Ecosystem-Based Management of Hydropower Facilities in the Bridge-Seton Watershed of British Columbia

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Abstract

Hydroelectric power has long been a cheap and easy source of renewable energy that is becoming more and more popular amid a world-wide transition to a low-carbon economy. However, hydropower facilities can have detrimental ecosystem impacts. Declining fisheries in particular is a concern that is motivating more sustainable approaches to water management. This study analyses the sustainability of the Bridge-Seton Power Project in Lillooet, British Columbia using criteria drawn from a literature review of ecosystem-based management. Ecosystem-based management provides a new approach to managing hydropower facilities. Ecosystem-based management outlines a procedure to sustainable development while coping with ecological uncertainty and competing interests. An environmental assessment has never been done on the Bridge-Seton Power Project, therefore this study provided new and valuable comprehensive third-party feedback on the management of these hydropower facilities. The results of the assessment show that BC Hydro is performing well as a sustainable developer of British Columbia's freshwater resources. The Bridge-Seton Power Project fulfilled the criteria for ecosystem-based management, providing an exemplary case for hydropower development elsewhere.

Contents

Abbreviations

B.C.- British Columbia

Introduction

Since the publication of *Our Common Future* (United Nations, 1987) sustainability has emerged as a leading influence in resource management (Slocombe, 1993). Sustainable resource management advocates for the use of ecosystem services and resources to meet human needs without jeopardizing the ability of ecosystems to continue providing these resources. Ecosystem-based management is a new theme in resource management that describes a practical way to approach sustainability. Ecosystem-based management recognizes the inter-relatedness of components of an ecosystem, and management targets are related to preserving ecosystem function as opposed to maximizing resource yield (Hilborn, 2004). Ecosystem-based management focuses on resource management to achieve ecological, economical, and societal goals and can thus be used as a tool towards realizing more sustainable development.

Although food and water are more critical to sustaining human life, ecosystems are often managed for energy production instead of preserving the natural resources we rely on. Worldwide, land and resources for food and clean water are being prioritized by the demand for energy. For example, the use of fertile North American farmland to grow crops for biofuels, deforestation and river pollution for oil and gas extraction in Northern Alberta, and the growth of hydroelectricity in China and Canada matched by declines in migrating fish populations.

The Bridge-Seton Power Project in interior British Columbia (B.C.) is one of the oldest and most important hydroelectric facilities in the province. Six to seven percent of B.C.'s electricity is generated in the Bridge-Seton watershed, through three reservoirs and four generating stations (BC Hydro, 2016a). However some of the most productive salmon runs in the province are obstructed by dams on the system (James, 2008). This report will assess how sustainably BC Hydro manages the Bridge-Seton Power Project with respect to balancing competing interests of energy production and ecosystem function.

I will be evaluating the management of the Bridge-Seton Power Project in B.C. based on criteria drawn from the literature to inform on sustainability and specifically ecosystem-based management. The management of the Bridge-Seton Power Project will be assessed for sustainability and ecosystem-based management based on the criteria developed (see Methods section for criteria). The Bridge River Water Use Plan, published by BC Hydro in 2011, will provide the main source to be evaluated along with all grey literature and academic literature on the subject of the Bridge River project (e.g. third-party technical and scientific information).

The report will be structured as follows- introduction, methods, results, discussion and conclusion. My introduction will address three topics divided by section. The first section will illustrate the conflict between dams and fisheries and touch upon issues specific to the study area of interior B.C. The second section addresses the subject of sustainable resource management. The third section describes the Bridge River System itself, including geography of the area and a history of the Power Project, associated environmental impacts, and early mitigation attempts.

My analysis will assess the management of the Bridge-Seton system based on the following sustainability criteria: 1) Humans as Ecosystem Components; 2) Building Scientific Understanding; 3) Spatial and Temporal Ecological Context; 4) Setting Objectives and Indicators; 5) Acknowledging Uncertainty; 6) Maintaining Dynamic Ecosystem Functioning; 7) Adaptive Management; 8) Consultation and Co-Management. Finally, conclusions and recommendations for management of the Bridge-Seton Power Project will be made based on any identified areas of improvement.

The resulting product will be the first comprehensive third-party assessment documents of the Bridge-Seton Power Project. The report will have practical value as a guideline for assessment of sustainable hydropower facility management according to principles of ecosystem-based management. It will also be a review of industry best-practices as they relate to freshwater resource management for human and environmental well-being, especially in the context of mitigating the impacts of hydroelectric development on fish populations.

Background

The Conflict between Dams and Fisheries

The Fraser River salmon resource of interior B.C. (Bridge River and Seton River are tributaries of the Fraser) has had economic and cultural importance to the people of the area for centuries. Historical records from the Hudson Bay Company show that fur traders and local Aboriginals depended on salmon from the Fraser River for food during the winter months (Andrew & Geen, 1960). When a landslide blocked a narrow portion of the Fraser River in 1914, severe declines were observed in sockeye salmon populations that depend on access to spawning grounds (Thompson, 1945). This event contributed to studies on the potential impact of constructing dams on the Fraser River. The International Pacific Salmon Fisheries Commission concluded that dam construction posed "*a serious threat to the expansion…and existence of the commercial and recreational value of the Fraser River fisheries resource*" (Andrew & Geen, 1960). The effect of the 1914 landslide on salmon populations is thought to have contributed to under-estimating the productivity of Bridge-Seton fisheries during evaluation of the Bridge-Seton Power Project (Fish and Wildlife Compensation Program, 2011).

Hydropower is by far the most important form of renewable energy that Canada produces, and generates nearly 60% of our total electricity (Natural Resources Canada 2016). Compared to other methods of energy production, hydropower is a low-cost and low-emissions option (Jager & Smith, 2006). But dams can have strong negative impacts in the surrounding ecosystem, putting the sustainability of hydropower in question. Dams are built according to legal requirements for water use and focus on maximizing energy generation, not maintaining the viability of the services a river ecosystem provides. A sustainably operated dam can be defined as meeting society's needs for water and energy while maintaining the long term health of the ecosystem (Jager & Smith, 2006).

BC Hydro is the main utility provider in British Columbia and operates 35 hydroelectric dams. Water use requirements were legislated since 1996 by the provincial Water Act, which was replaced this spring by the Water Sustainability Act. Under both Acts hydropower facilities are regulated by a site-specific Water Use Plan approved by the provincial Comptroller of Water Rights, in consultation with other provincial agencies and holders of water licences who might be affected, including First Nations and Fisheries and Oceans Canada. BC Hydro states that its goal is to meet BC's energy demand while finding a "*better balance between competing uses of water*" (BC Hydro, 2016).

"Water use planning is an example of sustainable work in practice at BC Hydro. The overall goal is to find a better balance between competing uses of water, such as domestic water supply, fish and wildlife, recreation, heritage, flood control and electrical power needs, which are environmentally, socially and economically acceptable to British Columbians."

Accessed March 25, 2016 from www.bchydro.ca.

The rivers of interior B.C. form the spawning grounds for many species of anadromous fish, including five species of Pacific salmon. Anadromous fish are fish that spend their adult lives in the ocean, then travel inland to reproduce in freshwater, swimming upriver for hundreds of kilometers to find their natal stream. When salmon are young, they take a chemical 'snapshot' of the water and later use that olfactory imprint to help navigate to the stream they were born in (Hasler, Scholz, & Horrall, 1978). This allows for the evolution of spawning populations with adaptations for that particular environment. Like other anadromous fish, juvenile salmon grow and feed in freshwater once hatched until they are big enough to migrate downstream to the ocean.

Declines in Pacific salmon have been documented in nearly all rivers with hydropower dams in the Pacific Northwest (Welch et al., 2008). The physical barrier posed by dams is an obvious disruption to anadromous fish. Even where fish passage facilities exist, the delay caused by difficult dam passage can result in injury and mortality to adult fish (Bell, 1985). Juvenile salmon can also experience delay and injury as a result of dams that impact overall population recruitment (Raymond, 1979; Rechisky, Welch, Porter, Jacobs-Scott, & Winchell, 2013). Record-low numbers of returning chinook adults to Washington's Snake River has been attributed to severe losses of juveniles two years prior as a result of new dams (Raymond, 1979).

Retention and release of water in reservoirs can impact temperature range and variability of a river (Petts, 1984). Fish are sensitive to temperature. Temperature changes result in impacts on their energy consumption (Andrew & Geen, 1960; Lee, 2003). An altered temperature regime can thus decrease the survivability of migrating fish by increasing energy loss. Water temperature is also an important environmental factor in triggering behavioral responses in fish, such as the initiation of migration from one habitat to another. Temperatures of above 21 ˚C have been shown to prevent sockeye salmon from entering the Okanogan River from the Columbia River during upriver migration (Major & Mighell, 1967).

Dam construction and operation alters the volume, velocity, and variability of river flow, and has correlated impacts on aquatic habitat. The combination of gravel removal and sediment deposition can strip or bury gravel beds that are required for spawning; these beds provide important habitat for the invertebrates that many juvenile fish feed upon (Reiser, 1989). Dams also block the downstream transport of nutrients in organic matter which can reduce primary production in rivers and deltas. Simulating a 10% reduction in waters discharged from the Three Gorges Dam on the Yangtze River was shown to reduce nutrient upwelling in the Yangtze delta, with a proportional decrease in primary productivity and fish catch expected (Chen, 2000, 2002).

In addition, flooding from hydroelectric reservoirs destroys spawning habitat and sources of food for fish populations (Petts, 1984). In the Columbia River watershed, an estimated 30-50% of original spawning habitat for anadromous fish is either submerged under reservoirs or blocked by impassable dams (Dick, 1994). Much of the negative impact of dams has been attributed to the loss of flow variability, including spring flooding, that creates excellent spawning and feeding grounds for all forms of aquatic life. It is estimated that the creation of the Carpenter Lake Reservoir by the Terzaghi Dam flooded the best fish spawning habitat on the Bridge River (Bradford, Higgins, Korman, & Sneep, 2011).

The above examples illustrate the negative impacts of hydroelectric dams on fisheries. Competing interests complicates the management of water resources so that long-term ecosystem health is not prioritized. Although hydroelectric dams are a very important source of renewable energy worldwide, the loss of fisheries as a result of dams has had large impacts on human populations. Spending to maintain the fish and wildlife populations in the heavily-dammed Columbia River basin is on the order of $400 million annually (Hilborn, 2013). Declining salmon populations can shut down commercial, recreational, and even First Nations subsistence fishing, as was the case with the St'at'imc of Lillooet in 2015. In the Bridge-Seton watershed, the food security of the St'at'imc people is tied to the abundance of sockeye salmon (Jacob, McDaniels, & Hinch, 2010). The majority of people interviewed said the community would be economically vulnerable if declining salmon populations meant they were unable to fish to feed themselves (Jacob et al., 2010).

The History of Ecosystem-based Management

Our Common Future, published in 1984 by the United Nations World Commission on Development and the Environment, introduced the popular notion of sustainable development to our society, but the idea of balancing human needs with ecological limitations had already been around for nearly half a century (Shafer, 2011). However, sustainability in resource management used to be based on maintaining a resource so that it could continue to be exploited in the future (Christensen et al., 1996). U.S. National Park field biologists were among the first to bring a new approach that recognized that protection of entire ecosystems was critical to maintaining species of interest. Late in the 1990's the Ecological Society of America recognized ecosystem-based management as an alternative to practices that 'maximize short-term yield and economic gain rather than long-term sustainability' (Christensen et al., 1996). Although resource yield continues to be an objective in the fields of forestry and fisheries, ecologists recognized the need for a long-term approach that accounted for the interconnectedness and dynamic nature of the environment.

Ecosystem-based management has arisen as a new approach to natural resource management. In the last two decades twelve US federal agencies have engaged in ecosystem-based management activities, including the U.S. Geological Survey, National Biological Survey, Food and Agriculture Association, National Oceanic and Atmospheric Administration and Department of Energy (Browman et al., 2004; Imperial, 1999). Propelled by a new focus on environmental stewardship and sustainable development, the main feature of ecosystem-based management is the focus on the long-term sustainability of the ecosystem. Instead of studying the impacts of development on a single species or resource, such as commercially fished salmon, ecosystem management considers impacts on all the components of an ecosystem (Slocombe, 1993). Recognition of the importance of the interrelations between species, trophic levels, and abiotic ecosystem components lead to a more holistic approach to management.

Ecosystem integrity is an important concept in ecosystem-based management because it promotes long-term sustainability. Ecological integrity is the biodiversity of an ecosystem and the processes that support diversity, including natural disturbance cycles, nutrient flows, and the presence of native species (Grumbine, 1994). In the context of ecosystem management, ecosystem resilience refers to the ability of the ecosystem to buffer disturbances while retaining its integrity (Peterson, Allen, Peterson, Allen, & Holling, 1998). Managing for resilience recognizes the dynamic nature of ecosystems. It focuses not on the preservation of a state, but on indicators of ecosystem integrity that demonstrate the ability of an ecosystem to withstand disturbance. Managing for ecosystem resilience can help mitigate the negative impacts of disturbances like dams. In addition, assessing pre-disturbance levels of resilience are useful for environmental impact assessments before a development takes place.

Ecosystem-based management is a way forward in sustainable resource management. However to provide useful guidelines for designing a sustainable management program or assessing whether a management program is sustainable further definition is required. Researchers from areas of resource management have attempted to define ecosystem-based management to increase its applicability in their field (Bormann, 1994; Ehler & Douvere, 2009). My methods section compiles these parameters into a framework that can be used in my area of research in hydropower facility management.

The Bridge-Seton Watershed

Geography

The Bridge-Seton watershed includes the basins of the Bridge and Seton Rivers. The Bridge River and Seton River are parallel river systems emptying into the Fraser, narrowly separated by a mountain called Mission Ridge. Together, they drain an area of 5000 km^2. The Bridge River originates in the Bridge Glacier and Lillooet Icecap, a snowfield in the Coast Mountains. The Bridge River valley is approximately 120 km long, it drains an area of nearly 4000 km^2 and joins the Fraser River (BC Hydro, 2011). Seton Basin originates in the alpine at the divide between the Lillooet River and Seton River basins. It drains an area of just over 1000 km^2 and empties into Anderson Lake and Seton Lake. Anderson Lake occupies the upper part of the Seton River basin, and is connected to Seton Lake via the Upper Seton River. The [Lower] Seton River leaves Seton Lake and is joined by Cayoosh Creek several kilometers before entering the Fraser River downstream of the convergence of the Bridge River and the Fraser.

The watershed is characterized by rugged topography and glacial landforms including extensive ice coverage in the alpine and steep sided valleys (BC Hydro, 2011).The watershed lies between the Coast Mountain Range and the Chilcotin mountains, and thus receives little precipitation due to the rain shadow effect of the mountains, resulting in a warm and dry climate (Weston, 2011). The St'át'imc are the original inhabitants of the area (See Figure 1 below).

Figure 1. The territory of the St'at'imc First Nation almost entirely encompasses the Bridge and Seton River watersheds. Accessed March 25, 2016 and adapted from www.statimc.net.

Lillooet is the largest community in the Bridge-Seton watershed, with a population of 2,341 and a total of 4,000 including the surrounding area (Statistics Canada, 2012). The St'at'imc Nation includes eleven communities surrounding Lillooet and the town of Pemberton further south. Pit house remains suggest the presence of the St'at'imc people in the Bridge-Seton area for the past thousands of years. Inhabitation of the Keatley Creek archeological site near Lillooet has been estimated at 7000 B.P. (Hayden, 2000).

According to the Declaration of the Lillooet Tribe in 1910, the St'at'imc are *ucwalmicw*, or people of the land. Under St'at'imc law, the St'at'imc are holders of Title, rights, and ownership of the territory and the resources within it.

> *"As holders of one of the richest fisheries along the Fraser River, the St'át'imc defend and control a rich resource that feeds our people throughout the winter, and serves as a valued staple for trade with our neighboring nations. The St'át'imc can think of no other better place to live."*
>
> *Accessed March 25, 2016 from* www.statimc.net

However, under Part 2 Section 5.0 of the provincial *Water Sustainability Act*, which updates the historical *Water Act*, the government is the owner and user of all freshwater resources, except where private rights have been otherwise established (British Columbia Water Sustainability Act, 2014). Water reservations may be included in a treaty with a First Nation, and one such water reservation exists in the *Act*. Although the 2011 BC Hydro-St'at'imc agreement provided compensation for losses as a result of hydroelectric development in their traditional territory, there is no treaty between the provincial government and the St'at'imc Nation (St'at'imc, 2011). This illustrates the competing interests for water use in the area.

Bridge River Power Project

The Bridge River Power Project was completed in 1960 and includes three dams, three reservoirs, and four generating stations. It is designed to capture energy from the Bridge River three times as it flows to the Fraser River (BC Hydro, 2016a). La Joie dam is the most upstream component of the Bridge River system. It forms Downton Reservoir, near the small mining town of Goldbridge. From there, the Bridge River enters Carpenter Reservoir, created by the Terzaghi Dam. The Terzaghi Dam has no generating station. Its purpose is to direct water through two parallel tunnels in Mission Ridge (BC Hydro, 2016a).

The most important part of the project in terms of capacity are the two generating stations fed by the Bridge River diversion through Mission Ridge. Together they generate approximately 2670 GWh/year, or 84% of the capacity of the power project (BC Hydro, 2011). Discharge from these generating stations flows into Seton Lake. Seton River flows out of Seton Lake where some water is diverted into a power canal which feeds the Seton generating station. Water from both the Seton River and the generation station empty into the Fraser River.

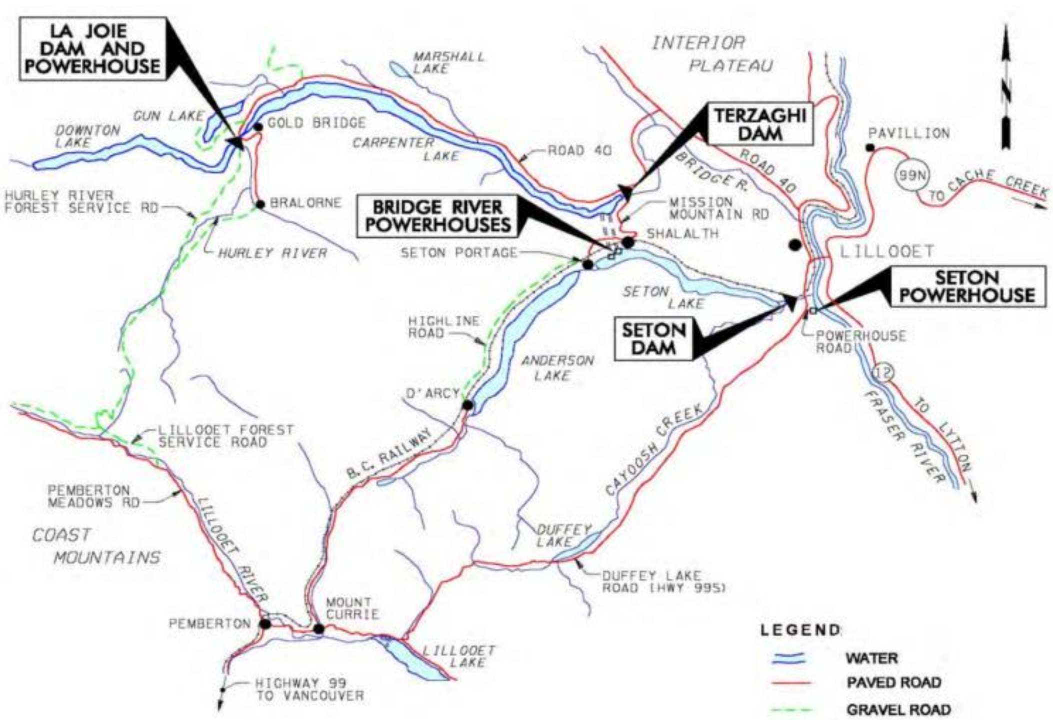

Figure 2. Map of the hydroelectric facilities of the Bridge-Seton Power Project. Adapted from St'at'imc Eco-Resources Progress Report 2015.

The energy production of the entire Bridge River Power Project relies on the Bridge River diversion through Mission Ridge, as it supplies the majority of the capacity of the system. The Bridge River Power Project supplies 6% of British Columbia's energy demand, or almost enough to power 300, 000 households (BC Hydro 2016a). The diversion would probably not have been approved today, as the environmental impact of diverting water from one watershed to another is potentially significant, and resulted in massive hydrological changes to the Bridge River (Bradford et al., 2011).

Between 1960 and 1999 there was no continuous flow released from the Terzaghi dam into the Lower Bridge River (Bradford et al., 2011). Since the two Bridge River generation stations in Mission Ridge supplied the majority of the power generated by the system, operation objectives were focused on diverting all of the Bridge River water through the Mission Ridge generating stations and into Seton Lake. Water was only released over Terzaghi dam in situations of excessive flows, for example during spring freshets (Bradford et al., 2011). The hydrological regime of the Bridge River was reduced to a mean annual discharge (MAD) of 1 cms (cubic meters/second), more than a 100-fold decrease from pre-development conditions of 100 cms (Bradford et al., 2011).

When Terzaghi Dam was built in 1960, the water licenses granted to BC Hydro did not include any provisions for fishery-related water releases or the construction of a fishway (ARC Environmental, 2001). This may have been because of the under-estimation of anadromous fish stocks in the Bridge River, due to the effects of the landslide that blocked a lower portion of the Fraser River in 1914 (ARC Environmental, 2001; Thompson, 1945). It was deemed feasible to install fish passage facilities in Terzaghi Dam once continuous flow returned in 1999 (ARC Environmental, 2001), but as of the time of writing nothing has been planned. Waterfalls on the

Upper Bridge River posed a natural barrier to migration and so the La Joie dam did not have any impacts on anadromous fish migration (ARC Environmental, 2001).

Seton Dam was constructed with a vertical slot fishway to provide access for salmon spawning upstream (Bell, 1985). However a secondary issue associated with migrations up Seton River was the tailrace of the Seton generation station downstream of Seton River. In 1957, one year after the completion of Seton Dam, Cayoosh Creek was diverted into Seton Lake to provide additional water for power generation (Bell, 1985). The diversion was blocked in 1969 once the water was no longer required, which significantly increased the dilution ration of Seton River as all the water from Cayoosh Creek now directly entered the Seton River (Bell, 1985). Studies have shown that post-blockage, the delay of up-migrating salmon at the tailrace significantly increased due to stronger olfactory cues at the tailrace (Bell, 1985; Roscoe & Hinch, 2010). Now a permanent diversion exists that improves the dilution ratio of Seton River during migrations and generation station shut-downs reduce fish mortality from entrainment in the tailrace (Casselman et al., 2014).

Other mitigation efforts include the construction of salmon spawning channels to compensate for spawning area flooded by the Seton Dam (International Pacific Salmon Fisheries Commission, 1959). Originally designed for pink salmon, in 2003 the channels were resdesigned to be useable by all fish species (Cayoose Creek Fisheries, 2003). BC Hydro initiated the Bridge-Coastal Restoration Program in 1999 to coordinate restoration efforts for ecosystems affected by hydroelectric development. Now called the Fish and Wildlife Compensation Program, a Salmonid Action Plan released in 2011 guides restoration projects for the Bridge-Seton area and identifying funding priorities (Fish and Wildlife Compensation Program, 2011).

In 1996 fisheries agencies proposed an experimental flow release program with the objective of determining what level of discharge from Terzaghi dam would stimulate salmon production (Bradford et al., 2011). Lost power generation from each 1 cms of discharge from Carpenter Reservoir was estimated at $2 million, making determining the optimal flow release program economically and environmentally important (Bradford et al., 2011). There was significant uncertainty surrounding the ecological response to flow release (Failing, Horn, & Higgins, 2004). Pre-development conditions may have been limiting to some species (Jowett & Biggs, 2008) and the reduction of flow in the Lower Bridge River created excellent spawning habitat that could be deteriorated by additional discharge (Bradford et al., 2011). Consultation with experts and stakeholders informed an evaluation of adaptive management options (Failing et al., 2004). The Lower Bridge River Adaptive Management program is one of the key components of the Bridge River Water Use Plan (BC Hydro, 2011).

Methods

My assessment of the sustainability of the Bridge-Seton Power Project was based on its alignment with a framework of ecosystem-based management parameters. These parameters, which I will call sustainability criteria, are drawn from a review of the literature on ecosystem-based management. The framework can be used as an informed criteria of ecosystem-based management to evaluate the sustainability of each component of a resource management program (Gibson, 2006)

The Bridge River Power Development Water Use Plan (BC Hydro, 2011) is the most official document on the Bridge-Seton Power Project and thus my review of the management program focused on this document. The Water Use Plan contains the official guidelines for water use of the Bridge-Seton system, authorized by the provincial Comptroller of Water Rights. Operating requirements, the scope of monitoring programs, and detailed descriptions of the power project are contained within this document.

Although much as the management process of the Bridge River system began before this document was published, the Water Use Plan incorporates past management actions and encompasses all present activities. All activities that took place before 2011, the year the Water Use Plan was approved, are incorporated into the plan. All publications on the Bridge-Seton Power Project since 2011 stem from and refer to the Water Use Plan. Thus, the Water Use Plan forms the basis of my sustainability analysis. I analysed the plan using the sustainability criteria listed above. Other documents treating the Bridge-Seton Power Project were used to supplement information provided by the Water Use Plan.

The following accessory documents were very important in my analysis. The report of the Bridge River Bridge River Consultative Committee informed on the Water Use Planning Process (Bridge River Consultative Committee, 2001). This report was essential in evaluating the approach taken to management, especially as it concerns stakeholder involvement. Other grey literature accessory documents include annual Water Use Plan implementation progress reports (BC Hydro, 2015; St’at'imc Eco-Resources, 2015). Terms of reference for each project are published online by BC Hydro (i.e. BC Hydro, 2012) as well as annual reports for most projects, prepared for St’at’imc Eco-Resources by various agencies (i.e. Casselman, Burnett & Bett, 2014; Coldstream Ecology, 2015).

There has been at least a half-dozen articles published in peer-reviewed journals on the subject of the Bridge-Seton system (Bell, 1985; Bradford et al., 2011; Failing et al., 2004; Higgins & Bradford, 1996; Jacob et al., 2010; Roscoe & Hinch, 2010). This literature provides a major component to my analysis as third-party information on the management program not contracted by BC Hydro. For example, the study by Bradford et al. (2011) provided critical information on the experimental flow release program.

The sustainability framework discussed above embodies the principles of sustainability: the consideration of the three pillars of economic, social, and ecological well-being, with the former depending upon the latter. The eight criteria that compose my framework: 1) Humans as Ecosystem Components; 2) Building Scientific Understanding; 3) Spatial and Temporal Ecological Context; 4) Setting Objectives and Indicators; 5) Acknowledging Uncertainty; 6) Maintaining Dynamic Ecosystem Functioning; 7) Adaptive Management; 8) Consultation and Co-Management were selected because they were common elements of ecosystem based management in a majority of the literature reviewed (i.e. Bormann, 1994; Christensen et al., 1996; Grumbine, 1994). I selected main themes of management from each paper I reviewed. Some papers that were themselves a literature review compiled a list of principles that an ecosystem-based management program should include. Other papers had less explicit themes. I read the review papers first to compile an extensive list of possible themes to look for in other papers. Where possible, I refined and combined similar themes from different sources.

From an initial literature review of scientific literature on the subject of sustainability and ecosystem-based management I produced twenty common criteria of sustainable management (see Table 1 below).

Table 1. Themes of Ecosystem-Based Management.

Generated from initial literature review on sustainability and ecosystem based management. I considered the criteria in bold to be important themes as they were present in three or more papers. A- Christensen et al. 2013; B- Grumbine 1994; C- Levin et al. 2009; D- Link 2002; E- Chapin et al. 2009; F- Imperial 1999; G- Slocombe 2013.

Sustainability	A						G
Adaptive Management/Adaptability	A	B	C				
Humans as Ecosystem Components	A	B			E		G
Ecological Data Collection	A	B				F	G
Modelling	A			D			G
Monitoring/Evaluation		B		D			G
Mitigation				D			
Consensus based Decision Making/Consultation	A			D			G
Systems Perspective	A	B		D	E	F	G
Objectives/Goals + Measureable Indicators	A		C	D			G
Ecological Boundaries		B					G
Cooperative Management		B				F	G
Dynamic Ecosystems/Resilience	A				E		
Long timeframes	A						
Acknowledge Uncertainty [with Risk/Probability]	A		C	D	E		
Reconcile Human needs/values with Ecosystem integrity	A	B			E		G
Processes and Function not Products	A				E		
Ecological Integrity/Diversity	A	B					
Organizational/Institutional Adaptability	A	B				F	G
Creation of Alternatives			C				

I narrowed these twenty criteria down to eight by including only the criteria that were present in at least three of the initial publications I reviewed. Being present in a majority of the publications qualified each of my criteria as a major theme of ecosystem-based management. Where I deemed acceptable, I combined important themes so they could be represented in the framework, giving it as wide a scope as possible. For example, consultation was combined with cooperative management to make ‘consultation and co-management’. Certain themes were filtered out because they were included under the umbrella of other themes, for example 'humans as ecosystem components' included 'reconciling human values with ecosystem integrity'. To provide additional support for my framework, I consulted three more publications (Bormann, 1994; Ehler & Douvere, 2009, Berkes & Folke, 1998). The result of my literature review can be seen below in Table 2. The style in which my data is presented is in the format of Grumbine (1994).

Table 2. Sustainability Framework.

My final sustainability assessment framework, based on a review of the scientific literature on sustainability and ecosystem-based management.

Criteria	Christensen et al. 2013	Grumbine 2016	Bormann et al. 1994	Levin et al. 2009	Link 2002	Chapin et al. 2009	Imperial 1999	Slocome 2013	Ehler and Douvere 2009	Berkes & Folke 1998
Humans as Ecosystem Components	x	x	x			x		x		x
Build Scientific Understanding	x	x	x		x		x	x	x	
Spatial and Temporal Ecological Context	x	x	x		x	x	x	x		
Set Objectives and Indicators	x		x	x	x			x		
Acknowledge Uncertainty	x		x	x	x	x				x
Maintain Dynamic Ecosystem Function	x	x	x			x			x	x
Adaptive Management	x	x	x				x	x	x	x
Consultation and Co-Management	x	x	x		x			x		

One of the papers I reviewed offered a set of themes of ecosystem management drawn from their own comprehensive literature review of 33 papers (Grumbine, 1994). Another paper was a recent report by the Ecological Society of America (ESA) that defined eight themes that ecosystem-based management must include (Christensen et al. 2013). After filtering the themes drawn from my literature review, all eight of my chosen indicators of ecosystem-based management were present in the 2013 Christensen et al. report for the ESA. The ESA is the largest society of professional ecologists in North America, and publishes seven extremely well-reputed journals, including the noteworthy journal *Ecology*. The alignment of my criteria with the themes presented by the ESA, plus the inclusion of another literature review and eight related publications from the various fields of forestry, fishery, and general ecosystem management lends confidence to my framework of analysis. The Bormann et al. (1994) report by the US Forest Service on sustainable ecosystem management also supports all eight of my criteria.

Fulfilling the criteria for ecosystem-based management based on this framework will aid in assessing a resource management program as sustainable. My sustainability assessment is also similar to work by Gibson (2006) on the assessment of projects from a sustainability perspective (Gibson, 2006), and by Armitage (Armitage et al., 2009) on adaptive co-management. A brief explanation of each of the eight sustainability criteria and why each has practical value in assessing the sustainability of a resource management program is presented below.

Sustainability Criteria

(1) Humans as Ecosystem Components.

Concepts like 'ecological health' have promoted the viewpoint that humans are a part of nature and not separate from it. Ecosystem-based management should include the actions and values of humans as processes that occur in an ecosystem. Accounting for human values in the context of ecosystem management can take the form of a societal cost-benefit analysis (Bormann, 1994). This approach strikes a balance between anthropogenic and eco-centric world views, and emphasizes the concept of humans as ecosystem components (Christensen et al., 1996).

(2)Consultation and Cooperation.

Reconciliation among multiple stakeholders is key to sustainable management of resources within a complex socio-ecological context (Armitage et al., 2009). Ecosystem-based management recognizes the values of all parties involved. Consensus-based decision making is often applied in ecosystem-based management, as no approach will be a perfect solution to every perceived problem, and compromise is often required (Christensen et al., 1996). A sustainable management program will involve public scrutiny of decision-making and encourage effective public participation (Gibson, 2006a).

(3) Objectives and Progress Indicators.

One of the first parameters of the ecosystem-based management frameworks I reviewed in the literature was the definition of goals or objectives (i.e. Christensen et al., 1996; Ehler & Douvere, 2009). This coincides with (2) Cooperation and Co-management by accounting for the goals of all involved parties, and making decisions on what management goals can be supported by the most parties. Objectives should be precise, measureable, and able to be expressed and understood by stakeholders. Appropriate indicators of ecosystem state should be developed after objectives are identified in a scoping process (Levin, Fogarty, Murawski, & Fluharty, 2009). Indicators should provide feedback through monitoring programs to indicate the success of mitigation and management techniques in relation to management objectives.

(4)Adaptive Management.

Adaptive management is an emerging focus in the field of ecosystem management (Armitage et al., 2009). Despite scientific research on the topic, there can be little predictability in the impact of a management action on a complex system. For example, the response of ecosystems to flow alternation is mostly unpredictable (Poff & Zimmerman, 2010). Adaptive management provides a solution by incorporating flexibility into management programs, making them responsive to ecosystem dynamics. Monitoring programs inform on the quality of management actions which results in better decision making in the future. Creating management alternatives is key to institutional adaptability. Adaptive management options can be assessed using modelling, stakeholder value assessment, and cost-benefit analysis (Failing et al., 2004; Higgins & Bradford, 1996). Adaptive management is explicitly stated as one of the themes of ecosystem based management (Christensen et al., 1996; Grumbine, 1994).

(5) Maintain Dynamic Ecosystem Function.

Grumbine's (1994) working definition of ecosystem-based management includes 'integrat[ing] scientific knowledge of ecological relationships…toward the general goal of protecting native ecosystem integrity over the long term'. Focusing on the long term is a strategy in sustainable resource management which avoids 'steady state' management goals that value production over ecosystem function. Ecosystem-based management takes broad-scale ecosystem changes into account with a long-term approach to goal setting. This is especially applicable in the context of climate change. As species ranges shift with changing temperature, management must adapt to focus on the ecosystem of the present, not the past.

(6) Scientific Understanding. In order for objectives to be set and progress measured, ecological data collection is required. The importance of baseline surveys is supported by the literature (Grumbine, 1994; Levin et al., 2009). Following the implementation of management actions, further data collection must take place in the form of monitoring (Bradford et al., 2011). Monitoring takes into account the dynamic nature of an ecosystem and evaluates progress towards objectives and any changes in resiliency. Collecting long-term monitoring data is critical to

separate the effects of human influence from climate and indicate the success of management activities (Berkes & Folke, 1998).

(7) Spatial and Temporal Ecological Context. A systems perspective can be referred to as the recognition of the interrelatedness of the components of an ecosystem. It has a spatial component, defined by ecosystem boundaries, and temporal component that recognizes how ecosystems change and evolve with time (Grumbine, 1994). Above all, attempts must be made to consider the impacts of an action on all parts of an ecosystem, instead of on one component. In fisheries management, feedbacks between non-adjacent trophic levels, instead of exclusively top-down or bottom-up ecosystem influences, have been recognized as important (Power, 1992). With climate change causing accelerated changes to ecosystems world-wide, the emphasis of any resource management program should be not on retaining ecosystem structure, but on retaining its function (Berkes & Folke 1998), which a systems perspective encourages. Successful ecosystem-based management is sensitive to the diversity of species distributions in space and time (Ehler & Douvere, 2009).

(8)Acknowledge Uncertainty. The precautionary principle is another emerging idea in environmental assessment (Gibson, 2001) which states that if an action could result in significant harm to the environment or society, the burden of proof lies upon those wishing to take the action and not those wishing to prevent it. Acknowledging uncertainty and limits to knowledge are one of Christensen et al. (1996) criteria of ecosystem-based management. Ehler and Douvere (2009) also cite the precautionary principle as a guideline of ecosystem-based marine area management. Cost-benefit calculations can be used to make decisions to be more certain that the worst outcome will be avoided (Failing et al., 2004). Incorporating the precautionary principle into resource management is optimal when the social, economic, or ecological costs of unsustainable management are high.

Results

I applied my assessment framework to the sources of information I gathered on the Bridge-Seton Power Project to assess whether or not it is managed sustainably according to criteria for ecosystem based management. I found that the management of the project fulfilled all the criteria of a sustainable management program to varying degrees.

The terms and conditions for hydropower facility operation outlined in the Water Use Plan demonstrated an ecosystems-based approach to management. By recognizing the interconnectedness of all features in the watershed, management guidelines were sensitive to temporal and spatial ecological context. Special attention was paid to how facility operations could be modified to mitigate negative impacts on anadromous fish species during adult and smolt migration. Recommendations in the Water Use Plan to carry out long-term monitoring projects and physical works demonstrated a commitment to scientific understanding. In addition, operation guidelines prioritized the experimental flow release program (Lower Bridge River Adaptive Management Program) above all other non-safety-related targets, such as maintaining target water elevation in the reservoirs. The presence of a Consultative Committee in the Bridge River Water use planning process was an excellent example of agency and stakeholder cooperation to achieve mutually satisfactory resource management. Table 3 on the next page summarizes the results of my assessment, organized by criteria and source.

Discussion

My discussion section will expand on the results of my analysis and provide insight on the strengths and weaknesses of the Bridge-Seton Power Project management. I will expand on selected criteria from my framework that are particularly relevant to other aspects of ecosystem-based management in the context of this case.

Humans as Ecosystem Components.

The Water Use Plan specifies impacts of the project on human interests such as recreational site access, culturally significant areas, and drinking water quality in Section 7.0 of the Water Use Plan (Expected Water Management Outcomes) (BC Hydro, 2011). Impacts on fish and wildlife habitat are also considered, and the fifteen of the sixteen monitoring programs provide measures of ecosystem health through population counts and habitat surveys. However, the Water Use Plan doesn't recognize the reliance of humans upon a functioning ecosystem. BC Hydro states on their website that the water use planning process is designed to balance human needs with ecosystem health, (BC Hydro, 2016) which portrays human health and ecological health as opposing each other, when they should be considered as one.

Table 3. Sustainability Analysis.

The results of my sustainability assessment comparing the Bridge Seton Power Project to a framework generated from the literature. The eight criteria represent major themes of ecosystem-based management. Sources are fully cited in my references section.

Criteria	Source	Details
Humans as Ecosystem Components	-WUP Section 7.0 -BC Hydro website -Bradford et al. 2011	• Expected Water Management Outcomes explicitly include impacts on recreation areas, fishing, First Nations heritage • Water use planning process has the objective of balancing competing environmental, economic, and social uses for water • Experimental flow program designed to optimize instream water while recognizing need for power generation
Build Scientific Understanding	-Bradford et al. 2011 -WUP Section 5.0 -WUP Section 4.0	• 15-year experimental flow release program • Experimental flow regime takes high priority in operations decisions • 16 monitoring programs mandated by the Comptroller to increase understanding
Spatial and Temporal Ecological Context	-WUP -WUP Bridge River Consultative Committee Report	• Break down of the Bridge-Seton system into relevant management units along ecological barriers (i.e. dams, confluences) • Explicit recognition of interconnectedness of all parts of the system (BR WUP CC) • Seton Station ramp-downs and shut-downs during smolt out-migration • Seasonal, annual, inter-annual monitoring (ten-year programs)
Set Objectives and Indicators	-WUP Section 7.0 -WUP Section 4.5 -WUP Section 5.0	• Objectives defined in Expected Water Management Outcomes • Clearly stated priorities when operational conflict arises in any part of the system • Objectives defined for each monitoring and mitigation program
Acknowledge Uncertainty	-WUP Section 5.0	• Monitoring programs designed to reduce scientific uncertainties over time • Bridge River Adaptive Management Program
Maintain Dynamic Ecosystem Function	-WUP Section 7.0 -WUP Section 4.0	• Monitoring and works focus on riparian and aquatic habitat maintenance • Focus on maintaining fish passage in the system (fish salvage, dilution targets) • Attempts to mimic natural hydrograph of Seton River and Bridge River (min/max discharge, ramp-downs)
Adaptive Management	-Failing et al. 2004 -WUP Section 4.5 -WUP Section 7.0	• 15-year Lower Bridge River Adaptive Management Program (experimental flow regime) • Results to inform a long-term flow release strategy • Monitoring designed to improve decision making in the future
Consultation and Co-Management	-WUP Bridge River Consultative Committee Report	• Bridge River Water Use Planning Bridge River Consultative Committee • St'át'imc revised the first drafts of the WUP in 2009 and 2010 • Collaboration between BC Hydro, Comptroller of Water Rights, fisheries agencies, and St'at'imc • St'at'imc Eco-Resources contracted to implement monitoring

Section 7.0 also includes St'at'imc considerations, as brought up in the Water Use Planning Process. These considerations are related to operating conditions that decrease fish mortality and programs that monitor fish health. The reliance of the St'at'imc on abundant fish populations is not explicitly mentioned in the Water Use Plan, which would strengthen the ecosystem-based management approach of the Water Use Plan, especially given the co-management role of the St'at'imc Nation with BC Hydro.

Objectives and Measureable Indicators

Like all BC Hydro Water Use Plans, the Bridge River Water Use Plan is built around operational requirements that balance power generation with recommendations identified by a Bridge River Consultative Committee. These recommendations were made based on the operating alternatives chosen by the Bridge River Bridge River Consultative Committee and 'reflect a balance between fish and wildlife interests in the reservoirs while protecting and enhancing like values in the rivers' (Bridge River Consultative Committee, 2001). The Bridge River Consultative Committee is further described in the section on the Consultation and Cooperation criteria.

The following objectives for the Water Use Plan were agreed upon by the Bridge River Consultative Committee. Performance indicators were developed that could model progress towards or away from the chosen objectives (Bridge River Consultative Committee, 2001).

Table 4. Bridge River Water Use Plan Objectives

The objectives agreed upon by agency and stakeholder members of the Bridge River Water Use Plan Bridge River Consultative Committee.

Fisheries	Maximize the abundance and diversity of fish in all parts of the system.
Wildlife	Maximize the area and productivity of wetland and riparian habitat.
Recreation and Tourism	Maximize the quality of recreation and tourism experience in all parts of the system.
Power	Maximize the value of the power produced at the Bridge, Seton and La Joie facilities.

Flood Management	Minimize adverse effects of flooding on personal safety or property.
Dam Safety	Ensure that facility operations meet requirements of BC Hydro's Dam Safety Program
Water Supply/Quality	Preserve access to and maintain the quality of water for domestic and irrigation use.

Over 20 operating alternatives were modeled using N2-P2, BC Hydro's operations model, and assessed for their suitability using the identified performance indicators (Bridge River Consultative Committee, 2001). The process of choosing objectives and evaluating alternatives through consultation and agreement was very strong in the Water Use Planning Process.

In addition, each of the monitoring and physical works project designed in the Water Use Plan have specified objectives (BC Hydro, 2011). The objectives are posed as questions that the monitoring program is designed to answer: for example, 'Is there a relationship between the minimum reservoir elevation [Downton Lake] and the relative productivity of fish populations?' (BC Hydro, 2011). Annual or bi-annual studies performed under the scope of each monitoring project assess the effectiveness of management on achieving these objectives, for example, the 'Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed' (Casselman et al., 2014).

Objectives set out in the Water Use Plan are specific and temporally sensitive. For example, one of the conditions is a partial or complete shut-down of the Seton Generating Station between April 20^{th} and May 20^{th}, the period of sockeye salmon smolt out-migration. The specific target for a successful shutdown is an annual smolt mortality of <5%, 'or such other target agreed upon by BC Hydro and that St'át'imc' (BC Hydro, 2011). The progress of all projects is summarized annually in progress reports by St'at'imc Eco-Resources and BC Hydro (BC Hydro, 2015;

St’at'imc Eco-Resources, 2015). The use of specific objectives and indicators identified through consultation is one of the biggest strengths of the Water Use Plan.

Consultation and Co-Management

The 2011 Bridge River Water Use Plan is the product of 12 years of consultation between BC Hydro and a Bridge River Consultative Committee (Bridge River Consultative Committee, 2001). The committee was composed of 13 members representing local residents, environmental groups, BC Hydro, and federal and provincial agencies (Bridge River Consultative Committee, 2001). One of the strengths of the process was the participation of members of the St’at’imc nation. Although St’at’imc representation was absent through Steps 1-5 of the consultation process the 2003 draft Water Use Plan received revisions by the St’at’imc in 2009 and 2010 (Bridge River Consultative Committee, 2001). Therefore, by the time the final Plan was approved by the BC Controller of Water Rights and implemented in March 2011 a good deal of consultation had with the St’at’imc Nation had taken place, such that that would not be considered an oversight in cooperation between BC Hydro and the St’at’imc. The 8-year time lag in implementing the Water Use Plan, from its drafting in 2003 to its acceptance in 2011, was primarily due to the time needed to complete the BC Hydro-St’at’imc Agreement (St’at'imc Eco-Resources, 2015).

The results of the Agreement were important, as they lead to what could be called co-management of the Bridge-Seton Power Project. Although none of the grey literature I reviewed used that term in describing the project, the explicit inclusion of recommendations by the St’at’imc in the final Water Use Plan speaks to the importance of consultation with the St’at’imc Nation above other parties involved. The awarding of all contracts associated with the Water Use Plan to the environmental consulting company St’at’imc Eco-Resources, as per the BC Hydro-

St’at’imc Agreement, has resulted in the delivery of a ‘collaborative program between BC Hydro and the St’at’imc Nation’ (St’at'imc Eco-Resources, 2015).

Consultation plays an important role in the preparation of Water Use Plans all over B.C. One of the key components of the Water use planning process is the use of Structured decision-making (St’at'imc Eco-Resources, 2015). Structured decision making defines trade-offs associated with alternatives, and elicits preferences and values from committee members. Consensus among the parties involved is the objective of structured decision-making.

Adaptive Management

One of the key components of the Bridge River Water Use Plan was the Lower Bridge River Adaptive Management Program, otherwise known as the experimental flow test. Adaptive management was recognized as particularly valuable in the Bridge-Seton System because of the high probability of obtaining useful information that would have important management consequences (Failing et al., 2004). Determining the minimum release of water that would achieve the maximum ecological benefit, measured in fish productivity, was the goal of the adaptive management program. Four of the sixteen monitoring programs were designed to inform on the results of the instream flow test.

Failing et al. (2004) describe how the structured decision making process of the Bridge River Consultative Committee in selecting an experimental flow regime assessed different adaptive management program alternatives. (Failing et al., 2004). The selected regime tested between a mean annual discharge of 0 cms (baseline, 1996-1999) 3 cms (1999-2011) and 6cms (2011-2015). One critique of the adaptive management program is the failure to test the 1 cms regime in the experiment flow program. It identified as the option most likely to stimulate salmon production while minimizing release from Carpenter Lake during the decision-making process involving experts and stakeholders (Failing et al., 2004). However, a court-ordered settlement in 1999, mandated the release of 3 cms until the implementation of the Water Use Plan, at which point 6 cms was tested until 2015 (Failing et al., 2004).

A final decision on future instream flow release was expected to be made in 2015, but in fact the 6 cms release will continue until 2020 to reduce the influence of year-to-year variation on the results on the monitoring programs (St’at'imc Eco-Resources, 2015). The Water Use Plan follows to the principles of adaptive management by acknowledging that the results of the 10-year monitoring programs will affect future management decisions, being the long-term flow release strategy from Carpenter Lake. Mathews et al. (2010) showed that ecological restoration after improvements to a watershed may take decades, but indicators of the process can be evaluated in the first 5 years, providing useful indication of management success of failure.

The Adaptive Management Program in the Lower Bridge River is one of the strongest components of the management of the Bridge-Seton Power Project. However, adaptive management of the project relies on the program, which has now finished. A lack of initiative to continue an adaptive management approach, where feedback exists between monitoring and operation conditions, could weaken the sustainability of the Plan in the future. The 2014-2015 Water Use Plan Implementation Progress Report states that ‘the program is adaptive; valuable experience was acquired and lessons were learned during previous years that will enhance Water Use Plan monitoring program delivery in future years’ (St’at'imc Eco-Resources, 2015). This demonstrates strong two-way feedback wherein the monitoring programs are also responsive operational conditions. Because the monitoring programs delivered by St’at’imc Eco-Resources are subject to annual review, they are more flexible than operational conditions. The conditions outlines in the Water Use Plan are subject to a 10-year review (BC Hydro, 2011).

Scientific Understanding

Implementing monitoring programs to fill 'knowledge gaps' is one of the key components of the Water Use Plan (BC Hydro, 2011). The monitoring programs designated in the Water Use Plan are designed to measure progress towards stated objectives and address uncertainties, improving future decision making (BC Hydro, 2011). Combined with prioritizing the experimental flow program in operation decisions, there has been significant commitment to increasing scientific understanding.

Longer monitoring programs will be more informative, especially when it comes to capturing the relationship between ecosystem change and complex, interwoven biotic and abiotic factors. The ten-year-long duration of the monitoring programs in the Water Use Plan is supported by the literature, as it has been shown that it takes ten years or more required to detect response of salmonids to restoration (Lawson 1993, Roni et al., 2002).

Acknowledge Uncertainty

As described above, the Water Use Plan explicitly recognizes that uncertainties and information gaps complicated the development of the proposed operating conditions (BC Hydro, 2011). The monitoring programs increase understanding in areas of uncertainty concerning the ecological response to management actions, and provide baseline ecosystem assessments. Uncertainty in the ecological response of the Lower Bridge River to instream flow releases prompted the adaptive management experiment (Bradford et al., 2011; Jowett & Biggs, 2008; Poff & Zimmerman, 2010).

The lack of a predictive relationship between flow alternation and ecological response has been acknowledged, but studies have shown that increasing alternation has increasing ecological consequences (Poff & Zimmerman, 2010). Castleberry et al. (1996) concluded that there was no empirical method for determining instream flows and that adaptive management was needed in order to effectively manage a stream with instream flow requirements.

The attenuation of the Lower Bridge River mean annual discharge provided excellent spawning conditions below the Terzaghi dam. In the 65 years since the river was obstructed (Terzaghi Dam replaced and improved Mission Dam, constructed in 1948), anadromous fish may have adapted to using the Lower Bridge River for spawning. The net effect of releasing instream water on fish populations continues to be determined by the flow experiment. Annual reviews by St'at'imc Eco-Resources and BC Hydro inform on the results of the adaptive management experiment and on each monitoring and physical works program, helping to reduce uncertainty and improve future decision-making (BC Hydro, 2011). The is arguably a strength of the Water Use Plan.

Maintain Dynamic Ecosystem Functioning

Section 4.0 (Operation Conditions for Facility) of the Water Use Plan has a strong focus on maintaining fish habitat. The focus of management objectives on maintaining fish passage and successful reproduction and survival demonstrate a management approach based on ecosystem function, not production. Instead of focusing on population counts or harvest yields, the plan manages for the ecosystem components that support healthy fish population. For example, objectives of nine of the sixteen monitoring programs outlined in Section 5.0 of the Water Use Plan ask questions related to the impacts to habitat quality for fish and wildlife of proposed operating conditions (BC Hydro, 2011). According to the definition of sustainable ecosystems by Berkes and Folke (1998), maintaining ecosystem function rather than a stable equilibrium state is integral to its long-term resilience. The monitoring programs in the Water Use Plan evaluate ecosystem function by surveying habitat parameters and aquatic populations as a proxy for ecosystem function. Riparian and aquatic habitat is vulnerable to changes in dam operation such as reservoir level changes. In addition, two physical works projects described as non-operating alternatives in Section 4.6, Seton Lake Erosion Mitigation, and Carpenter Lake Re-Vegetation, demonstrated the management goal of productive and resilient riparian habitat (BC Hydro, 2011).

The monitoring objectives Water also shows a focus on ecosystem function by evaluating biodiversity, a critical component of ecosystem resilience (Berkes & Folke, 1998). Monitoring all fish species in the Bridge-Seton watershed provides a more complete assessment of ecosystem sustainability than does focusing on only anadromous fish like salmonids, although concern over fisheries impacts was mostly centered on the salmon (Bridge River Consultative Committee, 2001). For example, all three reservoir monitoring programs attempt to establish biological characteristics of all resident fish populations, with a focus on community structure and composition (BC Hydro, 2011)

Other operating requirements that show a commitment to maintaining dynamic ecosystem function through the objective of maintaining fish passage in the Seton and Bridge River in Section 4.5 (Operating Conditions) of the Water Use Plan (BC Hydro, 2011). Ramp-down rates at the Seton and La Joie dams have hourly and daily maximums to reduce the likelihood of fish stranding in a river that has suddenly lost flow. Research has shown that the cost-benefit ratio of fish salvage operations in the Bridge River is 10:1, showing that avoiding stranding through operating guidelines is a more efficient strategy than mitigating the impacts of stranding. (Higgins & Bradford, 1996).

Guidelines for facility operations imposed by the 2011 Water Use Plan with are supported by the literature. The initiation of a minimum flow release program in the a river impounded by a hydroelectric dam has shown to increase abundance and diversity of fish species (Travnichek et al., 1995). Each generation station and dam in the power project has minimum and maximum discharge requirements related to the target flow schedules of the Seton River and Bridge River and with the purpose of protecting downstream habitat (BC Hydro, 2011).

Spatial and Temporal Ecological Context

The Bridge-Seton Power Project operation guidelines and programs were divided into functional units based on project boundaries (BC Hydro, 2011). La Joie Project, Carpenter Lake Reservoir Projects, Bridge River Project, and Seton Project formed the management boundaries. However, since the project boundaries also form the ecological boundaries of the watershed, the Water Use Plan still shows an appreciation of spatial ecological context. Organizing management around project boundaries makes sense for a document designed to define operating conditions of each hydroelectric facility. The Lower and Middle Bridge River, Seton River, and each of the three reservoirs in the power project each has their own monitoring programs and operating conditions (BC Hydro, 2011). Organizing monitoring programs based on ecological boundaries demonstrates an ecosystems-based approach to power project management. Managing for ecological context is intuitively effective and not the most challenging part of implementing an ecosystems-based management program, but nonetheless important.

The Bridge River Consultative Committee report also specifically states how the interconnectedness of system flows should be recognized in management decisions (Bridge River Consultative Committee, 2001). The list of operation priorities in Section 4.5 recognizes the possibility of conflict arising between management objectives in different parts of the system (BC Hydro, 2011), especially between reservoir elevations and dam and generating station discharge requirements. When flows have to be released for safety reasons, there is a hierarchy of objectives to be met, with the primary objective being the maintenance of the experimental flow program (BC Hydro, 2011). Excess flows are spilled at Seton Dam preferentially so as not to disturb the experimental program at Terzaghi Dam (BC Hydro 2011).

Different components of the Bridge River System have different recommendations, as can be seen in Table 5 below.

Table 5. Flow changes prescribed in the Water Use Plan

Operational changes to water use implemented in the Water Use Plan. Objectives are different for each component of the Bridge-Seton watershed. Table taken directly from St'at'imc Eco-Resources Progress Report 2014-2014.

Downton Reservoir	reduce deep drawdown frequency
Middle Bridge River	eliminate zero flow events
Carpenter Reservoir	minimize spills down LBR, 'lessen' draw down, better management of maximum level
Lower Bridge River	flow tests to determine best flow regime for fish, avoid spills
Seton Lake	none
Seton River	naturalized, less variable hydrograph, avoid spills

The Seton River and the Lower Bridge River target flow schedules vary monthly to resemble the natural hydrograph of a river (BC Hydro, 2011). According to the river downsizing theory (Trush, 2010), the variability of river flow is more important ecologically than the volume of river flow, and management of hydropower facilities should mimic the natural riverine flow regime. The objective of the operating condition changes implemented in 2011 by the Water Use Plan was to minimize unnatural hydro-variability in the system by lessening reservoir drawdown, avoiding spills in excess of target discharge schedules, and eliminating zero-flow events (St'at'imc Eco-Resources, 2015).

Conclusions

The Bridge-Seton Power Project met all the criteria for a sustainably managed program based on academically supported criteria for ecosystem-based management. Evidence and examples of all eight sustainability criteria were found in the Water Use Plan and associated documents (BC Hydro, 2011; Bridge River Consultative Committee, 2001; St’at'imc Eco-Resources, 2015). In particular, the Lower Bridge River Adaptive Management Program, delivery of monitoring projects through St’at’imc Eco-Resources, and the Bridge River Consultative Committee Water use planning process highlights the ecosystem-based management approach of the Bridge-Seton Power Project.

The literature showed extensive support for adaptive management as a criteria of sustainable resource management. Sneep and Hall (2010) suggested that adaptive management and or structured decision-making will be key management tools in the Bridge-Seton System because of uncertainty in biotic response to management. The application of adaptive management to the Bridge-Seton Power Project indicates the acknowledgement of uncertainty. The existence of ‘knowledge gaps’ was brought up multiple times the Water Use Plan, and the prioritization of the experimental flow program in operation priorities highlighted the commitment to adaptive management (BC Hydro, 2011).

The initiation of monitoring programs for each component of the power project were integral to the Water Use Plan and one of the key requirements for operations identified by the Bridge River Consultative Committee. The programs had many objectives, not least being to build baseline understanding of the populations in each component of the Bridge-Seton System, so that future monitoring could successfully inform on the success of mitigation efforts. Each annual report by

St’at’imc Eco-Resources cites lessons learned and progress made so that program delivery can be improved in the following year (St’at'imc Eco-Resources, 2013, 2015)

The use of a Bridge River Consultative Committee is a unifying factor of all BC Hydro Water Use Plans (BC Hydro, 2016) and a genuine form of including multiple stakeholders in the planning process (Bridge River Consultative Committee, 2001). In addition, the use of structured decision making to define trade-offs in the water use planning process showed acknowledgement of values among different parties (Failing et al., 2004). Awarding responsibility of the monitoring programs to the local company St’at’imc Eco-Resources is a unique arrangement for BC Hydro that satisfies requirements for co-management, in addition to fulfilling requirements of the 2011 BC Hydro-St’at’imc Agreement. Co-delivery of monitoring provides efficiency and capacity building for both parties (St’at'imc Eco-Resources, 2015).

The lack of historical baseline data from before the Power Project was completed in 1960 highlights the importance of the involvement of the St’át’imc nation in drafting and implementing the Water Use Plan. Traditional knowledge of the St’át’imc is one of the only sources of information on the past conditions of the Bridge River fisheries. According to the St’at’imc Eco-Resources Project Coordinator, the degree of loss to the fisheries relied upon by the St’át’imc Nation was the impetus for the years of talks that resulted in the 2011 BC Hydro-St’át’imc Agreement (Bonnie Adolf, personal communication, August 2015).

In addition to traditional knowledge, there is an opportunity to get quantifiable information on the historical state of the Bridge River fisheries through paleolimnology research. The PEARL Lab at Queen’s University is researching the impact of the Bridge River diversion on productivity in Seton Lake. Using core samples of lake sediments, the effect of the diversion on sockeye salmon productivity in the lake is being quantified for the first time (Cecilia Barouillet, in conversation, February 2016).

Future recommendations include continuing an adaptive management approach to the mitigation of impacts on migrating species. Experimentation as well as scientific studies delivered through the monitoring programs is required to inform on what operating conditions will achieve optimal results for fish populations. As with the question of the response of fish productivity to flow alteration, those conditions may require testing to overcome the lack of an empirical relationship (Bradford et al., 2011). In the case of the Lower Bridge River, it was surprising to note that higher flow release may not benefit the downstream environment, and that spawning fish populations adapt to conditions imposed by dams (Bradford et al., 2011).

The ten-year review timeline of the Water Use Plan reflects the fact that longer timeframes may be necessary to determine ecological responses to management, especially for salmonid species (Lawson 1993, Roni et al., 2002). Although this makes the operating conditions less flexible than the monitoring programs, the adaptability of the Water Use Plan in Section 9.0 allows for an earlier review date to be triggered if significant risks are identified (BC Hydro 2011). To fully adopt an ecosystem-based management approach this possibility should be taken seriously; however, the value of sustaining operating conditions for a sufficient timeframe to gain answers to management questions should be recognized. The extension of the 6 cms flow test from four years to eight reflects this commitment to scientific understanding (St’at'imc Eco-Resources, 2015).

Additional funding could benefit the delivery of the monitoring programs. The 2015 program report by BC Hydro indicated that seven programs require a budget increase, and that the required increase for four of those programs is due to an expanded scope (BC Hydro, 2015).

These changes should be approved by the provincial Comptroller of Water Rights because obtaining a higher quantity and quality of data will only improve the certainty of future management decisions. The original cost of the monitoring programs over 10 years was forecasted to be only $16 million (BC Hydro, 2011), a fraction of the annual value of electricity produced by the Bridge-Seton Power Project (Bradford et al., 2011).

Summary

- The Bridge-Seton Power Project is one of BC Hydro's largest hydroelectric developments, located in the Coast Mountains of interior British Columbia
- Power projects can have detrimental impacts on the function of freshwater ecosystems, especially anadromous fishery resources
- Ecosystem-based management is a sustainable approach to resource development and can be evaluated by a set of criteria
- When applied against a framework generated from the literature, the Bridge-Seton Power Project fulfilled all eight criteria for ecosystem-based management
- The strengths of the project included the experimental flow program, monitoring programs, and the consultative water use planning process
- Recommendations include continuing an adaptive management approach, maintaining or increasing investment in monitoring, and attaining quantitative information on baseline conditions in the Bridge-Seton watershed
- BC Hydro's management of the Bridge-Seton Power Project is a good model for sustainable hydropower development

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