Bridge-Seton Water Use Plan

Monitoring Program Terms of Reference

- BRGMON-6 Seton Lake Aquatic Productivity Monitoring

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BRGMON-6
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1 Monitoring Program Rationale

1.1 Background

The Bridge-Seton Water Use Plan Consultative Committee (CC) developed aquatic ecosystem objectives for Seton Lake that included the abundance and diversity of fish populations. The Seton-Anderson watershed provides habitat for a wide range of anadromous and resident species, which are valued from commercial, recreational, and cultural perspectives. A small diversion of water from the Bridge River watershed (Carpenter Reservoir) to the Seton-Anderson watershed started in 1934. The diversion increased in 1954 to power four turbines and it was fully developed by 1960 with the installation of four more turbines. There is poor understanding of the extent of impact on fish populations from the diversion and whether it is possible to modify the operation of the diversion to reduce this impact.

Effects of the Bridge River diversion were first investigated by the International Pacific Salmon Fisheries Commission (Geen and Andrew 1961). Those studies suggested the diversion of cold and turbid water from the glacial Bridge River and Carpenter Lake, reduced water temperature, increased light attenuation, and decreased primary productivity in Seton Lake. While these observations imply the existence of a “footprint” impact, that impact has not been shown with a quantitative historical account and the role of biological productivity and the structure of food webs in regulating the abundance and condition of anadromous and resident fish populations within the Seton-Anderson watershed is not well understood. For example, it is surprising that juvenile sockeye and kokanee (Gwenis) selectively rear in Seton Lake rather than in the adjacent, hydrologically unimpacted Anderson Lake (Geen and Andrew 1961).

In a comparison of limnological data between many Fraser and Skeena Basin lakes Shortreed et al. (2001) found that photosynthetic rates in hydrologically impacted Seton Lake were similar to morphologically similar but hydrologically unimpacted lakes in the Fraser Basin. Despite this similarity, Shortreed et al. (2001) found a disproportionately low zooplankton standing crop in Seton Lake. Another surprise is that the low zooplankton standing crop is sufficient to produce sockeye salmon smolts that are larger with expected greater overall survival rates than smolts rearing in the unimpacted Anderson Lake (Geen and Andrew 1961). This discrepancy between low availability of zooplankton and high biomass of sockeye juveniles has not been explained in data collected to date.

A further conundrum is that size at age and condition of lacustrine rainbow trout in Seton Lake is lower than in other large lakes of the Fraser Basin (unpublished DFO data from 2000-2003). This poor condition may be related to low abundance of zooplankton within Seton Lake but it may also be related to availability of food from littoral, benthic habitat and from terrestrial sources that are used by populations of rainbow trout in reservoirs (Perrin et al. 2006).

If the diversion effect on biological production in Seton Lake is present, the degree to which operations can be modified to mitigate the impact remains unknown. Uncertainty about the impact of the Bridge River diversion on biological production in Seton Lake cannot be resolved with existing information. The CC recommended that studies be done to fill data gaps to resolve these uncertainties and determine what water management actions may be used to mitigate effects of the water diversion that are shown to be present.

1.2 Management Questions

The key management questions focus on filling data gaps to reduce uncertainty about impacts of the Bridge River diversion on biological production in Seton Lake and how recent changes to the Bridge-Seton flow order (*Order* under the *Water Act* 2011) that affect operation of Downton Reservoir, operation of Carpenter Reservoir, flows in the Bridge River, and times of power generation at the Seton generating station may affect biological production in Seton Lake. The *Order* under the *Water Act* that took effect on March 30, 2011 included the following items.

1) Water release from Carpenter Lake to the lower Bridge River will be 1.5-15 $m^3 \cdot s^{-1}$ varied by month of the year.
2) Targets for the water surface elevation of reservoirs are defined but the elevation may go below a minimum elevation to provide minimum flows in downstream rivers.
3) Targets are set for ramping rates at the Terzaghi Dam that controls outflow from Carpenter Lake to the lower Bridge River and controls water surface elevation in Carpenter Lake. Ramping rate is the rate of change in flow during a lowering of water releases.
4) Partial (6+ hours) or blanket (24 hours) daily shutdowns are required for Seton Generating Station during smolt out-migration between April 20 and May 20.
5) Targets are set for flows in the Seton River to protect migrating salmon.

These items were cumulatively packaged as management alternative N2-2P by the Bridge-Seton Water Use Plan Consultative Committee, and this alternative was selected as the best among many options that were reviewed. Potential benefits of N2-2P for fish populations and other water uses are presently being tested in several ongoing monitoring projects. The management questions related to biological production and fish populations in Seton Lake are as follows:

1) Will the selected alternative (N2-2P) change biological production in Seton Lake?
    - What are the physical changes that occurred in Seton Lake due to N2-2P?
    - Do these physical changes have positive, negative or neutral impacts on biological production in the Seton Lake?
2) What is the inter-annual variation in physical conditions in the Seton Lake caused by the diversion and did the diversion change primary and secondary production in Seton Lake?
    - What is the inter-annual variation in physical conditions of Seton Lake compared with adjacent unimpacted Anderson Lake?
    - What is the inter-annual variation in physical conditions of the Seton Lake compared with potential historical variations as inferred from Paleolimnological assessments?
    - Do these inter-annual variations in physical conditions have positive, negative or neutral impacts on primary and secondary productivity in the Seton Lake?

3) To what extent does aquatic productivity alone limit the abundance and diversity of fish populations in Seton Lake?

4) Can refinements be made to the selected alternative to improve habitat conditions or enhance fish populations in Seton Lake?

1.3 Detailed Hypotheses about the Impacts of Bridge Generating Station Operation on Aquatic Productivity of Seton Lake

The primary hypothesis (and sub-hypotheses) associated with these management questions are as follows:

H_1: (from Management Questions 1 and 5): N2-2P changed physical and chemical attributes that affect the availability of food that is ingested by sockeye, kokanee, and rainbow trout in Seton Lake.

H_{1a}: N2-2P changed physical and chemical conditions that affect the availability of food for fish in pelagic habitat of Seton Lake.

H_{1b}: N2-2P changed physical and chemical conditions that affect the availability of food for fish in littoral habitat of Seton Lake.

H_{1c}: There is a correlation between physical changes in Seton Lake caused by N2-2P and physical processes that affect the availability of food for fish in Seton Lake.

H_2: (from Management Questions 2 and 3): The diversion changed physical and chemical attributes that affect the availability of food that is ingested by sockeye and kokanee in Seton Lake.

H_{2a}: Juvenile sockeye and kokanee in Seton Lake are planktivores.

H_{2b}: The diversion reduced the production of phytoplankton and zooplankton in Seton Lake.

H_{2c}: The diversion caused lower temperature and higher turbidity in the pelagic habitat of Seton Lake compared to conditions before the diversion.

H_{2d}: Sources of cool and turbid water that is diverted to Seton Lake are watersheds upstream of Carpenter Lake, not sources (e.g. shoreline erosion) within Carpenter Lake.

H_{2e}: Sockeye and kokanee do not vertically migrate in Seton Lake after the diversion because cover provided by turbidity reduces risk of mortality from predation and favours longer feeding times each day than in Anderson Lake where sockeye and kokanee do vertically migrate.

H_{2f}: There is a correlation between physical changes in pelagic habitat of Seton Lake caused by the diversion and physical and chemical processes that affect primary and secondary production in pelagic habitat of Seton Lake.

H3: (Management Question 4): The abundance of Seton Lake sockeye and kokanee (Gwenis) populations are limited by habitat impacts related to the operation of the Bridge River Generating System.

H_{3a}: Settled sediment from the diversion of water from Carpenter Reservoir reduces the quality of shoreline and / or deep water spawning habitat.

H_{3b}: Daily fluctuations in Seton Lake levels result in reduce effectiveness of spawning.

Testing of these hypotheses is critical for understanding and predicting the impacts of operations on fish; however, they could not be resolved with scientific data during the Bridge-Seton Water Use Plan process when the professional judgment and experience from other systems was used to help support critical trade-off decisions.

1.4 Key Water Use Decisions Affected

The key operating decision that may be affected by this monitoring program is whether the seasonal operation of the generating station/diversion between Carpenter Reservoir and Seton Lake can be altered to mitigate impacts of the diversion on aquatic productivity. Other specific water use management decisions that could change as a result of this study include: 1) the amount and timing of discharges from Lajoie Generating Station, especially during freshet periods when there is high turbidity, and, 2) desired operation of Carpenter Reservoir to mitigate the effects of its diversion on Seton Lake.

This monitoring program will also address data gaps associated with the effect of the diversion on aquatic productivity in Seton Lake. Given the uncertainty associated with the assessment models used by the Bridge-Seton Water Use Plan Consultative Committee, follow-up monitoring has been recommended to help provide assurance that unexpected negative impacts to aquatic productivity or fish populations do not result from implementation of the selected alternative.

2 Monitoring Program Proposal

2.1 Objectives and Scope

The fundamental objective of this monitoring program is to document the impacts of Carpenter Lake Diversion on the biological productivity of Seton Lake.

2.2 Approach

The main approach to this monitoring program is to conduct a before-after-control-impact design comparison of the effects of the implementation of the selected alternative on aquatic productivity in Seton Lake. To assess the influences of the Bridge River diversion on Seton Lake, Anderson Lake is used as a control/reference system given its proximity and similar geology, morphometry and orientation to that of Seton Lake. Parallel sampling at a lower intensity is proposed for Anderson Lake.

Based on this study design, detailed modern baseline assessments of Seton and Anderson Lakes were initiated during the Water Use Plan data collection phase and were continued by BC Hydro and DFO from 2000 to 2003. These studies categorized the trophic status of Seton and Anderson lakes, and their productive capacities under past operating conditions, and provided some insight into the effects of the diversion on the Seton Lake ecosystem.

Follow-up monitoring of the anticipated changes resulting from the implementation of the selected alternative flow regime is proposed to 1) document how the change in operations influence aquatic productivity, and 2) collect data under a range of inflow and diversion operating conditions, which will provide insight into the potential for making changes to existing seasonal diversion rates. It is proposed that aquatic monitoring continue for three years to capture inter-annual variability after the flow alterations, and to enable comparison with the multi-year data from the early 2000s. It is expected that a total of seven years of data will enable the resolution of the key management question surrounding opportunity to alter the seasonal pattern of diversion to optimize aquatic productivity.

A critical feature of this study is the strong experimental design and the application of standardized limnological and limnetic fish sampling. The proposed approach not only provides comparisons between years in Seton Lake and Anderson Lake, but makes it possible to compare conditions in Seton Lake to a large number of other large lakes in BC sampled by BC Ministry of Environment Fisheries Management and DFO Science Branch.

Paleolimnological Study

Paleolimnology is the study of past lake and environmental change through the analysis of material archived in lake sediments. As lakes constantly deposit sediment containing biological, chemical and physical indicators reflective of lake conditions at the time of deposition, and new sediments overlay older sediments, continuous lake histories can be reconstructed from dated sediment cores.

A concurrent paleolimnological study of Seton and Anderson lakes is proposed to provide pre-historical ecological context for both lake ecosystems, and to establish a continuous time series of physical, chemical and biological lake changes associated with the Bridge River diversion since its inception. These data will help to understand the effects of operations on productivity, food webs and ecosystem structure to address the Management Questions and the associated Hypotheses.

To date, impacts of diversion have been inferred indirectly based on the theory that cold turbid water yields low productivity. A paleolimnological study of Seton and Anderson lakes can more directly test the hypotheses that the diversion has decreased the productivity of Seton Lake. As with the modern lake study, inferences regarding the diversion impacts on Seton Lake in the paleolimnological study will be strengthened by the “Before-After, Control-Impact” study design (Stewart-Oaten et al. 1986). In fact, comparative paleolimnological techniques are an established approach for understanding the influences of hydro management on lakes (e.g. Serieyssol et al 2009).

The proposed paleolimnological investigation adds substantially to the overall assessment of the impacts of the Bridge River diversion on Seton Lake. By exploring past (i.e., centuries ago) lake conditions prior diversion impacts, natural variability in aquatic productivity, lake trophic status, and pelagic food webs can be established. This is particularly important, as all current and proposed limnological and fisheries data on Seton and Anderson lakes comes from the post-diversion era, a time period that is additionally impacted by potentially confounding ecological drivers such as climate change. A recent integrated limnological-paleolimnological study by Selbie et al. (2011) showed that climate change can significantly interact with and amplify the impacts of human activities on lake ecosystems. Additionally, by providing a continuous time series of lake change, the proposed paleolimnological study allows an examination of all past flow regimes from the Bridge River diversion on Seton Lake. This paleolimnological perspective provides important context for predictive modeling of aquatic productivity, food web and inorganic sediment loading impacts across a range of flow regimes.

2.3 Methods

There are three general tasks proposed for the Seton Lake Aquatic Productivity Study. Each task is described below.

2.3.1 Task 1 Project Coordination

Project coordination involves the general administrative and technical oversight of the program. This will include but not be limited to: 1) budget management, 2) staff selection, 3) logistic coordination, 4) technical oversight in field and analysis components; and 5) liaison with regulators and St'at'imc.

2.3.2 Task 2 Field Surveys

Seasonal Limnology Surveys

Seton and Anderson lakes will each be sampled six times (once monthly during the period May-October) each year at pre-defined sample locations for physical, chemical, and biological variables.

Physical data collection will involve profiling light transmission, temperature, and conductivity, and Secchi depth at seven locations along the axis of Seton Lake and three locations down the axis of Anderson Lake. Physical data collection will also occur at the Bridge River 1 Generating Station and Portage Creek to characterize inflow water quality. Note: Collection of physical and chemical information should be coordinated with other programs that are collecting similar data from similar locations (e.g., BRGMON-8 Seton Lake Resident Fish Habitat and Population Monitoring, BRGMON-12 Bridge-Seton Metals and Contaminants Monitoring).

This sampling approach will provide detailed documentation of the spatio-temporal changes in the physical conditions in the lake associated with the diversion, and are comparable to the reference data collected in the early 2000s. Additionally, at two of the limnological stations, a full suite of chemical and biological variables will be collected to explore lake productivity and pelagic food webs. Chemical variables include: total suspended solids, turbidity, alkalinity, pH, silica, total dissolved solids, nitrogen (nitrate, ammonia, particulate N, dissolved organic N), phosphorus (total P, particulate P, and soluble reactive P), and carbon (dissolved inorganic, particulate). Biological variables will include: bacterioplankton abundance, picoplankton abundance, phytoplankton biomass and species composition, chlorophyll a, photosynthetic rates (^{14}C uptake method), zooplankton species composition and biomass. Methods for field studies will closely follow those conducted during 2000 and 2001 to ensure comparability.

Paleolimnological Survey

Gravity and/or percussion sediment cores will be retrieved from the deep water depositional areas of Seton and Anderson lakes in Year 1. Two cores are proposed for Seton Lake to spatially link lake historical lake changes to the Bridge River diversion. One core would be retrieved at a proximal location to the Bridge River diversion outflow in the northwest basin, and the other a distally-located core in the southeast basin. One reference core is proposed for Anderson Lake as a control, and to assess the influence of confounding regional- and global-scale drivers (e.g. climate variability, climate change). Each core would be dated using naturally-occurring radioisotopes (^{210}Pb, ^{137}Cs, ^{14}C) and standard radiometric dating models (Appleby 2001, Bjorck and Wohlfarth 2001).

To establish past variations in lake productivity and food web structure, a multi-proxy paleolimnological approach would include chronostratigraphic and lithological analyses (loss-on-ignition (organics, carbonates, inorganics), grain size, magnetic susceptibility, sedimentation rates), geochemical indicator analyses (elemental N and

C analyses, stable N and C isotopes), and biological indicator analyses (i.e., algal fossils and/or pigments, zooplankton sub-fossils).

Summer and Fall Limnetic Fish Surveys

The summer and fall limnetic fish surveys will employ standard hydroacoustic and mid-water trawling techniques to determine the number, species composition, size and diet of limnetic fish in Anderson and Seton lakes.

Recent advances in molecular genetics enable the cost effective and detailed partitioning of juvenile *O. nerka* samples and abundance estimates by stock (Gates/Portage) and life history (i.e. anadromous vs. resident). Genetic determination will refine our understanding of the movement of Gates Creek sockeye between Anderson and Seton lakes, and with appropriate adult Gwenis baseline data, will allow determination of the growth and abundance of juvenile kokanee in the two lakes.

Methods for these studies will follow those conducted during 2000 and 2001, as well as conform to standards used by BC Ministry of Environment Fisheries Management for large lakes and DFO Science Branch for sockeye salmon assessments and research (MacLellan and Hume 2010). Details on sampling design and sampling frequency will be provided in contractor study proposals.

2.3.3 Task 3 Data Analysis and Reporting

A detailed technical report will be prepared prior to the review of the Water Use Plan that outlines the methods implemented for the monitoring program, the results of field measurements, analysis of these field measurements to assess the influence of the diversion operation on lake 1) physical conditions; 2) chemical conditions; 3) trophic conditions (aquatic productivity and food web structure); 4) limnetic habitat carrying capacity; and 5) anadromous and resident fish populations. The report will also provide recommendations for improvement of assessment methods (performance measures) to be applied in the review of the Water Use Plan and the potential for modifying seasonal diversion from Carpenter into Seton Lake.

2.4 Interpretation of Monitoring Program Results

Upon completion of the program, a synthesis report will be prepared for use in the next review of the Bridge River Water Use Plan. This synthesis will include, but may not be limited to:

1) Assessment of the status of aquatic production in Seton Lake relative to the local control system (Anderson) and other comparable large lakes in B.C. not impacted by diversions.
2) Quantitative comparison of aquatic productivity before and after the implementation of the N2-2P alternative.
3) Quantitative information on temporal variation in the physical and biological impacts of the diversion on Seton Lake to establish whether changes/refinements in the operation of the diversion would likely result in improved aquatic production.
4) Assessment of the dependence of anadromous and resident fish populations on aquatic productivity in Seton Lake (i.e., does trophic productivity limit fish populations or do other habitat factors play a larger role?)

2.5 Schedule

It is proposed that this program be conducted for three years. Specific timing is detailed in the Methods section above.

2.6 Budget

The total estimated cost of the Seton Lake Aquatic Productivity Monitoring is $1,287,423.

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