelagic productivity in Stave Reservoir.

SFLMON-2 - Littoral Productivity Assessment: An assessment of the relationship between littoral productivity and reservoir operations in Stave and Hayward Reservoirs.

SFLMON-3 - Fish Biomass Assessment: An assessment of the likelihood that an increase in overall fish biomass occurs as a result of increased littoral productivity due to greater stability in reservoir water levels in Stave Lake Reservoir.

SFLMON-4 - Limited Block Load as Deterrent to Spawning: A monitoring project to assess the success of the limited block loading strategy adopted in the WUP in minimizing redd stranding downstream of Ruskin Dam.

SFLMON-5 - Risk of Adult Stranding: A monitoring project to verify that adult stranding has not increased by implementing the fall limited block loading operation downstream of Ruskin Dam.

SFLMON-6 - Risk of Fry Stranding: An assessment of the rate of fry stranding in relation to the fall limited block loading operation downstream of Ruskin Dam.

SFLMON-7 - Diel Pattern of Fry Out-migration: An assessment of the daily pattern of fry migration, as well as their behavior response to rapid flow changes downstream of Ruskin Dam.

SFLMON-8 - Seasonal Timing and Assemblage of Resident Fish: An assessment of the impact of Ruskin Dam releases on the seasonal habitat use patterns of resident fish species, particularly non-salmonid species downstream of Ruskin Dam.

SFLMON-9 - Turbidity Levels in Hayward Reservoir: A project to collect turbidity data in order to confirm that the quality of drinking water drawn from Hayward Lake Reservoir remains within provincial standards for turbidity following a change in the minimum operating level.

SLFMON-10 – Archaeological Management: A project to develop an inventory, assesses, and mitigate impacts to archaeological remains in the Stave River Watershed.

4.0 ORDERED MONITORING PROJECT SUMMARY

4.1 SFLMON-1 Pelagic Monitor (Nutrient Load/Total Carbon Levels)

4.1.1 Summary

The Pelagic Monitor study was designed to assess the influence of reservoir management on pelagic productivity on Stave Lake Reservoir based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 7, for details).

The 14 years of data collection (four pre-WUP and ten during the WUP) determined that pelagic productivity followed a predictable seasonal trend while the inter-annual variance in pelagic production followed no trend over time. The study was divided into two phases: Phase 1 included baseline data collection (pre-WUP) and initiated full long-term monitoring; Phase 2 continued long term streamlined monitoring. Results of this study suggest that primary production is independent of WUP operations for the reservoir. The primary driver for the seasonal cycling pattern was availability of light and water temperature. Reservoir hydrology did not directly influence primary production; however, variables (i.e., inflow discharge, water retention time, reservoir elevation) were correlated with light and water temperature.

4.1.2 Management Questions

The study included four management questions:

1. What is the current level of pelagic productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical and biological processes, including the effect of reservoir fluctuation?
2. If changes in pelagic productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor?
3. To what extent would reservoir operations have to change to 1) illicit a pelagic productivity response; and 2) improve or worsen the current pelagic state of productivity?
4. Given the answers to the management questions above, to what extent does the Combo 6 operating alternative improve reservoir productivity in pelagic waters, and what can be done to make improvements, whether they be operations based or not?

(BC Hydro 2006, pp. 7-8)

4.1.3 Objectives and Scope

The objective of this monitoring study was to assess the influence of reservoir management on pelagic productivity in Stave Lake Reservoir. The following aspects define the scope of the study:

a) The study area included Stave Lake and Hayward Reservoirs with a single sampling site established for each reservoir.

b) The study was carried out in two phases, an initial four-year high intensity sampling program occurred prior to the TOR, and a subsequent ten-year base level sampling program.

The study focused primarily on variables associated with measures of pelagic productivity, a component of reservoir productivity that was assumed to be a suitable indicator of overall productivity.

4.1.4 Approach and Methods

The study was conducted from July 2000 to November 2014. High intensity Phase 1 sampling (pre-WUP Order, 2000 to 2003) led to refined sampling methodology for Phase 2 (2004 to 2014). As a result, not all parameters were sampled in all years. Phase 1 of the monitoring study was completed by Eco-Logic Ltd. and the Institute for Resources, Environment and Sustainability, University of British Columbia. Phase 2 was completed by Ness Environmental Sciences and Creekside Aquatic Sciences. Annual reports were compiled each study year following 2005 and the final year report summarized results for all study years and addressed the management questions listed above. All reports are available on BC Hydro's WUP website:

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

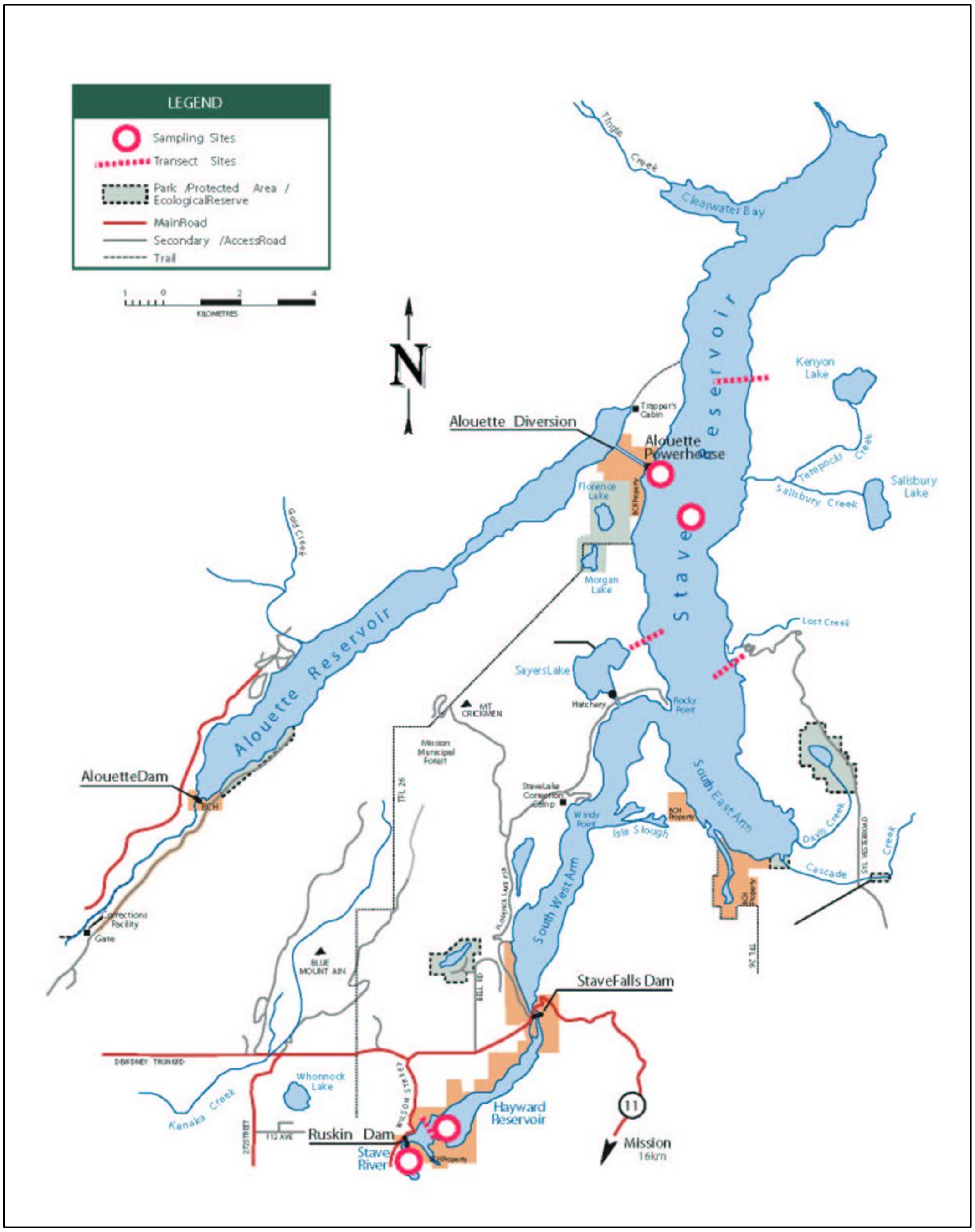
The general approach to this study was to identify the primary pathways by which reservoir operations may affect overall productivity, as indicated by changes in primary productivity, through impact hypothesis testing. Water quality and biological parameters (Table 4-1) were sampled every four to eight weeks across two phases over a 15-year period (Figure 4-1). Phase 1 data collection was completed prior to the development of the TOR and the initiation of the Pelagic Monitoring Program (2000-2003; Stockner and Beer 2004).

Data were used to explore seasonal, annual and spatial trends through post-hoc, two-way analysis of variance (ANOVA). Relationships between variables were also examined using multiple correlation and regression techniques, including forward stepwise regression techniques where required. All correlations were compared between Stave Lake and Hayward reservoirs using analysis of covariance (ANCOVA; reported in terms of T distribution).

Table 4-1 List of water quality and biological parameters sampled in Stave Lake and Hayward reservoir during the 2000 to 2014 monitoring period.

Water Quality Sampling	Biological Sampling
Reservoir Hydrology	**Primary Production**
Inflow Discharge (Q, m^{3}s^{-1})	General
Water surface elevation (WSE, m)	Chlorophyll a (Chl$_a$, µg/L)
Water Retention Time (τ, days)	^{14}C Assimilation Rate (mg/m^3/h)
Light	**Bacteria**
Light extinction coefficient (k, m^{-1})	Pico Cyano-Bacteria (mm^3/L)
Secchi Depth (m)	Heterotrophic Bacteria (mm^3/L)
Water Temperature	**Phytoplankton**
Average Surface Temperature (T_{Surf}, °C)	Edible Nano Phytoplankton (mm^3/L)
Epilimnion Depth where ɗT/ɗz > 1 (D_{Epi}, m)	Edible Pico Phytoplankton (mm^3/L)
Metalimnion Depth where ɗT/ɗz = Max (D_{Meta}, m)	Edible Macro Phytoplankton (mm^3/L) Inedible Macro Phytoplankton (mm^3/L)
Nutrients	In-ed./edible Macro Phytoplankton (mm^3/L)
Total Dissolved Phosphorus (TDP, µg/L)	**Zooplankton**
Total Phosphorus (TP, µg/L)	Zooplankton Abundance (count/L)
Nitrate (NO_3, µg/L)	Zooplankton Biomass (mg/L)

Figure 4-1 Map of Stave Lake and Hayward reservoirs identifying locations of water quality sampling sites (red circles) and periphyton sampling transects (dashed red line). Not all sites were sampled every year



4.1.5 Results

The Pelagic Monitor was successful in collecting data suitable to address the management questions. Issues with data quality and experimental design were overcome at the cost of statistical power; however, impact hypotheses were successfully tested, if not statistically, then by inference, reasoning, and weight of evidence.

Results indicated primary productivity varied seasonally following a predictable cycle with peak values occurring in September and was primarily influenced by availability of light and water temperature. Reservoir hydrology was not correlated with pelagic primary productivity though hydrologic variables were correlated to light availability and water temperature. Inter-annual variance in primary productivity or zooplankton biomass was not correlated with reservoir hydrology.

Answers to Management Questions

1. *What is the current level of pelagic productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical, and biological processes, including the effect of reservoir fluctuation?*

   Both Stave Lake and Hayward reservoirs are nutrient poor (i.e., ultra-oligotrophic). Pelagic primary production predictably varied seasonally with peak values typically occurring in September. As to be expected with exponential growth; environmental conditions early in the growth period had a larger effect on final zooplankton population size than conditions closer to the end of the growth period. Seasonality was strongly correlated with availability of light experienced at the previous sampling interval. A coincidental rise in water temperature increased the rate of metabolic processes which drove growth and development. A consequence of seasonal peaks in primary production was paired with a drop in NO_3, largely due to consumption of the nutrient being greater than the rate of replenishment. Similar but weaker relationships were observed between phosphorus and heterotrophic bacteria. Reservoir fluctuation, water retention or outflow discharge was never strongly correlated with primary production as seen with non-operational variables.

   No significant trend was observed in primary productivity over time. Inter-annual variance was not significantly correlated with year-to-year differences in reservoir hydrology. Observed changes over time included increase of diversity of phytoplankton species and decrease of average organism size, which was not correlated with inter-annual variance in reservoir hydrology. Increased species diversity was correlated with gradual decline of TP and NO_3 concentrations.

   Zooplankton biomass did not significantly change over the course of the monitoring period. Zooplankton varied seasonally peaking in September followed by a rapid decline coinciding with the seasonal drawdown of Stave Lake reservoir; however, this operation or other reservoir hydrology metrics did not explain year- to-year variance in zooplankton biomass.

   In summary, results of this study indicated that reservoir operations did not have a measurable impact on pelagic primary production.

2. *If changes in pelagic productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor?*

   Pelagic primary production did vary inter-annually, but no trend was observed over time. Inter-annual differences were not correlated with reservoir hydrology and likely driven by other environmental factors. There was also no correlation between zooplankton biomass and metrics of reservoir hydrology. These results suggest that pelagic productivity on an annual basis was independent of reservoir operations and other factors were influencers (e.g., nutrient loading, availability of light, and water temperature).

3. *To what extent would reservoir operations have to change to 1) illicit a pelagic productivity response; and 2) improve or worsen the current pelagic state of productivity?*

   Since there was no correlation between pelagic primary production and reservoir operations, there are no indications on how to improve productivity by altering operations. Production in Stave Lake and Hayward reservoirs is nutrient limited (i.e., phosphorus concentration).

4. *Given the answers to the management questions above, to what extent does the Combo 6 operating alternative improve reservoir productivity in pelagic waters, and what can be done to make improvements, whether they be operations based or not?*

   Results of this study determined WUP operations had little to no impact on the pelagic productivity of Stave Lake Reservoir. Stave Lake and Hayward reservoirs were ultra-oligotrophic with the lack of nutrient availability as the primary limitation to overall productivity.

4.1.6 Conclusions

Results suggest pelagic primary productivity was independent of reservoir operations as defined by the WUP operations. Inter-annual variation in zooplankton biomass was also not correlated with reservoir operations.

Both Stave Lake and Hayward reservoirs are nutrient poor and are considered ultra-oligotrophic. Since pelagic productivity is independent of reservoir operations, it is considered unlikely that any kind of change to WUP operations would lead to measurable changes in trophic status.

4.2 SFLMON-2 Littoral Productivity Assessment

4.2.1 Summary

The Littoral Productivity Assessment study was designed to determine the effect of water level fluctuation from reservoir operations on the productivity of the littoral zone in Stave Lake and Hayward Reservoirs based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 7, for details). The performance measure, Effective Littoral Zone (ELZ) model, was developed to quantify the area of aquatic shoreline habitat that received adequate photosynthetic active radiation (PAR) to promote photosynthesis for periphyton growth and remain continuously wetted to prevent mortality from desiccation.

The ten-year study determined that implementation of the WUP operations likely had a negative impact on littoral development compared to pre-WUP operations. However, simulation modeling done for the WUP CC found that even small increases in littoral habitat area, as defined by ELZ, could potentially incur losses in power generation. This would require further hydrologic modeling in the WUPOR. Changes to the WUP operations, such as delayed fall drawdown or lower summer targeted reservoir elevation, may increase functional littoral habitat area, albeit benefits would be small in magnitude and highly variable from year to year.

4.2.2 Management Questions

The program included five management questions:

1. What is the current level of littoral productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical and biological processes, including the effect of reservoir fluctuation?
2. If changes in littoral productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor?
3. A performance measure was created during the WUP process so as to predict potential changes in littoral productivity based on a simple conceptual model. The Effective Littoral Zone (ELZ) performance measure was used extensively in the WUP decision making process, but its validity is unknown. Is the ELZ performance measure accurate and precise, and if not, what other environmental factors should be included (if any) to improve its reliability?
4. To what extent would reservoir operations have to change to 1) illicit a littoral productivity response, and 2) improve/worsen the current littoral and overall productivity levels?
5. Does the Combo 6 operating alternative improve reservoir littoral productivity as was expected in the WUP. Is there anything that can be done to improve the response, whether it be operations-based or not?

(BC Hydro 2006, pp. 24-25)

4.2.3 Objectives and Scope

The objective of this study was to examine the relationship between littoral productivity and reservoir operations in Stave Lake and Hayward reservoirs. The following aspects define the scope of the study:

a) The study area included Stave Lake and Hayward reservoirs.

b) Data was collected at four sites; three on Stave Lake reservoir because of potential spatial differences, and one on Hayward reservoir.

c) The program was carried out in two phases, an initial three-year high intensity sampling program, and a subsequent base level sampling program.

d) The study continued for ten years.

The study focused on variables associated with measures of littoral primary productivity; a parameter assumed to be a component of overall reservoir productivity.

4.2.4 Approach and Methods

The Littoral Productivity Assessment study was conducted from 2000 to 2009. Phase 1 (three years) of the monitoring study was completed by Eco-Logic Ltd. and the Institute for Resources, Environment and Sustainability, University of British Columbia. Phase 2 (seven years) was completed by Ness Environmental Sciences and Creekside Aquatic Sciences. Annual reports were compiled each study year following 2005 and the final year report summarized results for all study years and addressed the management questions listed above. All reports are available on BC Hydro's WUP website:

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

Stave Lake reservoir was considered the treatment system with broad range of water level fluctuation (up to 8 m) and Hayward reservoir was considered the control system (relatively stable, <1.5m variance, maintenance drawdowns every two years). In 2006, maximum elevation for Hayward reservoir was dropped from 42.8 m to 41.4 m (RUS GOO 4G-47) to mitigate seismic concerns of Ruskin Dam creating a more stable reservoir (<0.5 m).

The general approach was predicted on a simple conceptual model of periphyton growth assuming:

a) Growth was proportional to light intensity (i.e., PAR);

b) Light intensity decreased exponentially with water depth;

c) At 1% of surface PAR intensity (i.e., compensation depth), there was insufficient light to sustain growth and biomass of periphyton would decrease over time;

d) At maximum PAR intensity near the water surface, growth was inhibited due to light saturation; and

e) When dewatered, periphyton dried out, exposed to intense UV light and morality occurred.

The effective Littoral Zone (ELZ) was defined as the area of littoral habitat that remained continuously wetted while receiving sufficient PAR to sustain growth.

In each reservoir, water chemistry and biological parameters were sampled (Table 4-2; Figure 4-2). Periphyton growth was measured on artificial substrate suspended 1 m above the reservoir bottom along a transect perpendicular to the shoreline at roughly 2 m depth intervals. Periphyton was measured at three transect lines in Stave Lake reservoir (10 sites/transect) and one transect line in Hayward reservoir (8 sites/transect). All transects were located where shoreline slope was generally less than 30% grade with approximately 3 m of horizontal spacing between sampling sites to prevent interference. Artificial plates were sampled after 6 to 8 weeks (March to October); all samples were collected in a single day. Ancillary water chemistry and physical data to characterize growth environment was collected through SFLMON-1 (see Section 4.1). These empirical data were used to update the ELZ model to predict effects of the implementation of WUP (Combo 6) operations.

To account for different durations when comparing biomass data, the TOR required biomass values be divided by the incubation period to yield measure of productivity; however, Bruce and Beer (2010) showed periphyton biomass increased exponentially over incubation time. To increase accuracy and allow more robust between site and between year comparisons in littoral periphyton production, exponential growth estimates were included in the productivity measures.

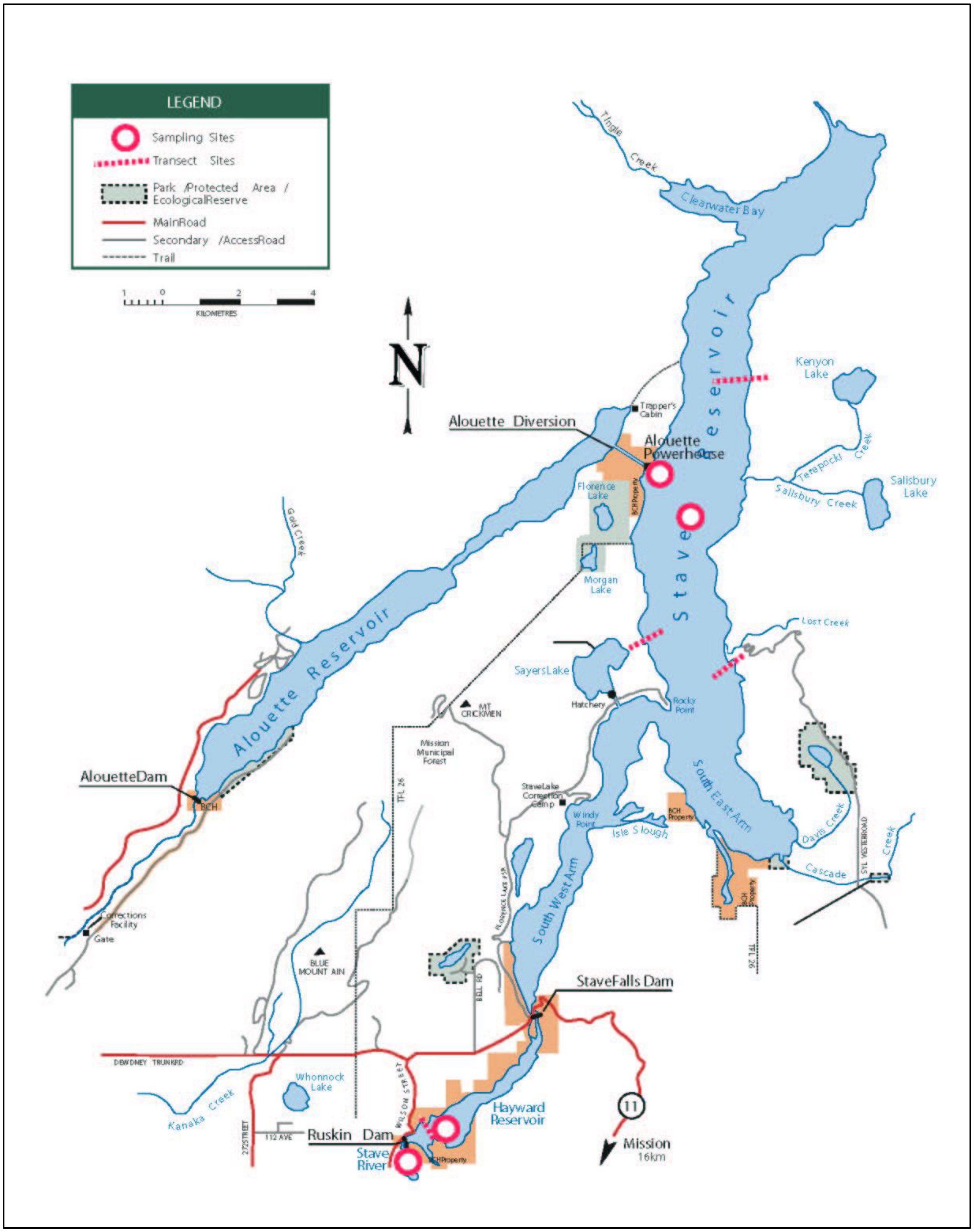
Periphyton growth rates were analyzed for relationships with water chemistry and other physical attributes measured at time of sampling using multiple correlation techniques. To identify influence of correlated variables, forward stepwise regression analyses were completed. Between-site and between year differences were explored using ANOVA and annual trends explored using simple time plots.

Two ELZ models, conceptual and empirical, were tested. The conceptual model was defined in the WUP based on general periphyton growth. Assuming a constant 8 m deep euphoric zone (potential for littoral periphyton growth), shoreline habitat area with a slope of less than 15% (the limit at which sediment can accumulate as epipelic soil and periphyton mats don't slough) and remained wetted sufficiently was estimated. These estimates were calculated using simulated or actual reservoir elevation data for Pre-WUP$_{Obs}$ (observed data, 1984 – 1995), Pre-WUP$_{Sim}$ (simulated data 1969 – 1995), WUP$_{Obs}$ (observed data, 1999 – 2014), and WUP$_{Sim}$ (simulated data, 1969 – 1995). The empirical model was derived from data collected during the study. ELZ models were compared primarily by plotting summary statistics.

Table 4-2 List of water quality and biological parameters sampled in Stave Lake and Hayward reservoirs during the 2000 to 2009 monitoring period.

Water Quality Sampling
Reservoir Hydrology
Inflow Discharge (Q, m^3s^{-1})
Water surface elevation (WSE, m)
Water Retention Time (τ, days)
Light
Surface irradiance
Surface PAR
Light extinction coefficient (k, m^{-1})
Water Temperature
Depth-Average Temperature (1 m intervals, ≤8 m; °C)
Nutrients
Total Dissolved Phosphorus (TDP, µg/L)
Total Phosphorus (TP, µg/L)
Nitrate (NO_3, µg/L)
Biological Sampling
Primary Production
Ash Free Dry Weight (AFDW; mg/m^2) General
Chlorophyll *a* (Chl_a, µg/L)
^{14}C Assimilation Rate ($mg/m^3/h$)

Figure 4-2 Map of Stave Lake and Hayward reservoirs identifying locations of water quality sampling sites (red circles) and periphyton sampling transects (dashed red line). Not all sites were sampled every year



4.2.5 Results

Littoral development was high during the summer months in most years due to relatively high and stable water levels; however, the need to draft Stave Lake reservoir in early September to accommodate increased winter inflows resulted in significant losses to this production. Most summer-time gains occurred at highest reservoir elevations causing large scale dewatering and ultimate desiccation of this production when the draw down occurred. Also, there are more shoreline areas with slopes >15% (where sloughing is more likely to occur) at higher reservoir elevations than at lower.

WUP operations are much different than pre-WUP operations, with current WUP operations being consistently higher in the summer months and drawdowns occurring more consistently later in the summer and less gradual than pre-WUP operations. These WUP changes likely contributed to an observed negative impact on littoral development compared to pre-WUP operations. While this is opposite to what was expected based on the results of the conceptually based ELZ pre-WUP modelling, an empirically derived ELZ model provided reasonably robust predictions of periphyton productivity.

Answers to management questions:

1. *What is the current level of littoral productivity in each reservoir, and how does it vary seasonally and annually as a result of climatic, physical and biological processes, including the effect of reservoir fluctuation?*

   Low nutrient levels (i.e., phosphorus) limit productivity of littoral habitats in Stave Lake and Hayward reservoirs. However, inter-annual differences in mean nutrient concentration did not appear to have a significant impact on littoral growth rates; WUP ELZ modeling showed inter annual differences in reservoir elevations had a greater impact, overriding any effect that changing nutrient concentrations may have had. Seasonal changes in littoral development appeared to be influenced by availability of light and prevailing water temperature. These influences were not linear. For example, periphyton growth rate initially increased steadily with light intensity then slowed to a saturation level where growth rates no longer change with further increases in light intensity. This relationship is a departure from the assumption of uniform growth potential in the original ELZ model.

2. *If changes in littoral productivity are detected through time, can they be attributed to changes in reservoir operations as stipulated in the WUP, or are they the result of change to some other environmental factor?*

   Reservoir operations were the most influential variable driving inter-annual differences in total littoral productivity. Availability of light and prevailing water temperatures had an effect on seasonal changes.

3. *A performance measure was created during the WUP process so as to predict potential changes in littoral productivity based on a simple conceptual model. The Effective Littoral Zone (ELZ) performance measure was used extensively in the WUP decision making process, but its validity is unknown. Is the ELZ performance measure accurate and precise, and if not, what other environmental factors should be included (if any) to improve its reliability?*

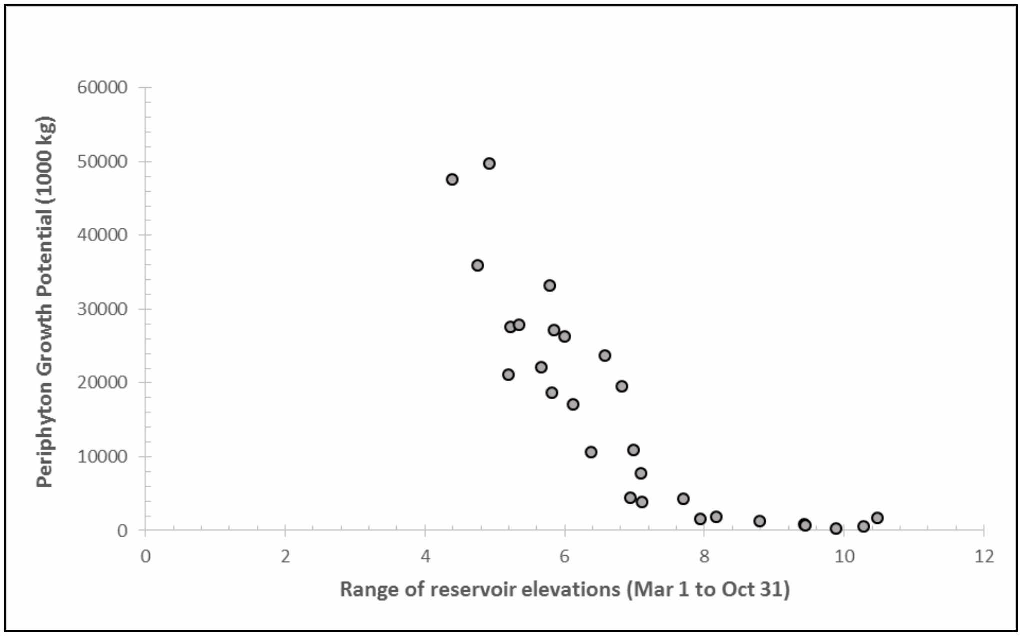
The conceptual ELZ metric used through the WUP decision making process was found to be inaccurate and over simplified failing to account for exponential growth, the importance of early growing conditions, and the effect of varying light intensity on growth as a function of water depth. An alternative empirically derived ELZ model was developed and is recommended to be used for future predictions.

4. *To what extent would reservoir operations have to change to 1) illicit a littoral productivity response, and 2) improve/worsen the current littoral and overall productivity levels?*

   The empirical ELZ model predicted a linear increase in productivity as the range of reservoir elevations narrowed from 8 to 4 m; with all littoral productivity lost at ranges above 8 m (Figure 4-3).

   The relationship between littoral and pelagic productivity was not addressed in this study; therefore, the response of overall productivity remains uncertain. Studies in other ultra-oligotrophic systems suggest an increase in littoral productivity can play a significant role in increasing overall productivity levels.

Figure 4-3 Periphyton growth potential in Stave Lake reservoir as a function of reservoir elevation range for the period between May 1 and October 31 for all years of periphyton growth simulation (pre- and current-WUP). Values are derived by the empirical ELZ model.



5. *Does the Combo 6 operating alternative improve reservoir littoral productivity as was expected in the WUP? Is there anything that can be done to improve the response, whether it be operations-based or not?*

   The empirical ELZ model suggested that the average annual littoral productivity likely declines with the WUP operations. While littoral development was higher during the summer months compared to the pre-WUP operations, the current-WUP operation to draft the reservoir in early September, combined with higher reservoir elevations thought to be less productive than lower elevations, likely contributed to the observed decline.

One option to improve littoral production would be to delay September drawdown for several weeks allowing the littoral zone to continue functioning for a longer time period.

4.2.6 Conclusions

Overall, the empirical ELZ model indicated that implementation of the WUP operations likely had a negative impact on littoral development compared to pre-WUP operations. Potential operations that may increase littoral productivity:

a) Delay the September drawdown for several weeks, allowing the littoral zone to continue function until the end of the growing season in mid to late October; the longer the delay, more summer production remains accessible to littoral organisms.

b) Lower the summer-time target reservoir elevation to reduce the magnitude of reservoir drawdown in the fall and marginally increase the shoreline area with slopes < 15%.

However, the benefit to fish production: (a) is currently unknown and both changes would have significant impacts of other values in the reservoirs (i.e., generation, downstream fish flows, recreation). There is no optimal solution to maximizing littoral production in Stave Lake Reservoir except to reduce reservoir fluctuations completely. No particular reservoir threshold or fall drawdown date can be recommended without taking in account other variables.

An approach may be to consider the range of reservoir elevations from March 1 or freshet to October 31 each year as a littoral zone performance measure. It was found to be linearly related to the empirical ELZ model predations (Figure 4-3); however, it would still require an operations model to predict likely Stave Lake reservoir elevations for each operating alternative.

4.3 SFLMON-3 Fish Biomass Assessment

4.3.1 Summary

The Fish Biomass Assessment study was designed to assess the likelihood that an increase in overall fish biomass in Stave Reservoir would occur as a result of increased littoral productivity due to greater stability in reservoir water levels. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 7, for details).

The results of the ten-year study suggested no effect of WUP operations on fish abundance in Stave Lake reservoir. No relationship between Kokanee condition factor, a pelagic species, and hydrologic metrics of WUP operation was found. Further, opportunistic feeding fish (e.g., Cutthroat Trout, Bull Trout) are unlikely to be affected by reservoir operations. Given these results, there was no strong rationale to expect WUP operating strategy would provide a benefit to fish populations in Stave Lake Reservoir.

4.3.2 Management Questions

The study assessed two management questions:

1. Is the relationship between fish production and littoral production such that the expected increase in littoral productivity as a result of the Combo 6 operating strategy leads to a measurable increase in fish biomass?
2. By what extent does littoral productivity have to change in order to elicit a fish biomass response?

(BC Hydro 2006, p. 42)

4.3.3 Objectives and Scope

The objective of this study was to assess the likelihood that an increase in overall fish biomass occurs as a result of increased littoral productivity due to greater stability in reservoir water levels. The following aspects define the scope of the study:

a) The study area was limited to Stave Lake Reservoir.

b) Biomass estimates were collected annually at a standardized time of year.

c) The study was completed in ten years.

4.3.4 Approach and Methods

The Fish Biomass Assessment study was conducted over ten years from 2005 to 2014 by Shuksan Fisheries Consulting and Limnotek Research and Development Inc. Annual reports were compiled each study year and the tenth-year report summarized results for all study years and addressed the management questions listed above. All reports are available on BC Hydro's WUP website:

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

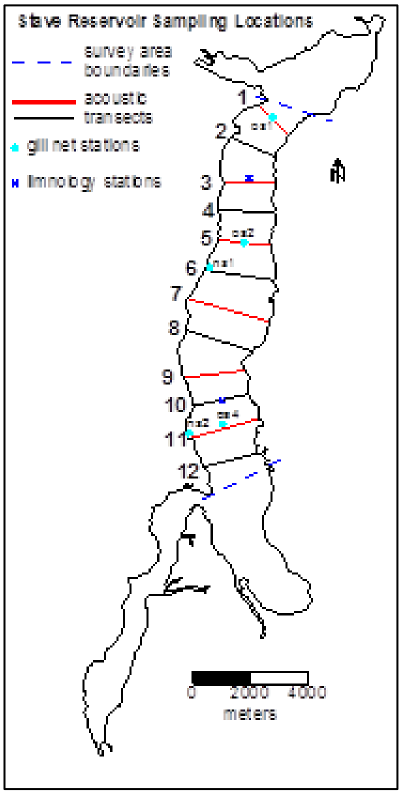
The general approach to the study was to estimate fish biomass and abundance by means of coordinated acoustic (scientific echo sounding) and gill net surveys. Acoustic surveys occurred annually for ten years in the fall (mid-September to mid-October) across six transects (Figure 4-4). Gillnet surveys were conducted at five locations every other year for a total of six years over the same sampling period (Figure 4-4). Gillnets of varying mesh sizes were randomly fished to minimize effects of size selectivity on spatial trends. Both sampling techniques were conducted at night and surveyed surface, middle, and bottom of the water column in both littoral (nearshore) and pelagic (offshore) zones. Minnow trapping was inefficient and discontinued after two sampling periods. Water quality profiles (temperature and dissolved oxygen) were recorded at two locations every year to aid the interpretation of vertical distributions of fish.

Data collection during gillnet surveys included fish abundance, species, size (fork length and weight), age, sex and maturity, stomach samples for diet information, and species-specific spatial distributions. Small fish (~100 mm) were assumed to be kokanee fry eliminating the need for trawling. Acoustic data were used to estimate fish abundance, size, density, biomass and spatial distribution patterns. Relative abundance of fish captured in gill nets (as indicated by catch per unit effort; CPUE) was used to apportion the acoustic abundance of fish among species.

To address Management Question 1, abundance and biomass were plotted over time to examine temporal trends. If apparent, regression analysis was used to describe response by fish abundance to the WUP operations. Biomass data was not fitted to a model as the data violated the assumption that observations were independent. The study addressed Management Question 2 by exploring the relationship between photosynthetic rate (primary production data obtained through SFLMON-1 and SFLMON-2) and fish abundance. If no relationship was found, the relationship between fish condition and water surface elevation was evaluated.

It is important to note that response of the biomass measure would likely be gradual over time as the impact of increased productivity works its way through the food web and through the full multi-year life cycle of different fish species. The duration of this monitoring program was intended to capture this lag effect if applicable.

Figure 4-4 Map of Stave Lake reservoir study area showing sampling stations and acoustic survey transects (main transects in bold red lines)(Stables et al 2016).



4.3.5 Results

Estimates of total fish abundance and biomass (all species) showed a pattern of increase from 2005-2010 followed by a decline following 2010 in both sampling zones (littoral and pelagic). The majority of fish were observed within the pelagic zone (Figure 3-2) with Kokanee being the predominant species. Over ten years of monitoring there was no consistent trend in fish response to the WUP (Combo 6) operations.

Answers to Management Questions

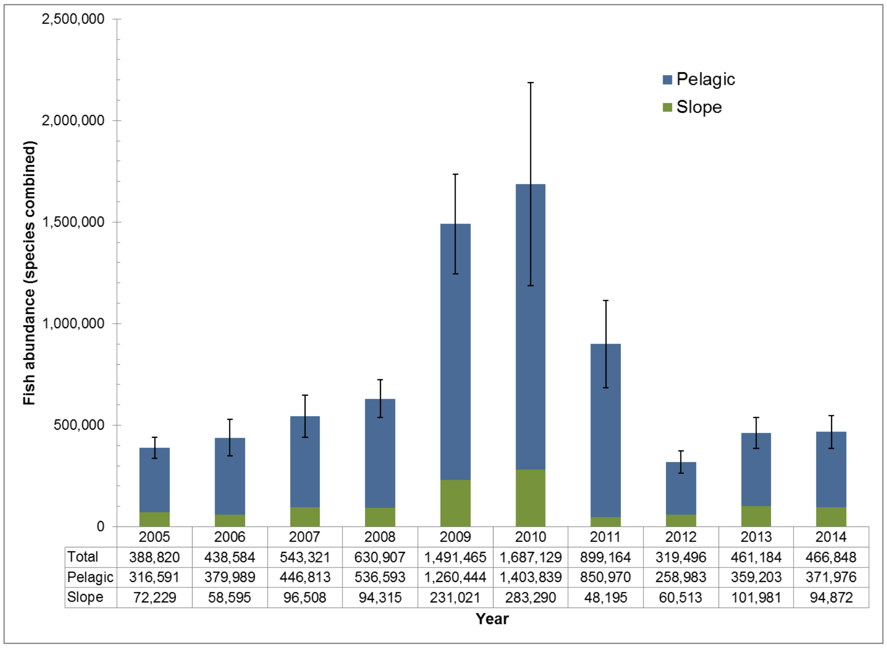
1. *Is the relationship between fish production and littoral production such that the expected increase in littoral productivity as a result of the Combo 6 operating strategy leads to a measurable increase in fish biomass?*

   Results provide no evidence that WUP operations produced a time course increase in total fish abundance. Fish abundance (Figure 4-5) and biomass (Figure 4-6) did not follow a consistent temporal trend and there was no net change in either metric over the course of the study. The majority of fish abundance was represented by Kokanee which also accounted for most of the observed variance in abundance over time. Relative abundance of highly littoral species (non-salmonids) decreased in gillnet CPUE over time. No trend was observed between condition factor of kokanee and other explored hydrologic metrics including minimum water surface elevation or number of days when water surface elevation exceeded 80 m during the critical growth period (May 15 through November 7).

2. *By what extent does littoral productivity have to change in order to elicit a fish biomass response?*

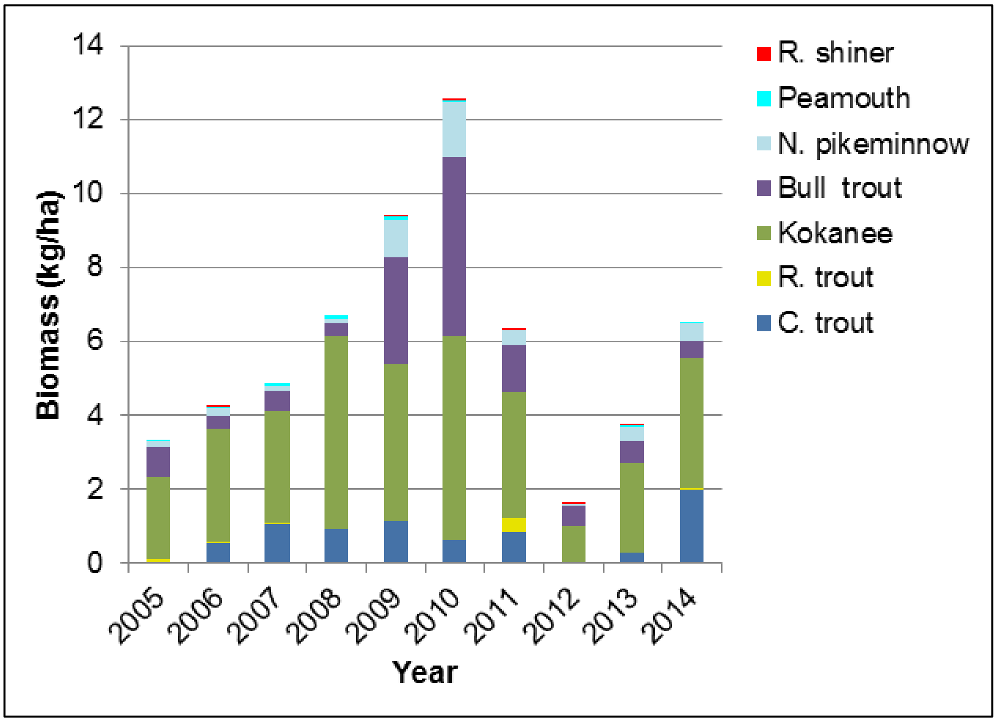
   The study suggests no effect on fish biomass would be expected with a change in littoral productivity. Kokanee, the most abundant species in the study area, are mainly pelagic species and would not be affected by this change. This assumption is supported by the lack of relationship between kokanee condition factor and hydrologic metrics of WUP operations. While changes in littoral productivity observed in SFLMON-2 may influence the relative abundance of non-salmonid species discussed above, less pelagic species including Cutthroat Trout and Bull Trout were found to be opportunistic feeders ingesting terrestrial insects and other fish species, with limited amount of benthic invertebrates. Any change in availability of benthos and non-salmonid littoral species in the upper littoral area may have little to no effect on availability of food for these species.

Figure 4-5 Annual estimates of fish abundance in Stave Lake reservoir (species combined) by habitat zone, littoral (slope) and pelagic, from 2005-2014 fall acoustic surveys. Kokanee were the most abundant Salmonid in both zones. Other species captured included Cutthroat Trout, Bull Trout, Rainbow Trout, Northern Pikeminnow, Peamouth, Redsided Shiner, Prickly Sculpin, and Largescale Suckers.



	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Total	388,820	438,584	543,321	630,907	1,491,465	1,687,129	899,164	319,496	461,184	466,848
Pelagic	316,591	379,989	446,813	536,593	1,260,444	1,403,839	850,970	258,983	359,203	371,976
Slope	72,229	58,595	96,508	94,315	231,021	283,290	48,195	60,513	101,981	94,872

Figure 4-6 Annual fish biomass (fish/ha) by species during the 2005-2014 Stave Lake reservoir fall acoustic surveys apportioned using fall RISC gillnet survey data. Gillnetting was conducted in 2005, 2007, 2009, 2011, 2013, and 2014.



The following summarizes other key findings of the Fish Biomass Assessment Study:

Gillnet Sampling

a. Salmonid relative abundance showed wide fluctuations over the years with no discernible trend of increase or decrease in either littoral or pelagic zones.

b. Species composition in the two zones differed greatly with kokanee recorded as the most abundant Salmonid in both zones.

c. Consistent species-specific spatial distribution patterns were observed over all sampling years.

d. Weight-length relationships of individual species were similar in all years with a high degree of correlation among years ($R^2 = 0.895 – 0.996$). Condition factor did not consistently increase or decrease over the course of the study. No trend was observed in species specific length at age during the study period.

e. Distinct differences in diet among species were consistent across all study years.

Acoustic Sampling

a. Small fish (<~100 mm) represented the majority of the frequency distributions and estimates of fish abundance of acoustically sized fish across all years.

b. During most years, fish abundance was highest in 10-30 m depth range. At increased fish abundance, more fish were distributed below 30 m. Small fish were concentrated shallower than medium and large fish.

c. Annual abundance and biomass by species show kokanee predominated the fish community (93-99% and 44-77%, respectively).

4.3.6 Conclusions

Ten years of fish population monitoring observed no temporal trends in fish abundance or biomass data suggesting there were no ecological reasons to expect a treatment effect from WUP operations.

Kokanee was the most abundant fish species, and as a pelagic species, habitat was not affected by any of the hydrological changes. Therefore, there was no reason to expect a response from the numerically dominant kokanee population to WUP (Combo 6) operations. In addition, fish species inhabiting the littoral zone, and potentially most affected by WUP operations, were found to be opportunistic feeders, ingesting large amounts of terrestrial insects (Cutthroat and Rainbow Trout) and other fish (Cutthroat and Bull Trout), as well as limited amounts of benthic invertebrates.

Given these lines of evidence, there was not a strong rationale to expect that any alterations to WUP operations would provide a benefit to fish populations in Stave Lake Reservoir as implied in the fish abundance and biomass data. It is possible that inter-annual variation exceeded any time course trend, thus obscuring a temporal trend if one was present.

4.4 SFLMON-4 Limited Block Load as Deterrent to Spawning

4.4.1 Summary

The Limited Block Load as Deterrent to Spawning study was developed to evaluate the success of the limited block loading strategy in minimizing red stranding downstream of Ruskin Dam. From October 15 to November 30 (the spawning period for Chum and Coho), Ruskin Generating Station output is subject to block loading. Block loading is when a generating station is operated at a set output for a specific period of time. The intent is to maintain relatively constant water flow from Ruskin during the block load period. When the discharge from Ruskin is 100 m^3s^{-1} or less, the discharge must remain constant for a minimum of seven days after each change in discharge and each new block load on the plant must be greater than the previous block load. In making a plant load change, it is recognized that this may consist of several individual unit changes over a period of four hours. When flows exceed 100 m^3s^{-1} there is no restriction on the frequency of changes (up or down) provided the flows are reduced for greater or equal to one hour, every 12 hours. (BCH SFLWUP 2003).

A monitoring plan terms of reference was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details). This ten-year study found no evidence that operational parameters (e.g., discharge, tailrace elevation) are strongly linked to Chum escapement. Results suggest the limited block loading strategy may be providing mitigation to reduce high elevation spawning and its associated detrimental effects on Chum escapement.

4.4.2 Management Questions

The study included one management question:

Is the limited block loading strategy adopted in the WUP as successful in minimizing redd stranding as was the pre-WUP ‘fall’ block loading strategy? (BC Hydro 2006, p. 50).

a. If successful, can the range of partial peaking be extended by lowering the base flow from the 100 m^3s^{-1} without impacting reproductive success (measured here in terms of escapement)?
b. If unsuccessful, should the concept of limited block loading be continued, or should another modification be made to lessen the impact, such as impose an upper boundary to the daily fluctuations?

4.4.3 Objectives and Scope

The objective of this study was to evaluate the success of the limited block loading strategy adopted in the WUP in minimizing redd stranding downstream of Ruskin Dam. The following aspects define the scope of the study:

a) The study area was restricted to the 1.5 km section of Stave River located immediately downstream of Ruskin Dam.
b) Data collection occurred during the Chum-spawning period, which was typically between October 15 and November 30.

c) Depending on the component of the study, data was collected throughout the study area, or within a clearly defined study site (one of the braided channels) that was accessible at all flows and has a 200 m minimum channel length.

d) The limited block loading assessment was completed in two Chum-spawning seasons, while escapement monitoring (conducted by DFO) was completed over 10 years, with reporting and analysis every three years.

4.4.4 Approach and Methods

The Limited Block Loading as Deterrent to Spawning study was conducted over ten years from 2005 to 2014 by InStream Fisheries Research Inc. Three interim reports were compiled throughout the study period and a final report (Year 10) summarized results for all study years and addressed the management questions listed above. All reports are available on BC Hydro's WUP website:

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

The general approach to the study was comprised of two phases of data collection to determine the success of the WUP limited block loading strategy in sustaining annual escapements of Chum Salmon. Phase 1 was a short term monitoring component (two sampling years) to examine redd distribution, redd density, and total area at elevations above and below the 100 m^3s^{-1} waterline mark at the margins of a mid-channel island 500 m downstream of Ruskin Dam during experimental partial peak block loading operations (100-325 m^3s^{-1}) over the Chum spawning season. Egg presence was estimated by excavating redds to determine if the number of egg pockets was correlated to redd area. Water depth and velocity was also measured (Swoffer flow meter) at randomly selected redds. Phase 1 was initiated in October 2005 but ended prematurely due to insufficient inflows causing the suspension of the limited block load operation. Two full sampling seasons were conducted in 2006 and 2007.

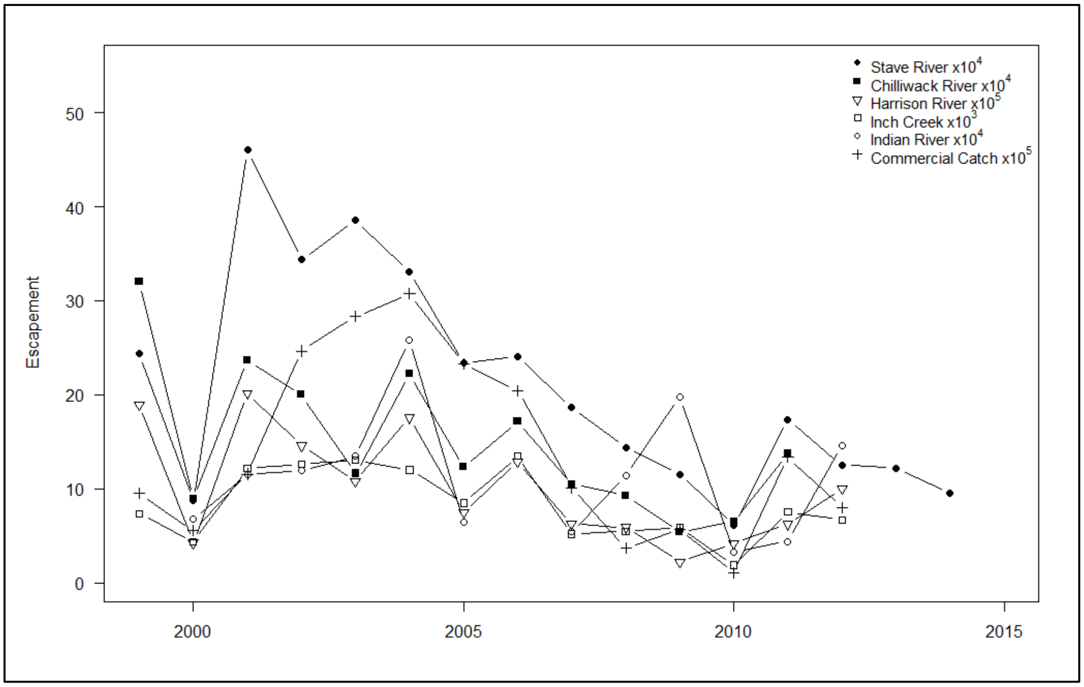
Phase 2 was a long-term monitoring component (ten sampling years) exploring the relationship between escapement and implementation of the limited block loading strategy. Spawner escapement was estimated using data collected during DFO aerial surveys. Hourly Ruskin Dam discharge and tailwater elevation, and hourly Fraser River water discharge and tidal elevations were monitored.

Comparisons of individual redd area, number of egg pockets, and high versus low elevation redd density and area was conducted using ANCOVA (redd density) or ANOVA (egg pockets). Observed and estimated spawning Chum salmon numbers were obtained from weekly helicopter surveys and used in area-under-the-curve (AUC) estimation. Average Stave River spawner escapement pre- and WUP was compared using Welch's two-sample t-test. These measurements were also compared to other Fraser River stocks using linear regression to determine if parallel changes in escapement have occurred. Welch's two-sample t-test was used to determine change in environmental variables (Ruskin Dam discharge, Ruskin Dam tailrace elevation, Fraser River discharge, number of days with discharge >100 m^3s^{-1}) between pre-and during WUP flows and if Chum returns are associated with changes in physical conditions. Linear regression determined whether changes in escapement were associated with individual variables and multiple regression was used to examine the range of influences river variables and brood year escapement may have on future Ocean age-4 spawner escapement. Regression tree analysis determined which of the environmental variables had the greatest ability to predict return escapement.

4.4.5 Results

Despite the fact that the study found redd densities and redd stranding were lower within the block loading operating zone than below, the study found no conclusive evidence linking Ruskin Dam operational parameters to Chum salmon escapement in the Stave River system. Chum escapement had been declining since the onset of the WUP; however, significant correlations with other Fraser River stocks suggest conditions outside of the Stave River system are affecting escapement (e.g., regional climate conditions, characteristics of ocean environment; Figure 4-7).

Figure 4-7 Estimated regional Chum salmon escapement (1999-2014) for Lower Fraser River and DFO commercial catch (Ladell and Putt 2015).



Answers to Management Questions:

1. *Is the limited block loading strategy adopted in the WUP as successful in minimizing redd stranding as was the pre-WUP 'full' block loading strategy?*
    a. *If successful, can the range of partial peaking be extended by lowering the base flow from the 100 m^3s^{-1} without impacting reproductive success (measured here in terms of escapement)?*
    b. *If unsuccessful, should the concept of limited block loading be continued, or should another modification be made to lessen the impact, such as impose an upper boundary to the daily fluctuations?*

Although spawners were observed utilizing habitats subjected to reductions in water depth and velocity due to variable water elevations, redd density was significantly lower and redds were 30-50% smaller above the 100 m^3s^{-1} discharge watermark compared to below the 100 m^3s^{-1} discharge watermark (Figure 4-8). These results suggest the partial block loading strategy is partially successful at minimizing redd stranding by deterring high elevation spawning.

Figure 4-8 Density of high and low elevation chum salmon redds estimated during 2005 surveys (Troffe et al. 2008).

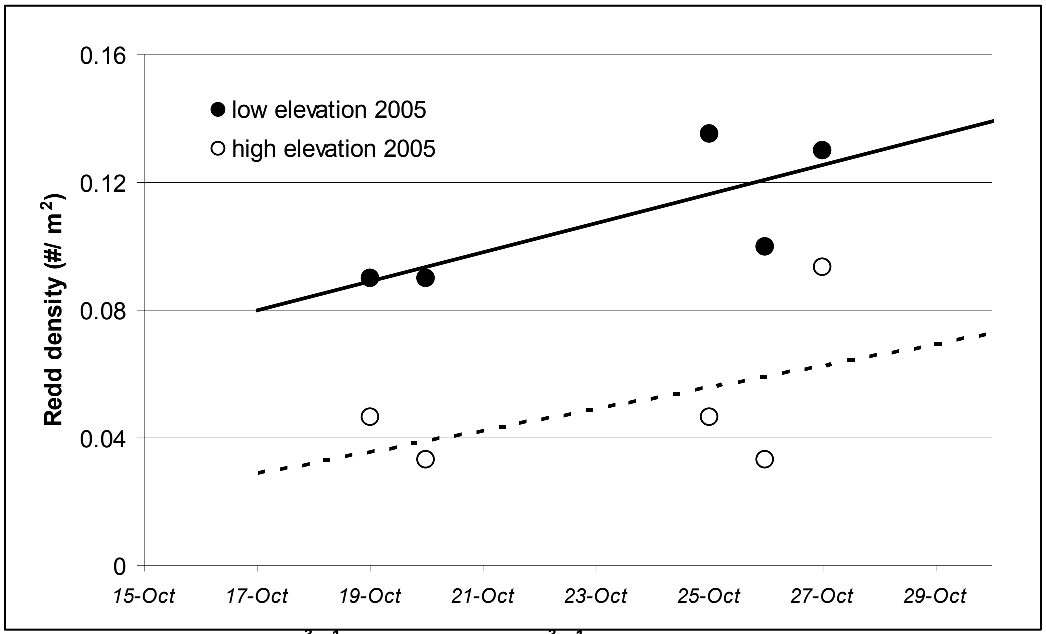
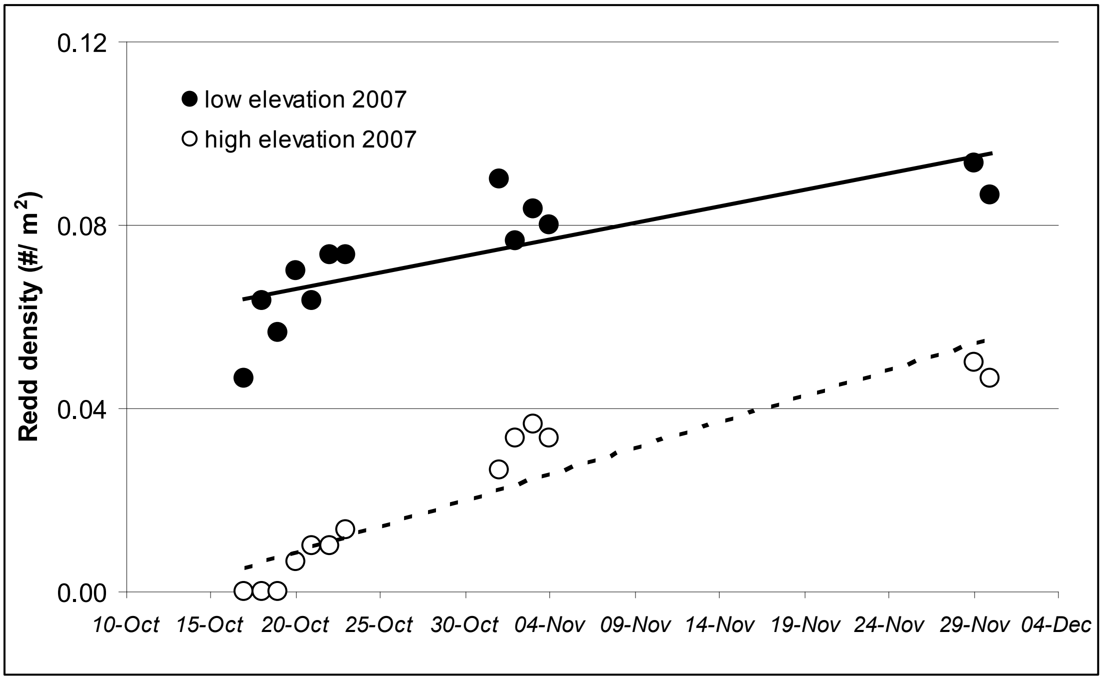


Figure 4-9 Density of high (> 100 m^3s^{-1}) and low (< 100 m^3s^{-1}) elevation Chum salmon redds estimated during 2007 surveys (Troffe et al. 2008).



The following summarizes other key findings of the Limited Block Load as Deterrent to Spawning Program:

Phase 1: Redd Monitoring

a) Superimposition of redds were noted below the 100 m^3s^{-1} discharge watermark when redd densities became greater than 0.13 redds/m^2.

b) Redd construction was similar between low and high elevations requiring two to three days for redd construction.

c) Both operational discharge and daily tidal exchange significantly influenced Stave River elevations. Fraser River tidal variation of up to 0.78 m was observed at the downstream portion of the monitored spawning area while Ruskin Dam operations were held constant.

d) Spawners were observed utilizing habitat subjected to reductions in water depth and velocity particularly later in the spawning season following peak escapement dates suggesting variable tail water elevations may be most effective later in the spawning season after the optimal spawning habitat has been saturated.

Phase 2: Escapement

e) Stave River escapement has been highly variable over the past 15 years with the population on a decline since early 2000’s. This trend has also been observed in other Fraser River stocks including Chilliwack River, Harrison River, Inch Creek and coast-wide commercial catch.

f) Significant predictors of escapement using the multiple linear model included Ruskin Dam discharge, tailwater elevation, and Fraser River discharge; however, overall model fit, and individual correlations were weak. Regression tree analysis found environmental variables to be weakly associated with return escapement but not statistically strong enough to confidently predict escapement.

4.4.6 Conclusions

In summary, based on observations at high escapement levels, limited block loading appears partially successful at reducing spawning chum salmon from utilizing sub-optimal high elevation spawning habitat in the Lower Stave River. Significantly fewer and smaller redds were observed at the few high elevation sites discovered when compared to low elevations sites.

4.5 SFLMON-5 Risk of Adult Stranding

4.5.1 Summary

The Risk of Adult Stranding study, was conducted to verify that adult stranding downstream of Ruskin Dam was not biologically important after implementing the fall limited block loading operation. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details).

This monitoring study determined the daily maximum stranding rate of unspawned female Chum salmon during limited block loading operations was

0.38% of total female escapement representing an estimated 0.40% of total annual egg production.

4.5.2 Management Questions

The program included two management questions:

1. What is the rate of gravid Chum salmon spawning during the limited block loading operations?
2. Is the level of stranding biologically important?

(BC Hydro 2006, p. 60)

4.5.3 Objectives and Scope

The objective of this study was to verify that adult stranding downstream of Ruskin Dam was not biologically important after implementing the fall limited block loading operation. The following aspects define the scope of the study:

a) The study area was restricted to a 500 m section of Stave River located downstream of Ruskin Dam.

b) Data collection occurred during the Chum spawning period between late October and mid-November.

c) Stranding assessments were completed at low tide, and when possible, during periods of low flow to maximize carcass recovery.

d) The adult stranding monitoring occurred over one Chum-spawning season.

4.5.4 Approach and Methods

The Risk of Adult Stranding Study was conducted over the 2006 Chum spawning season by InStream Fisheries Research Inc. The final report summarizing the study results and addressing the management questions listed above, are available on BC Hydro's WUP website:

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

The general approach to the study was to survey stranding of gravid adult female Chum salmon above the 100 m^3s^{-1} discharge watermark 500 to 1000 m downstream of Ruskin Dam (Figure 4-10). A total of 16.1 km of shoreline distance was surveyed with a range of 1.37 to 3.59 km surveyed each sampling date. Surveys were conducted at low tide and at minimum discharge of 100 m^3s^{-1} over eight days during the spawning period between October 31 to November 14. Sampling was suspended when normal limited block loading operations were interrupted by two rainfall induced spill events with peak discharges >600 m^3s^{-1}.

Each stranded Chum was enumerated and examined for sex, body condition (indicator of time stranded), gonad condition, and egg retention. Females were assessed as spawned out, partially spawned out, and unspawned. Chi-squared contingency tests were used to determine if female condition was independent of egg retention. DFO escapement data (2006) and observed sex ratio was used to estimate stranding rate. Estimates of female stranding rate were correlated to previous 48-hours discharge and tail water elevation (tidal and block loading) to determine if spawner stranding is independent of operational release with the assumption that unspawned and partially spawned females are equally likely to become stranded. Estimated stranding rate was compared with the expected normal variance in pre-spawner mortality as establish in the literature.

Figure 4-10 Downstream representation of islands 1, 2, and 3 surveyed during the 2006 adult spawner survey on the lower Stave River.

4.5.5 Results

Despite the observation that female Chum stranding increased with the magnitude of operational change during block loading operations, the female chum stranding rate of 0.39% is unlikely to have a population level effect.

Answer to the Management Questions:

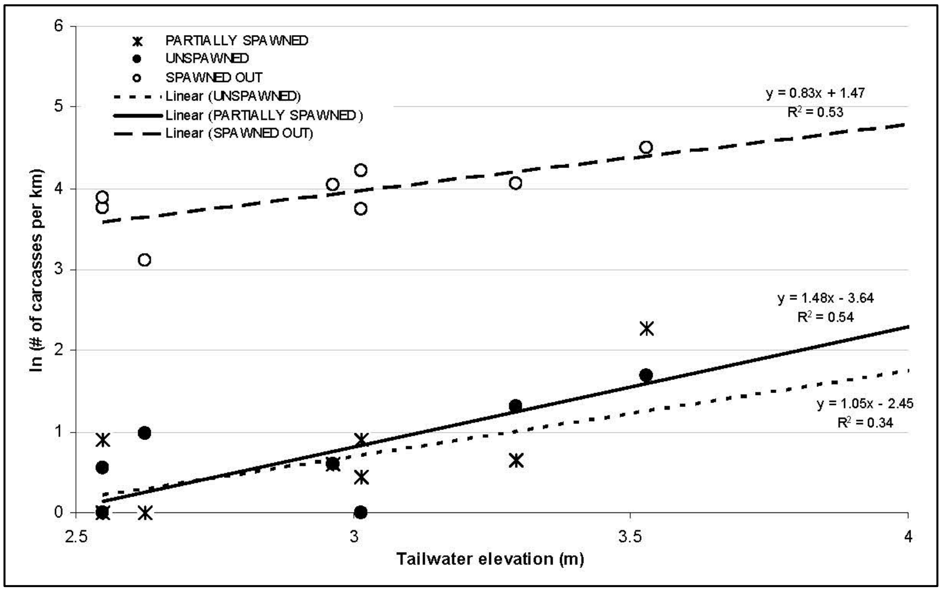
1. *What is the rate of gravid Chum salmon spawning during the limited block loading operations?*

   During limited block loading operations, where tail water elevations were <3.0 m, daily maximum stranding rate of unspawned females was 1.6 females/km representing 0.39% of total female escapement (Figure 4-11).

2. *Is the level of stranding biologically important?*

   An estimated 0.40% of total egg production was lost to stranded females (partially spawned and unspawned) representing 802 females (assuming average fecundity of 2800 eggs/female) representing 0.36% of total yearly female escapement. It is recommended that a performance measure is used to identify biologically significant levels of adult stranding.

Figure 4-11 Natural log linear regression of the number of Chum salmon carcasses per kilometer of survey shore versus the maximum lower Stave River tail water elevation (m) observed in the 48 hours previous to the survey date.



The following summarizes other key findings of the Risk of Adult Stranding monitoring:

a) A total of 841 females were observed stranded above the 100 m^3s^{-1} discharge watermark where 95.0% were spawned out, 2.6% were partially spawned and 2.3% were unspawned.

b) Chi-squared contingency analysis determined egg retention was independent of body condition.

c) Risk of stranding for unspawned, partially spawned, and spawned out female Chum was positively correlated with the magnitude of the operational drawdown during limited block loading operations.

d) ANCOVA indicated stranding rates as a function of tail water elevation did not differ between spawner categories (Figure 4-11).

e) ANOVA indicated stranding rate of unspawned and partially spawned females were similar while stranding rate of spawned out females were significantly higher.

f) Positive relationship was observed between the total number of eggs retained per km by all females and water elevations; a similar relationship was found with unspawned females.

g) During unscheduled spill events, when water elevations were >3.0 m, stranding rate of unspawned females was 4.4/km representing 1.1% of total female escapement.

4.5.6 Conclusions

While rates of stranding are correlated with change in dam discharge, it is unlikely that the observed adult stranding rates from the block load operations are biologically significant. To further ensure this is the case, the study authors recommended that a performance measure is used to identify biologically significant levels of adult stranding where the maximum yearly stranding rate of unspawned females is set at 0.39% of the total yearly female escapement (based on DFO estimates) during normal fall limited block loading operations. If the assessment discussed here is repeated, an evaluation of pre-spawn stranding/mortality in an un-regulated watershed should be considered for comparison.

While considering the above recommendations during the WUP Order Review process, it should be noted that this study took a conservative approach assuming:

1. Unspawned females were categorized as retaining >1000 eggs (while Chum fecundity is 2500-3000);
2. Females were stranded from persistence to remain on the redd despite dropping water levels;
3. Stranding was caused solely by limited block loading operations or spill events and not due to other natural (e.g., water temperature, time of freshwater entry, density dependent mechanisms) or unnatural (angling pressure) occurrences causing egg retention and pre-spawn mortality; and
4. No influences of Fraser River tidal backwatering on spawning ground water elevations. Incidence of pre-spawn mortality or tidal influence was therefore not considered and may have resulted in an over-estimate of operations-induced stranding rates.

4.6 SFLMON-6 Risk of Fry Stranding

4.6.1 Summary

The Risk of Fry Stranding study was developed to assess the rate of fry stranding downstream of Ruskin Dam in relation to spring limited block loading operation. Block loading is when a generating plant is operated at a set output for a specific period, to maintain a relatively constant water flow from Ruskin Dam. From February 15 to May 15, there is a maximum of one plant load change each day within a period of four hours if discharge is < 100 m^3s^{-1}. If discharge is >100 m^3s^{-1}, there are no requirements for changes in discharge. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details).

This two-year study determined if the spring limited block loading operation limited fry stranding at rates below the 1.5% acceptance threshold with a <0.1% probability in exceeding the performance measure threshold.

4.6.2 Management Questions

The study included one management question:

1. Is the stranding mortality caused by the spring limited block loading strategy less than 1.5% of the total Chum fry population?

(BC Hydro 2006, p. 66)

4.6.3 Objectives and Scope

The objective of this study was to assess the rate of fry stranding downstream of Ruskin Dam in relation to the spring limited block loading operation. The following aspects define the scope of the study:

a) The study area was restricted to the 1.5 km section of Stave River located immediately downstream of Ruskin Dam.

b) Data collection occurred during the fry emergence period between February 15 and May 15.

c) Stranding assessments were scheduled to coincide with low tide.

d) The fry-stranding study was completed in two years.

4.6.4 Approach and Methods

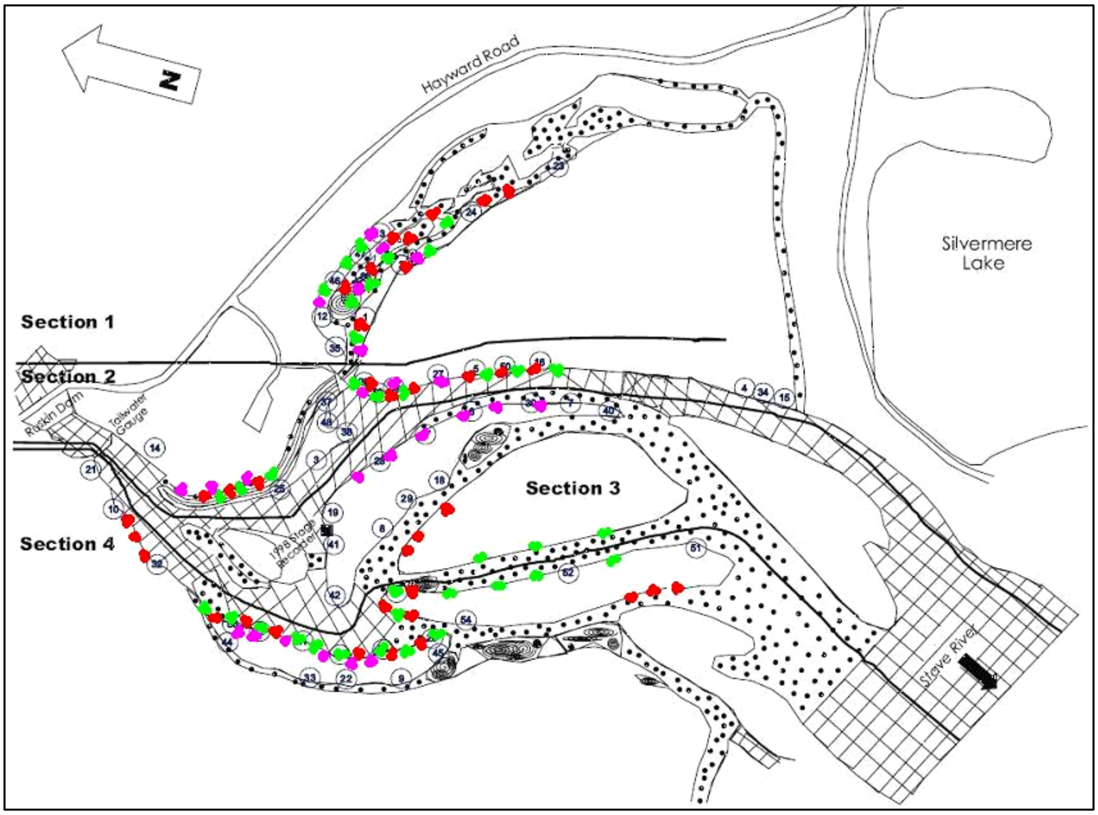
The Risk of Fry Stranding Study was conducted in the spring of 2008 and 2009 concurrent with the Chum salmon fry out-migration period by InStream Fisheries Research Inc. The final report summarizing the study results and addressing the management questions listed above is available on BC Hydro's WUP website:

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

The general approach of this study was to determine if fry stranding exceeded the threshold of 1.5% of total out-migrating fry following the methods of Leake and MacLean (1998). The lower Stave River was divided into four sections and sampling was conducted at three sites within each section two hours following a ramp-down event (>0.2m; Figure 4-12). Condition of all stranded fry was assessed to determine if mortality occurred as a cause of or prior to the surveys stranding event. Tailwater elevations and shoreline slope were recorded to estimate total dewatered area (m^2) for each ramp-down event.

Fry emergence curves were derived using lower Stave River water temperature profiles and DFO spawner abundance and runtime estimates from the previous spawning period. The relationship between estimated number of daily out-migrating fry (based on DFO adult escapement estimates) and observed stranded fry density was developed to calculate estimated total number of stranded fry and percent of total fry production stranded. A Z-test was used to compare the performance measure (1.5% of total fry production stranded) to estimated total stranded fry for each sampling year (including Leake and MacLean, 1998) to assess the likelihood of a significant annual stranding event to warrant a change to operations.

Figure 4-12 Shoreline sites surveyed during the 2008/2009 lower Stave River fry stranding assessment. Survey sites include: 2008 daytime surveys (n=24; pink dots); 2009 daytime surveys (n=36; red dots); 2009 night surveys (n=36; green dots), and; 1997/1998 surveys (white numbered circles).



4.6.5 Results

The partial spring block loading operation was found to limit Chum fry stranding risk downstream of Ruskin Dam. Over two monitoring years, observed stranding rates were below the performance level threshold set by the CC.

Answer to the management question:

1. *Is the stranding mortality caused by the spring limited block loading strategy less than 1.5% of the total Chum fry population?*

The percent of total fry production stranded was 0.19% and 0.92% in 2008 and 2009, respectively. This was similar to Leake and MacLean (1998) estimates of 0.17% and 1.48% of total fry production stranded for the sampling years 1997 and 1998, respectively. Compared to the pre-WUP performance measure of 1.5%, three of the monitoring years (1997, 2008, and 2009) resulted in a <0.1% probability in exceeding the performance measure threshold. In 1998, there was a 44% chance the performance measure threshold would be exceeded.

The following summarizes other key findings of the Risk of Fry Stranding study:

a) Over the two sampling years, observed fry stranding densities ranged from 0.12-1.86 fry/m^2, which were similar to the range of 0.11 to 2.11 fry/m^2 observed by Leake and MacLean (1998; Figure 6-2).

b) The significant regression model comparing Chum fry stranding densities to number of daily emergent fry suggests that estimated daily abundance of emergent fry during ramp down events is an important factor contributing to stranding fry (Figure 4-13).

c) A null relationship was observed when a stage change was compared to the density of fry stranded suggesting that within the ranges observed, the amount of dewatered area exposed during ramp down event has little impact on the number of fry becoming stranded (Figure 4-14).

d) Fry stranding mortality in 2008/2009 was estimated to reduce the 2011/2014 female escapement by approximately 0.17% (1079/600,000 females) should adult escapements remain similar through time.

Figure 4-13 Relationship between Chum fry stranding density (fry/m^2) and the estimated number of daily emergent fry observed during 1997/1998 and 2008/2009 lower Stave River fry stranding assessments (n=15).

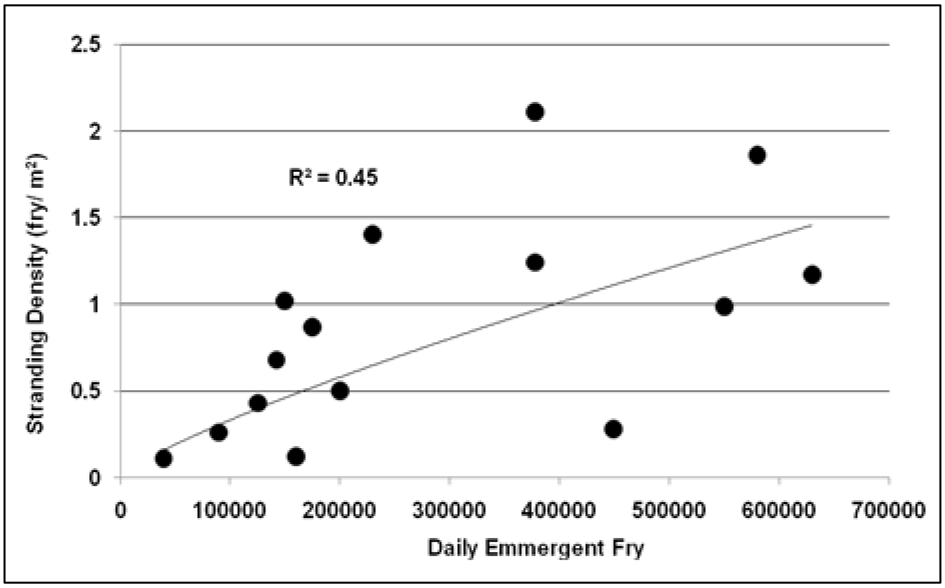
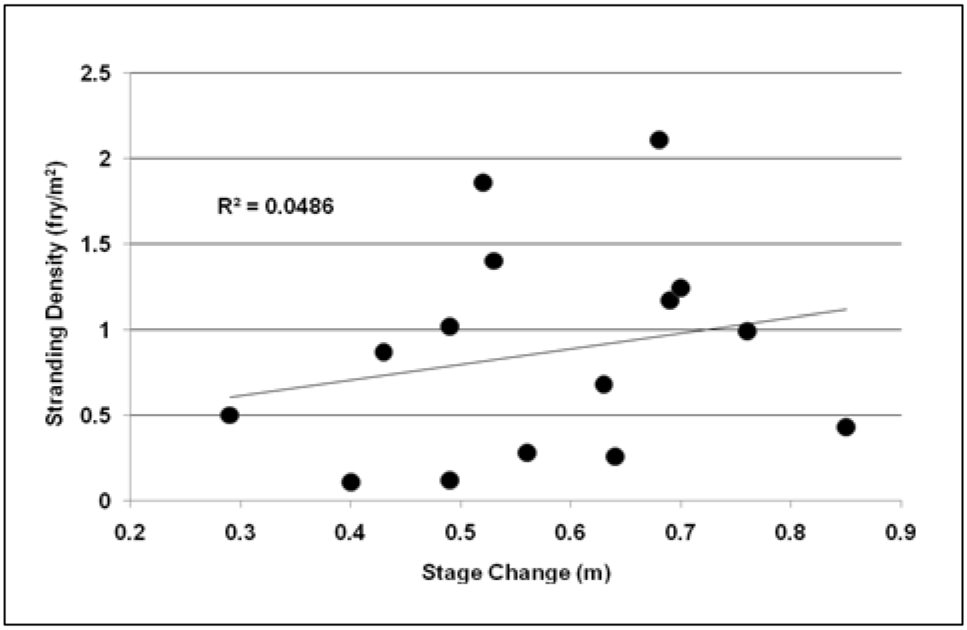


Figure 4-14 Relationship between Chum fry stranding density (fry/m^2) and stage changes greater than 0.2 m observed during 1997/1998 and 2008/2009 lower Stave River fry stranding assessments (n=15).



In addition to the diel effect on stranding densities as observed by Leake and MacLean (1998) and in SFLMON-7 (Section 4.7), findings of this study suggest the timing of limited block loading in relation to the timing of emergence is a principle factor contributing to the number of emerging fry becoming stranded, whereas the magnitude of rampdown has less of an effect on stranding rate. Mean total dewatered area in 2009 (22,200 m^2) was less than 2008 (26,600 m^2); however, stranding rate was increased greater than 3-folds in 2009. A strong positive relationship between the number of fry stranded and the projected number of daily emergent fry present during ramp down events was observed. These results suggest the magnitude of stage reduction (i.e., total area dewatered) has a limited effect on the total fry stranding rate compared to the time of draw-down in relation to peak fry emergence. Regardless, results determined a fry stranding rate of below the 1.5% of total fry production threshold.

4.6.6 Conclusions

The 2008 and 2009 assessments estimated a loss of fry due to stranding below the performance measure threshold was deemed acceptable by the Consultative Committee. Results of this study determined a likelihood of post-WUP operations exceeding the fry stranding rate performance measure threshold was <0.1% for both 2008 and 2009 operations. Further, these results may be skewed higher due to an experimentally altered flow regime scheduled under SFLMON-7 (see Section 4.7).

Continue operations as described in the WUP while minimizing drawdown events during the peak weeks of out-migration will likely ensure that the thresholds set in Water Use Plan discussions will be met.

4.7 SFLMON-7 Diel Pattern of Fry Out-migration

4.7.1 Summary

The Diel Pattern of Fry Out-Migration study was designed to assess the daily pattern of fry migration, as well as their behavioural response to rapid flow changes, downstream of Ruskin Dam. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details).

This study resulted in clear evidence that Chum fry show a daily pattern of out-migration that occurs primarily at night. Fry exhibited heterogeneous spatial distribution during out-migration where horizontal movements were affected by flow conditions and vertical movements were effected by time of day. However, sampling method restrictions did reduce confidence in the spatial distribution results.

Following the completion of the monitoring described within the TOR, a pilot study to assess the feasibility of using a Dual-frequency Identification Sonar (DIDSON) to monitor behavior responses of dispersing Chum fry to changing operational flows in the lower Stave River was conducted. Results found peak movement shortly after dark at 2100 h and declining throughout late evening to early morning. No change in fry position was observed during increasing flows while a small proportion of individuals were seen to laterally move during decreasing and stable flows. If stable flows are treated as a control, movement during a change in flow may not be biologically significant.

4.7.2 Management Questions

1. Does out-migrating fry express a daily pattern of migration, and if so, is it primarily at night, crepuscular, or during the day?
2. Is the behavior of emerging fry influenced by rising, steady and falling water levels, and do these responses change with the time of day and/or transverse location in the channel?
3. Can operations be modified to further minimize stranding from the 1.5% threshold?
4. If so, can operations lead to additional opportunities for increased operational flexibility?

Information gathered to support management questions 1 and 2 is used to inform answers to management questions 3 and 4. This study is designed to focus on the information necessary for discussion of the operational aspects within Management Questions 3 and 4 during the WUP Order Review.

(BC Hydro 2006, p. 72)

4.7.3 Objectives and Scope

The objective of this study was to assess the daily pattern of fry migration, as well as their behavioural response to rapid flow changes, downstream of Ruskin Dam. The following aspects define the scope of the study:

a) The study area was restricted to the 1.5 km section of Stave River located immediately downstream of Ruskin Dam.

b) Data was collected at two sites, each differing in the extent to which tidal backwater effects attenuate operational changes to water level.

c) Data collection occurred during the fry emergence period, which was typically between February 15 and April 10.

d) Variability in the periodicity and duration of high flow events during the spring block load period (considered here to be the study treatment) was systematically scheduled.

e) The study was completed in one year.

4.7.4 Approach and Methods

The Diel Pattern of Fry Out-Migration study was conducted in the spring of 2008 by LGL Limited. A final report summarizing the study results and addressing the management questions listed above is available on BC Hydro's WUP website:

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

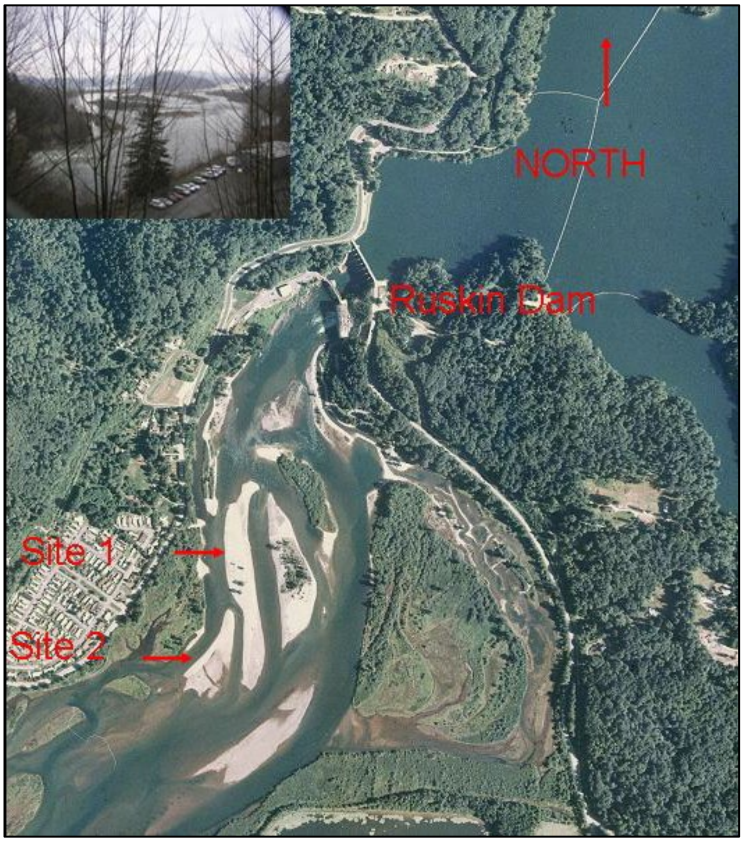
The general approach of this study was to collect behavioural and spatial distribution data on out-migrating Chum fry in response to operational flow changes and time of day. Four sampling periods occurred between February and April at two sampling sites 750 m and 1200 m downstream of Ruskin Dam where water level fluctuations were greatest and tidal effects attenuated water level changes, respectively (Figure 4-15). Flow conditions were scheduled by randomly assigning low (<100 m^3s^{-1}), high (>200 m^3s^{-1}) or in flux (>100 m^3s^{-1}, <200 m^3s^{-1}) flows every 8 hours for each sampling period. Estimates of relative catch per unit effort (CPUE; fish/trap/h) of out-migrating fry were derived across a 48-hour period and varying discharges using two inclined-plane traps (IPTs) at each site. Horizontal and vertical spatial distributions were evaluated over 24-hour periods using four driftnets paired in one horizontal array and one vertical array. The potential of stranding and fry behavior (resting vs. active) in response to different flow regimes was assessed using underwater videography (two Pentax Optio W60 and Sealife 600C cameras) and direct observations (snorkeling); however, visual techniques were considered unsafe in high flows, ineffective through observer efficiency trials and discontinued after the first sampling period. Environmental variables recorded hourly during sampling included water temperature, air temperature, river water level, Ruskin dam discharge, tailwater elevation, light intensity (LUX), and percent cloud cover.

Drift net and IPT fry captures were enumerated for calculation of CPUE and life stage was assessed (alevin vs. fry). IPT CPUE data were fitted with a full-factorial two-way model including Ruskin Dam flow condition (low, <100 m^3s^{-1}; high, >200 m^3s^{-1}) and time of day (day and night) as factors. In flux discharge (>100 m^3s^{-1} and <200 m^3s^{-1}) and crepuscular (dusk and down) data were excluded from the analyses. Raleigh's test for circular uniformity (Batschelet, 1981) was used to further examine effects of time of day including all time intervals and analyzing high and low flows separately. The effect of tide on the downstream IPT capture rates were estimated using Poisson-distribution log-link general linear models when Ruskin Dam discharge was low. Paired t-tests were used to evaluate differences between horizontal and vertical fish distribution. Significant paired differences were modelled using standard parametric ANOVA as a function of Ruskin Dam flow condition (high or low) and time of day (day or night). All analyses were completed separately for alevins and fry. Since the alevin life stage is outside the scope of the management questions, results are not discussed here.

Following the completion of the monitoring described within the SFLMON-7 TOR, a pilot study to assess the feasibility of using a Dual-frequency Identification Sonar (DIDSON) to monitor behavior responses of post-emergent Chum fry to changing operational flows in the Lower Stave River was conducted in the spring of 2009. Monitoring occurred for one day (1700 through 0600 h) at each of three sites upstream of tidal effects. The DIDSON was oriented perpendicular to the prevailing flow direction to sample the water column horizontally. A subsample of data (50%) was processed by enumerating fry and individually categorized as moving towards, away, or remaining stationary in relation to the nearest bank. Total hourly counts were estimated for each sampling site and period. The proportion of counts that occurred during increase, decreasing, and stable flows was also calculated. For methods and full results refer to the link below.

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

Figure 4-15 Lower Stave River sampling locations (Site 1 and 2) downstream of the Ruskin Generating Station for the Diel Pattern of Fry Out-Migration Study.



4.7.5 Results

The findings of this study indicate that rapid flow changes in the lower Stave River did not appreciably affect Chum fry out-migration behaviour. Daily pattern of Chum fry out-migration occurred primarily at night peaking soon after dusk, declining overnight to near negligible levels by dawn, and remaining at low levels from dawn to dusk.

Answers to the Management Questions:

1. *Does out-migrating fry express a daily pattern of migration, and if so, is it primarily at night, crepuscular, or during the day?*

   A distinct periodicity of out-migration was observed with catch rates higher at night (51.7 fry/h) than during the day (2.9 fry/h; $\chi_1^2 = 79.56.0$, $P<0.0001$). Fry catches peaked soon after dusk (22:47 h; 95% CI: 22:42 – 22:52 h), declining through the night and remaining negligible throughout the day (Figure 7-2). The pilot DIDSON study confirmed the pattern of fry movement peaking soon after dusk (2100 h) and declining throughout the late evening to early morning.

2. *Is the behavior of emerging fry influenced by rising, steady and falling water levels, and do these responses change with the time of day and/or transverse location in the channel?*

   Timing of fry dispersal did not change relative to changes in flow with capture rates similar between flow conditions (high: 25.3 fry/h; low: 25.0 fry/h; $\chi_1^2= 1.8$, $P = 0.18$). Mean peak capture time of fry dispersal did not vary significantly with flow (95% CI high flow: 23:09 – 23:24 h; 95% CI low flow: 22:11 – 22:24 h). Occurrences of peak abundance during in flux flows, as seen in Figure 4-16, was considered to be due to coinciding dusk conditions; the overriding factor initiating the onset of fry dispersal. The pilot DIDSON study also found no effects of flow condition on fry dispersal.

   Fry exhibited a heterogeneous spatial distribution during out-migration. Horizontal distribution was affected by flow conditions with smaller catch rates inshore (mean = 0.8 fry/h) compared to offshore (mean = 1.0 fry/h; $F_{1,390} = 4.9$, $P = 0.027$) at low flows. Vertical distribution was affected by time of day with larger catch rates at the surface (mean = 6.6 fry/h) compared to the bottom (mean = 2.5 fry/h; $F_{1,102} = 10.3$, $P = 0.0018$) at night. The pilot DIDSON study found horizontal distribution to be affected by decreasing flows; however, during stable flows horizontal movements were also observed.

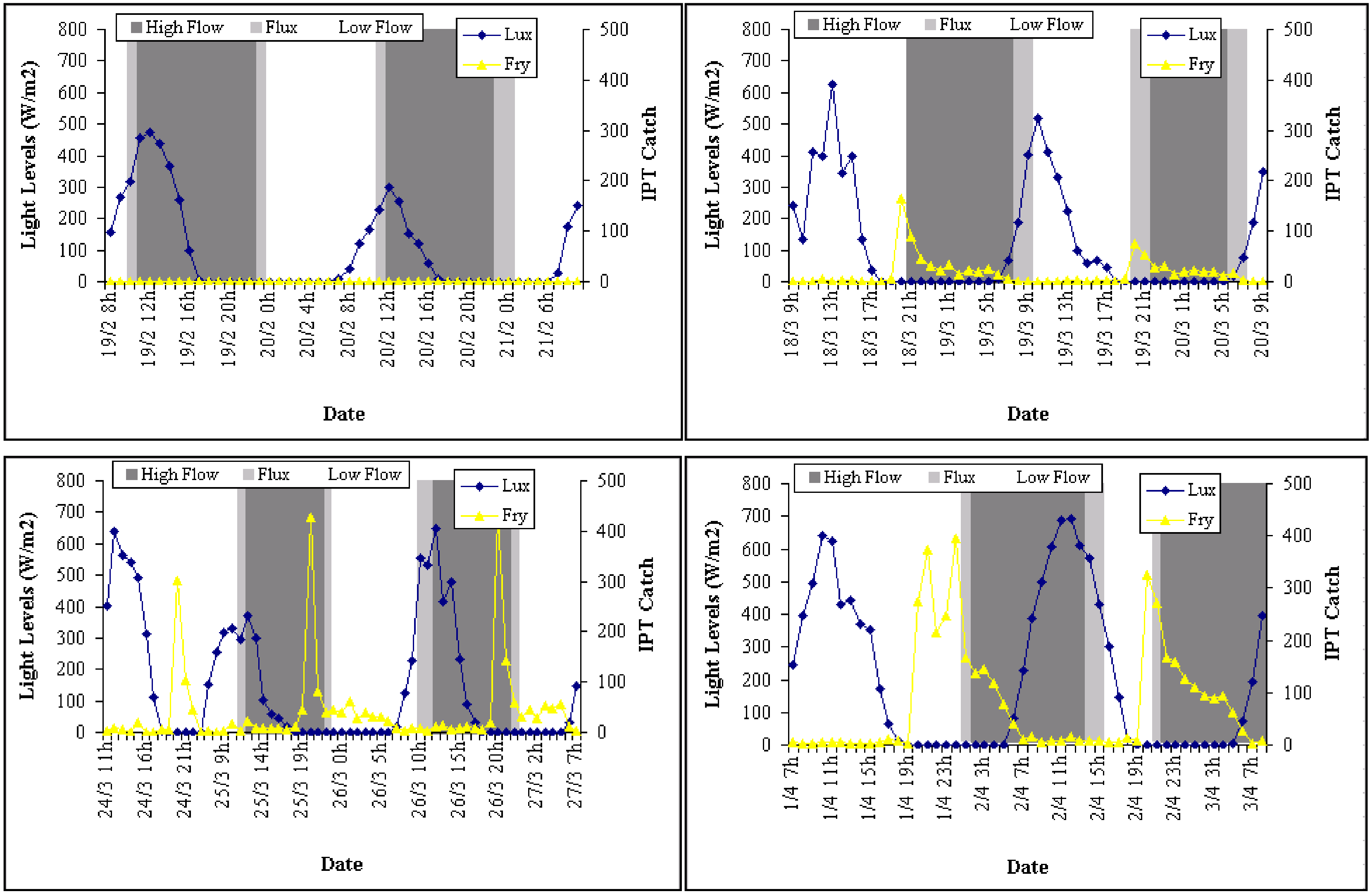
   Observations of fry during periods of no movement in response to flow treatments were inconclusive since valid day versus night period comparisons, as well as low versus high flows, could not be made due to viewing conditions and safety concerns.

The following summarizes other key findings for the Diel Pattern of Fry Out-Migration Study:

a. For the total 208 hours of monitoring, flow levels were recorded as low for 103 h (49.5%), high for 85 h (40.8%), and in flux for 20 h (9.7%). A total of 9137 fry were captured and processed with the majority of capture by IPT techniques (79% and 73%, respectively).

b. During periods of low flow there was a significant effect of tides on fry catch rates with a significantly greater CPUE at low tide (40.5 fry/h) than at high tide (23.2 fry/h; $\chi_1^2= 96.2$, $P <0.0001$).

Figure 4-16 Catch of Chum fry for both IPTs combined superimposed on flow conditions and light levels for each of the four trial periods during February 10 to April 3, 2008. Conditions include: low flow (white shading), in flux flow (light grey shading), high flow dark shading), and light levels (Lux, [W/m^2] where night = 0; blue line).



4.7.6 Conclusions

This study resulted in clear evidence that Chum fry show a daily pattern of out-migration that occurs primarily at night. Based on one year of IPT and drift net data, the results indicate:

1. Neither periodicity nor quantity of Chum fry dispersal downstream was significantly affected by daily fluctuating flow regimes; and
2. Vertical distribution of fry in the water column is unlikely to be affected by fluctuating flows, whereas horizontal distribution is likely to be greater offshore during times of lower flows.

It is therefore unlikely that flow variations associated with spring block loading operations would require changes in consideration of outmigration behaviour.

4.8 SFLMON-8 Seasonal Timing and Assemblage of Resident Fish

4.8.1 Summary

The Seasonal Timing and Assemblage of Resident Fish study was developed to assess the impact of Ruskin Dam releases on the seasonal habitat-use patterns of resident fish species, particularly non-salmonid, downstream of Ruskin Dam. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details). Two TOR changes were made and one contractor change, one in 2011 and 2015 in order to test different sampling methods that would potentially increase resident fish catchability and habitat suitability data collection. Despite these changes, only limited information supporting the study objectives is available. The information suggests that seasonal resident fish use and habitat availability are highly variable, making it unlikely that fall and spring block loading operations compromise resident fish use in the Lower Stave River.

4.8.2 Management Questions

The study included one management question:

1. Are the following assumptions valid (i.e., do WUP operations based on anadromous salmonid rearing and spawning criteria conflict with the seasonal habitat use patterns of other resident fish species)?
   a. Water releases from Ruskin dam found to impact or benefit spawning and incubation activities similarly affect rearing conditions for resident fish species. For example, the 100 m^3s^{-1} base flow during the anadromous spawning and incubation periods (as per the Combo 6 strategy) would benefit resident species as well.
   b. During the summer, operations that minimize within-day and between-day variability in flows improve rearing conditions for juvenile salmonids and resident fish species. This includes access to and availability of side channel habitats.

(BC Hydro 2006, p. 80)

4.8.3 Objectives and Scope

The objective of this study was to assess the impact of Ruskin Dam releases on the seasonal habitat-use patterns of resident fish species, particularly non-salmonid, downstream of Ruskin Dam. The following aspects define the scope of the study:

a) The study area was restricted to the 1.5 km section of Stave River located immediately downstream of Ruskin Dam.

b) Data collection occurred though out the year at 6-8 week intervals.

c) The study was conducted over three sampling years (by extension).

4.8.4 Approach and Methods

The Seasonal Timing and Assemblage of Resident Fish study was conducted over a three sampling seasons (2010/2011, 2013/2014, and 2015/2016) by LGL Limited, Kwantlen First Nations, and PGL Environmental Consultants. A final report summarizing the study results and addressing the management questions listed above is available on BC Hydro's WUP website:

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

The general approach of this study was to assess potential impacts of operational flow changes on seasonal native residential fish species composition and habitat use downstream of Ruskin Dam. This study was originally scheduled for one year but was extended by three TOR addendums (see BC Hydro's WUP website for details: https://www.bchydro.com/about/sustainability/conservation/water_use_planning/lower_mainland/stave_river.html). Methods for each study year are described below.

Study Years 2010/2011

The study area was divided into 5 segments including mainstem (segments 1 through 4) and side channel (segment 5) habitats (Figure 4-17). Two-day surveys were conducted for each segment at 6 – 8 week intervals over a year period (2010-2011) for a total of 8 sampling surveys. Sampling gear/methods, including beach seine, electrofishing, gillnet, minnow trap, and snorkeling, were not consistent over time or among segments (Table 4-3); therefore, catch rate was skewed as a function of number of sets performed. Due to inconsistencies, differences in abundance/species composition as a function of month was analyzed for river segments 1-4 (beach seine data only) and river segment 5 (minnow trap data only). Differences in abundance/species composition as a function of river segment (1-4) was analyzed with beach seine data.

Fish were measured for length (mm), identified to the lowest taxonomic level (typically species or family), and categorized as native migratory, native resident, or introduced resident. Only data regarding taxa categorized as native resident were analyzed. All fish groups, defined by age and taxon, were analyzed separately. Only fish groups captured more than ten times were analyzed. Due to complexities, capture data was coded as presence/absence. Chi square analyses were used to examine the effect of month and river segment on the presence/absence of each fish-group. Logistic regression was used to determine the effect of flow on the proportion of sets for which a given fish-group would be expected to be present.

Measured environmental variables included air temperature, water temperature, depth, substrate, turbidity, and tidal state. Hourly flow data on days of sampling (ranging from 50 – 200 m^3s^{-1}) was provided by BC Hydro.

<u>Study Years 2013/2014</u>

The study area consisted of the same 5 segments as the 2010/2011 study years (Figure 4-17). Two sampling surveys were conducted in all five segments during late September and early October at flows of 125 m^3s^{-1} and 175 m^3s^{-1}, respectively. Based on previous results, sampling methods were restricted to beach seining (segments 1-4; 10 and 9 sites for the September and October surveys, respectively) and minnow traps (segment 5; 12 sites). All segments were surveyed over two days.

Fish and environmental data were collected following 2010/2011 study methods. Data analysis was limited to summarization of resident fish catch rates by group for each habitat (mainstem and side channel) and treatment flows.

<u>Study Years 2015/2016</u>

The study area consisted of the same 5 segments as the previous study years (Figure 4-17). Sampling occurred in mid-October at 11 sites over the 5 segments during flows ranging from 69 m^3s^{-1} to 175 m^3s^{-1}. Sampling methods included electrofishing and minnow traps. Captured fish were measured for fork length (mm), weight (g), identified to the lowest taxonomic level (typically species or family) and released at location of capture. All segments were surveyed over four days.

Water quality, velocity, depth, substrate, and habitat type data were collected at each site. Water quality included measurements of temperature (°C), pH, specific conductivity (µS/cm), dissolved oxygen (%), dissolved oxygen (mg) and alkalinity (mg/L $CaCO_3$). Daily and hourly discharge data for Ruskin Dam was provided by BC Hydro. Discharge from other lower Fraser River locations (i.e., Mission, Whonnock, Port Mann, Pitt River) were obtained for comparison.

Summary statistics were used to describe fish habitat and population conditions. Relative fish density was calculated using methods described in Ptolemy (1993). Weighted useable areas (WUA) and Habitat Suitability Index curves were calculated. Due to risk of safety, not all habitat assessments were conducted therefore measurements of useable area and rearing capacity were not completed for all segments.

Figure 4-17 Lower Stave River downstream of Ruskin Generating Station showing the mainstem area (divided into four ~375 m segments; 1 -4) and side channel (5) located on the true left of the river; start and end points of side channel are noted.

Table 4-3 Sampling method applied by river segment and month during the 2010/2011 sampling. Sampling effort (number of sets) for beach seine (BS) and minor trap (MT) are provided in parentheses.

	Survey Month							
River Segment	Mar-2010	Apr-2010	Jun-2010	Aug-2010	Oct-2010	Nov-2010	Jan-2011	Mar-11
1	BS (4)	BS (2)	GN	BS (2)	BS (2)	BS (4)	BS (6), SK	BS (5), SK
2	BS (4)	BS (3), MT (1)	GN	BS (2)	BS (2)	BS (4)	BS (5), SK	BS (6), SK
3	BS (4)	BS (5)	GN	BS (2)	BS (3)	BS (5)	BS (5), SK	BS (4), SK
4	BS (4)	BS (5)	GN	BS (2)	BS (2)	BS (2)	BS (3), SK	BS (4), SK
5	MT (5), EF	MT (1), EF	MT (1), GN	MT (5), EF	MT (1), BS (3)	MT (1), BS (0)	MT (2)	MT (2), BS (2)

Gear types: BS = beach seine; EF = electrofishing; GN = gill net; MT = minnow trap; SK = snorkel

4.8.5 Results

Methods were revised for years two and three of the program to address issues identified in previous years. Because of the variation in habitats between the 5 segments of the study, the use of comparable fish capture methods was not possible. The information suggests that seasonal resident fish use and habitat availability are highly variable, making it unlikely that fall and spring block loading operations compromise resident fish use in the Lower Stave River. It was confirmed that seasonal off channel habitat access was not limited by WUP operations.

The following summarizes findings for all three years of the Seasonal Timing and Assemblage of Resident Fish Study:

a) Resident species analyzed by groups included Cottidae (adults and fry), Peamouth Chub (adults and fry), Northern Pikeminnnow (adults), Three-spined Stickleback, Rainbow Trout (adults and fry), Mountain Whitefish (adults).

b) In 2010/2011, there was a higher abundance of Peamouth Chub (fry), Northern Pikeminnow (adult), and Three-spined Stickleback in the mainstem during summer and Peamouth Chub (adult) during fall. High abundance of Peamouth Chub (adults) was observed in the side channel during the winter

c) No observed effects of river segment on fish groups over the 2010/2011 study period.

d) In 2013, the same fish groups were captured in the mainstem during the two flow regimes but at lower abundances at flows of 175 m^3s^{-1}; reductions in catch were among Peamouth Chub, Rainbow Trout, and Cottids fry and adult Three-spined Stickleback. Capture abundance within the side channel was approximately fourfold more in high flows (exclusively adult cottids).

e) In 2015, fish collection was an issue with no target fish species and limited non-target fish species captured. Further, due to sampling methods, habitat suitability could not reliably be calculated.

f) Environmental monitoring in 2015 confirmed that the Water Use Plan operations provide access to all engineered Lower Stave River sidechannels through all tide cycles and seasons (PGL 2017)

4.8.6 Conclusions

The study suggests that seasonal resident fish use and habitat availability are highly variable, making it unlikely that fall and spring block loading operations compromise resident fish use in the Lower Stave River. Separate contractors using a variety of methods found that seasonal WUP operations do not negatively impact resident fish use in the Lower Stave River. Environmental monitoring in 2015 confirmed that sidechannel access is maintained through all seasonal WUP operations.

4.9 SFLMON-9 Turbidity Levels in Hayward Reservoir

4.9.1 Summary

The Turbidity Levels in Hayward Reservoir study was developed to assess the quality of drinking water in response to reservoir drawdown during normal operations of fall and spring block loading, when increased reservoir flexibility is required to maintain fisheries flows downstream of Ruskin Dam. A monitoring plan TOR was drafted based on the recommendations of the Consultative Committee (please refer to Failing 1999 Appendix 8, for details).

Results of this study provided no evidence of impacts on mean reservoir turbidity by normal fluctuations of reservoir level and no variation between block and non-block loading periods was observed, suggesting changes made to the operating regime to accommodate downstream fisheries issues have not negatively impacted the drinking water resource in Hayward Lake Reservoir.

4.9.2 Management Questions

The study included one management question:

1. Does the quality of drinking water drawn from Hayward Lake reservoir remain within provincial standards following a change in the minimum operation level?

(BC Hydro 2006, p. 85)

4.9.3 Objectives and Scope

The objective of the study was to confirm that the quality of drinking water drawn from Hayward Reservoir remains within provincial standards following a change in the minimum operating level. The following aspects define the scope of the study:

a) The study area was restricted to Hayward Reservoir.

b) Turbidity observations were collected bi-monthly along with the annual shoreline surveys.

c) The study was completed in five years.

4.9.4 Approach and Methods

The Turbidity Levels in Hayward Reservoir study was conducted over five years from 2005 to 2009 by Living Resources Environmental Services. Annual reports were compiled each study year and a final report (year 5) summarized results for all study years and addressed the management questions listed above. All reports are available on BC Hydro's WUP website:

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

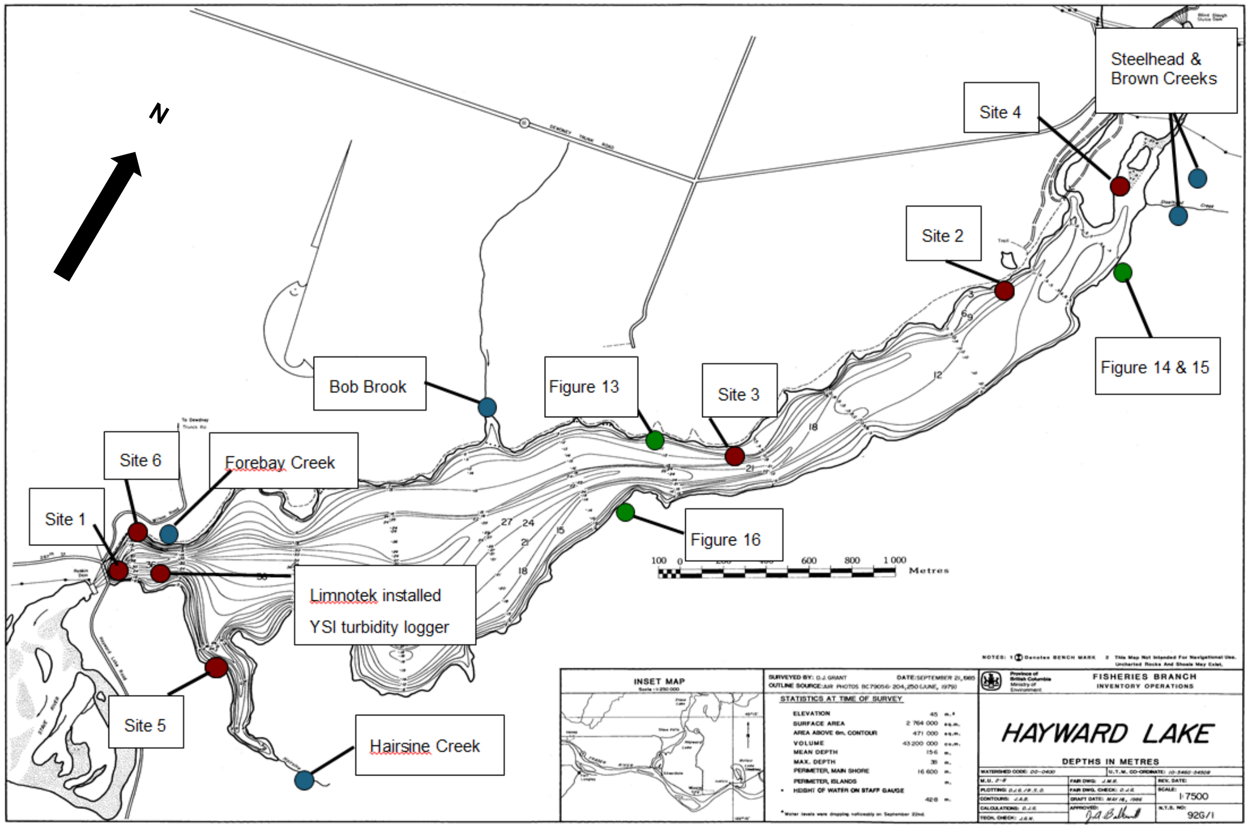
Turbidity was measured bi-monthly at six locations in Hayward Reservoir (Figure 9-1). Additionally, 5 tributaries to Hayward Reservoir were monitored to assess potential impact of these inputs on turbidity (Figure 9-1). Water samples were collected at arms-length from the shore, 5 to 10 cm deep and assayed on site for turbidity using a Hach Turbidity Meter (nephelometric units; NTU). Three samples were collected and turbidity levels were averaged at each site. All sampling sessions (n = 28) were conducted between 10:00 and 14:00 hours.

In 2007, supplementary turbidity data was available for time periods that were not covered by shoreline sampling via a YSI logger permanently installed (1-2 m below full pool) and monitored by Limnotek Research and Development, and from the District of Mission pump house daily turbidity records(10 m below full pool). Precipitation data was obtained from the Canadian Climate data website, Maple Ridge Creek, station ID 1104R02. Simple linear regression models were applied to evaluate correlation of turbidity with reservoir elevation and precipitation, separately.

In fall 2009, sampling was extended with five sampling sessions occurring between October 30 and November 16 to target heavy rain events combined with low reservoir levels in range of the fall block load minimum (39.5 m). Four sampling sessions were conducted during the draw down period near minimum operating level. An additional session occurred outside of the drawdown test period but within the block loading and heavy rainfall period.

Visual erosion surveys including photographs were completed annually (Figure 9-1).

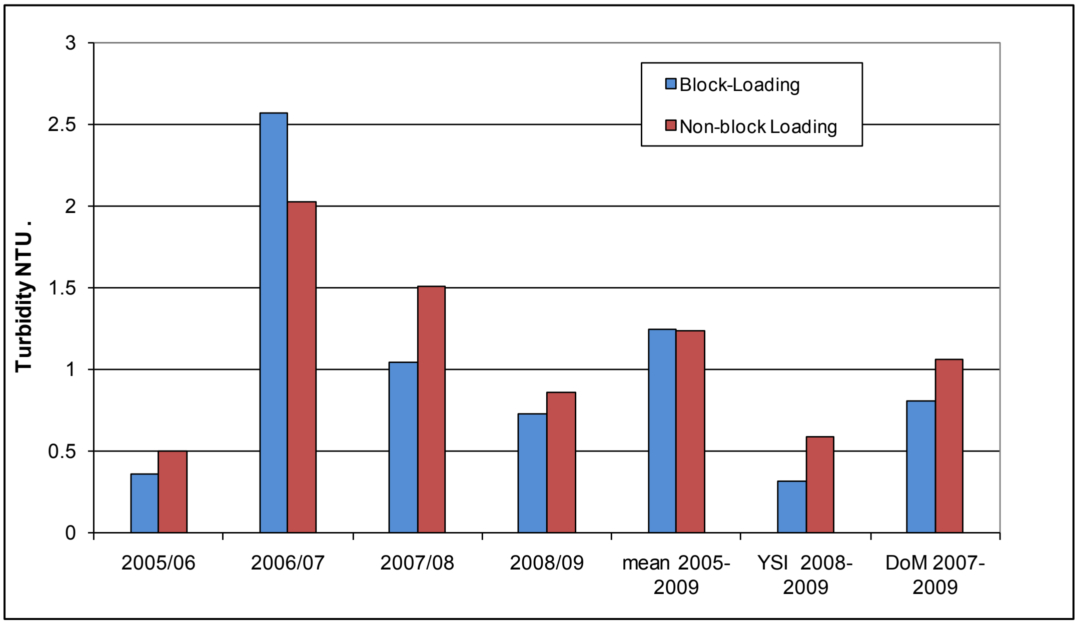
Figure 4-18 Map of Hayward Lake showing sampling sites (in red) and shoreline erosion sites (in green).



4.9.5 Results

Turbidity levels after five years of monitoring showed no correlation between Hayward Lake Reservoir elevation and block loading operations. Daily records from the YSI data loggers and District of Mission pump house loggers determined that turbidity is not higher during non-block loading versus block loading periods, while shoreline data shows turbidity levels to be equal between the two operating regimes (Figure 4-19). As expected, turbidity levels in the lake were impacted by expected environmental conditions such as rainfall, wind and temperature, regardless of operating regime.

Figure 4-19 Comparison of yearly mean reservoir turbidity during block and non-block loading periods (yearly values shown use shoreline sampling data only).



Answer to management questions:

1. *Does the quality of drinking water drawn from Hayward Lake reservoir remain within provincial standards following a change in the minimum operation level?*

Results of this study demonstrate turbidity levels of Hayward Reservoir are generally low (mean 1.27 NTU). The Canadian and Provincial drinking water guidelines prescribe turbidity standard of 1.0 NTU for untreated water; however the District of Missions water filtration capabilities has a threshold of 1.5 NTU before requiring further treatment. Turbidity levels recorded through this study remained within the District of Mission's capability of providing quality drinking water to local residents.

The following summarizes other key findings of the Turbidity Levels of Hayward Reservoir Study:

Drawdown Test Period: October 30 – November 16 2009

a) Mean turbidity for all sites during fall drawdown test sampling (5 sessions, 6 sites) was 1.27 ± 0.28 NTU, above the 1.0 NTU Canadian and Provincial drinking water quality standard and below District of Mission water filtration guidelines. No measurements exceeded the boil water advisory threshold (5.0 NTU)

b) The highest average turbidity by sampling session (1.65 ± 0.71 NTU' n=5) was measured outside the manipulated reservoir elevation drawdown period during the highest reservoir elevation (40.87 m). The lowest recorded mean turbidity (0.97 ± 0.24) was measured at the pump house.

c) Higher turbidity levels were not correlated with lower reservoir levels (R^2 = 0.033, P = 0.93) or precipitation (R^2 = 0.246, P = 0.49).

d) Tributaries (1.62 NTU) were slightly higher than lake samples.

Turbidity Monitoring: August 2005 – Nov 2009

a) Turbidity levels in reservoir were not impacted by reservoir elevation and the introduced block loading minimum operating level (R^2 <0.01, P = 0.93).

b) No observable difference in shoreline data when comparing turbidity levels during block loading (average 1.25 NTU) and non-block loading (1.24 NTU) periods. District of Mission pump house and YSI records determined turbidity was lower during block loading periods (Figure 9-2). Average precipitation for last three years was 34.6 mm (block loading) and 29.0 mm (non-block loading).

c) The higher turbidity levels in 2006/2007 surveys were correlated with high precipitation in the five days prior to sampling (R^2 = 0.91, P = 0.003). This strong of a relationship was not observed when all data years were combined (R^2 = 0.453, P = 0.27, n=28). However, all monitoring sessions (2005-2009) that exceeded the District of Mission threshold (7 out of 28 sampling sessions) were sampled immediately following or during a heavy to moderate rain suggesting extended periods of heavy rainfall can lead to elevated turbidity.

d) District of Mission pumphouse and YSI data indicate turbidity exceeds the 1.5 NTU threshold only in December/January. These incidences occurred outside of block-loading period and appear to be related to the freezing and thawing on Hayward Lake producing a bloom of organic sediment.

Shoreline Erosion Monitoring: 2005-2009

Only three areas of moderate concern were identified: Area 1) bank was stabilized with rip rap in 2006 and shows no further sign of failure/erosion; Area 2) marginal differences were observed between years (2007 to 2009) potentially resulting in a future sediment source; and Area 3) a recent slope failure observed in 2009.

4.9.6 Conclusions

Results of this study provided no evidence of impacts on mean reservoir turbidity by normal fluctuations of reservoir level and no variation between block and non-block loading periods was observed, suggesting changes made to the operating strategy to accommodate downstream fisheries issues have not negatively impacted the drinking water resource in Hayward Reservoir. Turbidity levels have not shown an escalating pattern during block or non-block loading periods, nor when compared to reservoir level or under poor weather conditions across monitoring years.

The manipulation of the reservoir during the 2009 drawdown test period, where the drawdown zone was 0.83 m lower than normal conditions and achieved a five-year block-loading reservoir low, did not produce elevated turbidity levels or exceed the District of Mission NTU threshold.

4.10 SFLMON-10 Archaeological Management

4.10.1 Summary

A five-year Stave River Archaeological Management Plan (McLaren 2002) was designed to undertake inventory, site evaluation, impact assessment, and to develop means of minimizing impacts to archaeological sites in the Stave River watershed. As specified in the Order and in the Stave River Archaeological Management Plan (Plan) dated June 10, 2002, based on the results of the studies conducted in accordance with the Plan, reports were prepared which discuss how operations may be affecting archaeological resources within Stave Reservoir, Hayward Lake Reservoir, and the Stave River downstream from Ruskin Dam.

4.10.2 Management Questions

The study included five research questions (McLaren 2002):

1. How are First Nation archaeological sites affected by erosion?
2. How would sites be affected by other operational strategies?
3. How can they be protected or salvaged?
4. Are there other sites in the area, including lands adjacent to the reservoir that are associated with reservoir operations?
5. How would these be affected by other operational strategies?

4.10.3 Objectives and Scope

The objective of the study was to assess impacts to archaeological sites and implement strategies for mitigation.

4.10.4 Approach and Methods

Several tasks were undertaken including site inventory, site assessment, mitigation and interpretation.

Site inventory work was completed in areas not previously surveyed and in areas not adequately surveyed previously. Site assessments were prepared and completed for each site re-visited or recorded during the study. The study collected data during surface inspections, evaluative testing, and analysis of results. The significance of each site was evaluated against a standardized method following the *British Columbia Archaeological Impact Assessment Guidelines*. Impacts were assessed using quantitative and qualitative observations of site alteration in regard to the mechanisms and amount of impact. Kwantlen First Nation contributed field researchers during the project, and provided support cataloguing artifacts.

Mitigation approaches to manage archaeological sites in the Stave watershed included erosion protection, investigative excavation, systematic surface collection and raising heritage awareness.

Analysis of the material and data from the Stave watershed included several approaches and accurate interpretation relied on several different analytical strategies.

4.10.5 Results

A total of 78 archaeological sites were inventoried during the study. Fifteen of these sites were newly recorded during inventory work. The remaining 63 sites were recorded during the course of earlier projects undertaken in the study area. Of the 78 archaeological sites in the study area, 69 are located fully or partially in the drawdown zone of Stave and Hayward Reservoirs. The additional sites are located along the banks of the Stave Delta, below Ruskin Dam. Primarily, these sites were found to contain stone tools. Archaeological material appears to be present across the landscape of the study area, occurring at different densities and revealed in areas of active erosion. The primary cause of impacts to archaeological sites is erosion occurring as a result of reservoir operation.

At least 72 of the 78 archaeological sites located in the study area are indicated as being impacted by reservoir operations. Sixty-nine of these sites are located in the Stave Watershed and three are located downstream of Ruskin Dam.

Rain and wind related erosion is the primary erosional impact to sites that are exposed when the water (reservoir) level is drawn down. This is amplified in areas that have no vegetation cover. Wave erosion is most significant in the range of 1-2 m above and below the reservoir level. However, waves and currents appear to erode deposits up to eight meters below the reservoir level. It has been identified that significant archaeological sites are located throughout the operation levels of Stave Reservoir. As reservoir levels change erosional agents operating on site deposits change and thus any operational strategies that are adopted may help protect some sites while increasing erosion at other site locations.

4.10.6 Conclusions

The study recommends that archaeological sites in the upper portion of the drawdown zone may be better protected if operational strategies which influence reservoir water levels promoted shoreline re-vegetation by keeping water levels low during prime growing seasons (McLaren 2008). The study also noted that in the Stave Delta region erosion is ongoing, but is amplified by spill events. One of the consequences of keeping reservoir levels at or near full pool is that more spill events may be necessary, particularly at times of high or unexpected inflow. Archaeological sites in the Stave Delta region and upper Hayward Reservoir are affected from spilling. The study recommends limiting spill episodes.

The Water Use Plan Order Review (WUPOR) will review these operational implications. Any recommendations, aside from operational changes, that involve direct archaeological site management have been provided to BC Hydro's Reservoir Archaeology Program (RAP)[3], as these activities fall under the purview of the Heritage Conservation Act and are outside the jurisdiction of the Comptroller of Water Rights.

5.0 SUMMARY OF CONCLUSIONS

Table 5-1 below, summarizes key results from the 9 aquatic studies and operational implication resulting from study findings. The nine studies led to the following results:

- Three studies (SFLMON 1, 3 and 8) showed no biological response linked to operations;
- Three studies (SFLMON 2, 6 and 7) did display a biological response and those results have indicated that an operational change could improve biologic conditions in Stave Lake Reservoir and in the Lower Stave River;
- SFLMON-9 showed no evidence of impacts on mean reservoir turbidity by normal fluctuations of reservoir level and no variation between block and non-block loading periods was observed, suggesting changes made to the operating strategy to accommodate downstream fisheries issues have not negatively impacted the drinking water resource in Hayward Reservoir; and
- The two remaining aquatic studies propose the continuation of the limited block loading operation in the Lower Stave River.
- SFLMON-2 proposes a delay of Stave Reservoir drawdown in September to potentially increase littoral productivity. SFLMON-6 and SFLMON-7 both propose continuing the limited block loading operation in the Lower Stave River but restricting flow changes to only daylight hours to reduce potential fry stranding.

The remaining study, SFLMON-10, was an Archaeological Management Plan. The study results recommended limiting spill episodes, and considering operational strategies that promote re-vegetation of the shoreline which may better protect sites in the upper part of the drawdown zone (e.g., keeping water levels low during prime growing seasons). Any recommendations for direct archaeological site management have been provided to BC Hydro's Reservoir Archaeology Program (RAP), as these activities fall under the purview of the *Heritage Conservation Act*.

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[3] Through the RAP, BC Hydro works with the Archaeology Branch of the B.C. Ministry of Forests, Lands and Natural Resource Operations and affected First Nations to assess and manage impacts to protected archaeological sites in the active erosion zone of the reservoir.

Table 5-1 Summary of Conclusions

Study name	**Implications**
SFLMON-1 Pelagic Monitor (Nutrient Load/Total Carbon Levels	Both Stave Lake and Hayward reservoirs are nutrient poor and are considered ultra-oligotrophic. Pelagic productivity was found to be independent of reservoir operations, it is considered unlikely that any kind of change to WUP (Combo 6) operation would lead to measurable changes in pelagic productivity.
SFLMON-2 Littoral Productivity Assessment	Littoral productivity in Stave and Hayward Reservoirs was found to be directly influenced by reservoir operations: WUP (Combo 6) operations produced slightly reduced littoral production compared to pre-WUP operations. 1. Littoral productivity decreased linearly as fluctuations in reservoir elevation increased between 4 and 8m, while fluctuations greater than 8 m tended to eliminate littoral productivity altogether 2. Delaying the Stave Reservoir September drawdown until late September-early October would likely increase productivity. 3. Reducing the Stave Reservoir mean summer elevation may provide increased littoral area, but could significantly impact other objectives.
SFLMON-3 Fish Biomass Assessment	No benefits to fish population in Stave Lake Reservoir were observed as a result of the WUP (Combo 6) operation. It is unlikely that alterations to the WUP (Combo 6) operation would provide a benefit to fish populations in Stave Lake Reservoir
SFLMON-4 Limited Block Load as Deterrent to Spawning	The adopted limited block loading strategy was successful in providing mitigation of high elevation redd stranding.
SFLMON-5 Risk of Adult Stranding	Annual adult stranding is unlikely to have a population level effect assuming that observations were typical of annual operations. Further monitoring may be warranted to ensure adult stranding rates do not influence confirmed population levels.
SFLMON-6 Risk of Fry Stranding	Limited block loading operations are successful in keeping fry stranding rates below accepted levels in the Lower Stave River. Restricting flow changes to daylight hours may further reduce the risk of potential stranding as found in SFLMON-7.
SFLMON-7 Diel Pattern of Fry Out-migration	Results from this one-year study indicate: 1. Chum fry out-migration was distinctively higher at night indicating that any flow changes during this timeframe could potentially impact the out-migrants in terms of stranding risk; 2. Operational changes, to restrict load changes to daylight period should be considered; and Neither, timing of out-migration, nor quantity of Chum fry dispersal downstream was significantly affected by daily fluctuating flow regimes.

Study name	**Implications**
SFLMON-8 Seasonal Timing and Assemblage of Fish Residence	Resident fish use in the Lower Stave River was found to be dynamic and responsive to flow conditions, and there was no evidence that WUP flows have negatively impacted resident fish use in the system.
SFLMON-9 Turbidity Levels in Hayward Reservoir	Turbidity levels recorded throughout this study remained within the District of Mission's drinking water quality standards. Therefore there are no operational implications due to turbidity. Turbidity was not affected by reservoir elevations or the changes.
SFLMON-10 Archaeological Management	Archaeological sites in the Lower Stave River Delta region and upper Hayward Reservoir are affected from spilling. The study results recommended limiting spill episodes, and considering operational strategies that promote re-vegetation of the shoreline which may better protect sites in the upper part of the drawdown zone (e.g., keeping water levels low during prime growing seasons).

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