A COMPARISON OF THE AQUATIC IMPACTS OF LARGE HYDRO AND SMALL HYDRO PROJECTS

by

Lara A. Taylor, P.Eng.
B.A.Sc. Civil Engineering, University of British Columbia 2004
A.Sc. University College of the Fraser Valley 2000

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Name:	**Lara A. Taylor**
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Supervisory Committee:	
Chair:	**Garett Cooper**

Dr. Duncan Knowler
Senior Supervisor
Associate Professor

Dr. Andrew Cooper
Supervisor
Associate Professor

Date Defended/Approved: **December 3 2010**

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ABSTRACT

The expansion of small hydro development in British Columbia has raised concerns surrounding the effects of these projects, and the provincial government's decision to proceed with Site C has brought attention to the impacts of large hydro. Together, these decisions highlight that there are impacts associated with all energy development. My study examines the aquatic effects of large and small hydro projects using two case study sites: Site C and the Upper Harrison Water Power Project. I first determine the aquatic effects of each of the case study sites. Next, I use existing literature and benefits transfer to determine the monetary value of these effects. My results suggest that, with mitigation, small hydro projects have less of an effect on the environment than a large hydro project per unit of electricity. I also describe the implications of my study in the context of current British Columbia energy policy.

Keywords: hydropower; aquatic effects

Subject Terms: environmental impact assessment; benefits transfer

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ACRONYMS

AMEC	AMEC Earth and Environmental
AMSL	above mean sea level
BC	British Columbia
BCEAO	British Columbia Environmental Assessment Office
BC Hydro	British Columbia Hydro and Power Authority
BCUC	British Columbia Utilities Commission
C	carbon
CBA	cost-benefit analysis
CCGT	combined cycle gas turbine
CEA	cost-effectiveness analysis
CEAA	Canadian Environmental Assessment Agency
CH_4	methane
CHA	Canadian Hydropower Association
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEA	Danish Energy Association
DFO	Fisheries and Oceans Canada
EIA	environmental impact assessment
EPA	electricity purchase agreement
ft	feet
GWh	gigawatt hour
HDPE	high density polyethylene
IFR	instream flow release
IPP	independent power producer
ha	hectare
KCB	Klohn Crippen Berger Ltd.
km	kilometre
kV	kilovolt
kWh	kilowatt hour
LGL	LGL Ltd.
m	metre
MAF	mean annual flow
MCDM	multi criteria decision making method
min	minute
MoEMPR	Ministry of Energy, Mines and Petroleum Resources
MW	megawatt
NDP	New Democrat Party
NPV	net present value
NRCan	Natural Resources Canada
OECD	Organization for Economic Co-operation and Development
ppm	parts per million
PV	present value
RLL	R.L. & L. Environmental Services Ltd.
RRCS	Renewable Resourcews Consulting Services Ltd.

s	second
SNC	SNC-Lavalin Inc.
tC	tonne carbon
UHWPP	Upper Harrison Water Power Project
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US	United States
USEPA	United States Environmental Protection Agency
WCD	World Commission on Dams
WTA	willingness to accept
WTP	willingness to pay

GLOSSARY

Anadromous	Fish that spawn in fresh water but spend the majority of their life cycle in salt water.
Blue-listed	A BC Ministry of Environment classification used to designate an ecological community, indigenous species or subspecies considered to be of special concern.
Diadromous	Fish that travel between fresh and salt water.
Distributed generation	The installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer side of the meter (Banerjee 2006).
Diversion Reach	The section of creek between the intake and powerhouse of a diversion-type hydroelectric project.
Epilimnion	The top layer of a stratified lake.
Hypolimnion	The bottom layer of a stratified lake.
Impoundment	A body of water formed by a dam or weir.
Littoral area	According to the BC Ministry of Environment, the portion of the lake that is less than 6 m deep. It can also be considered the area over which light reaches the lake bottom.
Lentic	A water body with still water.
Lotic	A water body with flowing water.
Penstock	A pipe that conveys water from the intake to the generating equipment in the powerhouse.
Run-of-River	Hydroelectric projects that have minimal storage associated with them and therefore do not alter the streamflow regime downstream of the powerhouse.
Weir	A small dam.

1 INTRODUCTION

1.1 Problem Statement

According to the World Commission on Dams (WCD; 2000), dams have made significant contribution to human development and there have been considerable benefits derived from these structures. However, they go on to say that, in many cases, there has been an unacceptably high social and environmental price paid to secure these benefits. In addition, the social and environmental price paid has often been inequitably borne by poor and marginalized groups.

During the twentieth century, large dams were largely viewed as "symbols of modernisation and humanity's ability to harness nature". Worldwide, dam construction peaked in the 1970s when two to three large dams were commissioned daily worldwide (WCD 2000). In 2000, nineteen percent of the world's electricity supply was generated using hydroelectric dams. Although large dam construction has largely ceased in North America and Europe, emerging countries such as China and Brazil continue to pursue large hydroelectric developments. For example, China completed the 18,000 MW Three Gorges Dam (the world's largest dam) in 2009, and Brazil has several large hydro projects under development, including the 11,000 MW Belo Monte Dam and the 3,150 MW Santo Antonio Dam.

Along with this increase in dam construction has come an increase in knowledge about their social and environmental consequences. It is now well understood that large dams can have irreversible impacts at the ecosystem level that can be propagated downstream and into the marine environment. Increased awareness of the consequences of large dams combined with concerns regarding fossil fuel generation and its environmental impacts have led to a worldwide push for alternate energy sources. For example, the *American Recovery and Reinvestment Act* (2009) included more than US$80 billion to be invested in renewable energy and energy efficiency, including the generation of renewable energy sources. Similarly, Denmark has embraced the development of renewable energy sources to reduce its reliance on fossil fuels, and exports of Danish energy technology now account for 11% of total

Danish exports (DEA 2010). The renewable energy sources under investigation include wind, biomass, geothermal, tidal, solar and small hydroelectric developments.

Canada

Canada is a world leader in hydroelectricity production, second only to China, with total installed hydroelectric generating capacity of more than 70,000 MW (CHA 2008). Canada is home to numerous large hydroelectric developments including:

- Churchill-Nelson, Manitoba (3,932 MW; Hertlein 1999);
- La Grande - Phases 1 and 2, Quebec (15,700 MW; Hornig 1999); and
- Churchill Falls, Labrador (5,200 MW; Cleo Research Associates 2003).

The heyday of large dam construction in Canada occurred from the 1950s through the 1970s. Since then, there have been relatively few large hydroelectric projects developed. This is largely because the environmental and social effects to be mitigated make them increasingly difficult and expensive (NRCan 2009).

British Columbia

The 1950s through the 1970s also saw the rapid expansion of hydropower development in British Columbia and the signing of the Columbia River Treaty with the United States. During this period, both the Peace River and Columbia River systems were developed. The Peace River system currently includes the 2,730 MW G.M. Shrum Generating Station (W.A.C. Bennett Dam) and the 694 MW Peace Canyon Generating Station (BC Hydro 2010a). Four Canadian dams regulate flows on the Columbia River: Mica, Hugh Keenleyside, Duncan and Revelstoke. The Mica, Hugh Keenleyside and Duncan dams were built as a result of the Columbia River Treaty; the 1,736 MW Mica Generating station is the only one of the treaty projects that generates electricity (BC Hydro 2010b). The Revelstoke Generating Station (1,843 MW), commissioned in 1984, was the last large dam built in British Columbia.

For many years, British Columbians have relied on the electricity produced by these large heritage projects (including the Peace and Columbia systems) and little mainstream attention was focused on the projects or their effects. Until 2002, BC Hydro was generally perceived as being solely responsible for generating, transmitting and distributing electricity in British Columbia. However, in practice, BC Hydro did purchase some of its electricity from independent power producers (IPPs).

Energy policy was brought to the forefront of public consciousness in 2002 with the introduction of the BC Energy Plan (MoEMPR 2002). In this plan, the government of British Columbia limited BC Hydro's ability to develop new generating facilities. BC Hydro's mandate became to manage its heritage resources and to make efficiency improvements at its existing facilities; all new generation was required to come from IPPs. One of the results of the decision to purchase all new generation from IPPs was the proliferation of water license applications for power generation across British Columbia. A search of the BC water license database on April 15, 2010 revealed that the following applications were either current or active:

- 130 licenses/applications for Power-Commercial;
- 815 licenses/applications for Power-General; and
- 370 licenses/applications for Power-Residential.

The majority of these water license applications will never be developed into projects for a variety of reasons, including financial and environmental. However, the large number of water licenses has raised concerns surrounding both the ideology behind who should be responsible for power generation and the cumulative effects of many small projects. The decision to limit new electricity production to IPPs also brought independent power production to the forefront of political and public consciousness. The politicization of IPPs was particularly evident during the 2009 provincial elections when independent power production became an election issue (e.g., NDP 2009).

Despite limiting BC Hydro's capacity to develop new energy sources in 2002, the 2007 Energy Plan mandated BC Hydro to renew investigations of the Site C Hydro Project (Site C): a large hydroelectric project on the Peace River near Fort St John (MoEMPR 2007). Site C was initially investigated in the late 1950s; it is slated to be the next large hydro project built by BC Hydro. On April 19, 2010, the BC Minister of Energy, Mines and Petroleum Resources, Blair Lekstrom, announced that Site C will advance to Stage 3 (environmental and regulatory review) of the five stage process. The renewed potential for development of Site C has been raising concerns with the public, First Nations and environmental organizations. These concerns are primarily related to the inundation that would result from the formation of a reservoir behind the newly constructed dam and the potential social and environmental effects associated with the reservoir. The opposition to both hydroelectric development by IPPs and the renewed investigations of the Site C project highlights that there are both positive and negative consequences arising from any form of energy development.

The *Clean Energy Act*, which was passed on June 5, 2010, brought energy policy further into the spotlight. This act sets out a path for energy development in British Columbia and it has been controversial on a number of points. In particular, the act exempts Site C from Sections 45 to 47 and 71 of the Utilities Commission Act, which means that the project will not require a certificate from the BC Utilities Commission prior to commencing construction. The *Clean Energy Act* also allows BC Hydro to pursue energy exporting opportunities.

Environmental Reviews

In British Columbia, hydropower projects must undergo a series of environmental reviews by federal and provincial government agencies prior to construction. The number of approvals required varies depending on the complexity of the project being developed as well as the environmental attributes of the project area.

The provincial government reviews take two different forms depending on the capacity (size) of the project. For projects of less than 50 MW, the permitting is done through a document known as a development plan. Projects 50 MW in capacity or greater trigger the *Environmental Assessment Act* and must obtain a certificate allowing construction. Both processes require similar studies and result in the same permits; however, the environmental assessment process provides a more structured process for reviewing major projects. The aim of the environmental assessment process is to ensure that major projects meet the goals of environmental, economic and social sustainability (BCEAO 2007).

Federally, the *Canadian Environmental Assessment Act* is triggered if a project requires a federal authorization, is built on federal land, or uses federal funding (CEAA 2010a). Federal reviews may be triggered either with or without a provincial environmental assessment. According to the Canadian Environmental Assessment Agency, their goal is "to better integrate Canada's environmental goals with its economic, social and cultural values" (CEAA 2010b).

While development plans and federal and provincial environmental assessments all discuss the economic, social and environmental repercussions of a project, these effects are typically discussed qualitatively. In addition, the project effects are rarely discussed in relation to the economic benefits (i.e., do the economic benefits justify the social and environmental costs).

In their report, the WCD (2000) discusses the importance of integrating the economic, social and environmental reviews of a project. Similarly, the Organization for Economic Co-operation and Development (OECD; 1994) emphasizes the need to account for environmental costs in the same terms as the conventional development costs and benefits. These measures are intended to ensure that the true costs and benefits of a project are reflected in its economic analysis, yet they are rarely undertaken. In British Columbia, there is no requirement to undertake such an analysis before approvals are issued for project construction.

In this study, I will undertake to address the concerns raised in policy documents (e.g., WCD 2000 and OECD 1994) regarding the need to integrate the social, environmental and economic aspects of a project into one analysis. I use a case study to better understand the effect that quantifying (i.e., valuing) project effects would have on the environmental assessment process and energy policy in British Columbia. In particular, I focus my study on large hydroelectric projects, which as discussed earlier in this section have been the foundation of the British Columbia generation system for decades, and small hydroelectric projects, which are generally considered a lower impact alternative to conventional hydropower. To limit the scope of the study, I will focus the study on the aquatic effects of these projects.

1.2 Case Study Background

1.2.1 Context

BC Hydro (2009a) predicts that within the next 20 years British Columbia's electricity use will increase by 20 to 35%. Of this demand increase, it anticipates that three-quarters of the forecasted generation shortfall can be met through conservation. In addition to energy conservation, BC Hydro plans to generate and purchase additional electricity (BC Hydro 2010c).

As described in Section 1.1, BC Hydro has renewed investigations into Site C, which would be the third large dam in its Peace River system and the first large hydroelectric project built in British Columbia in more than 25 years. In addition, BC Hydro plans to purchase additional power from renewable energy projects (e.g., wind, biomass and small hydro).

Site C has entered the environmental assessment stage of its development, and it will most likely be undergoing both provincial and federal environmental assessments in the upcoming two to three years. During the environmental assessment process, government agencies will need to determine whether the project has unacceptable environmental and social effects. In addition, pending the approvals, the provincial government and BC Hydro will need to determine whether to allow Site C to proceed to the next stage of development. Is Site C, small hydro or a combination of the two the best way to supply energy to British Columbians? My study will look to inform these decisions (albeit with a limited scope) by assigning a value to the projects' aquatic impacts in order to compare the effects of Site C and small hydro projects on the aquatic environment.

Throughout my study, I assume that a unit of electricity produced by a small hydro project is equivalent to a unit of electricity produced by a large hydro project. From a utility planning perspective, this is not true. Hydro projects with storage can produce electricity on demand whereas the electricity production of hydro projects without reservoirs is subject to the natural streamflow regime. These differences are discussed in more detail in Section 6.2.

1.2.2 Study Sites

For the case study, I compare Site C to Cloudworks Energy Inc.'s Upper Harrison Water Power Project (UHWPP), which is a cluster of small hydro projects. A brief description of each of the projects is included below and their general locations are shown in Figure 1. Additional information on Site C can be found in Appendix A, and additional information on the UHWPP can be found in Appendix B.

Figure 1: Case study sites general location

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Site C Hydroelectric Project

According to the Site C Fact Sheet (BC Hydro 2007a), BC Hydro originally identified hydroelectric potential along the Peace River Canyon through survey work conducted in the mid-1950s. This survey led to the construction of the W.A.C. Bennett Dam and G.M. Shrum Generating Station in 1968. Work conducted in 1958 identified five locations near Fort St John as possible sites for a dam (A, B, C, D and E). BC Hydro selected the current location of Site C in 1976 (Figure 2). It then shelved development plans for Site C because at the time there was no indication that the electricity would be required for the near future.

Figure 2: Site C project location

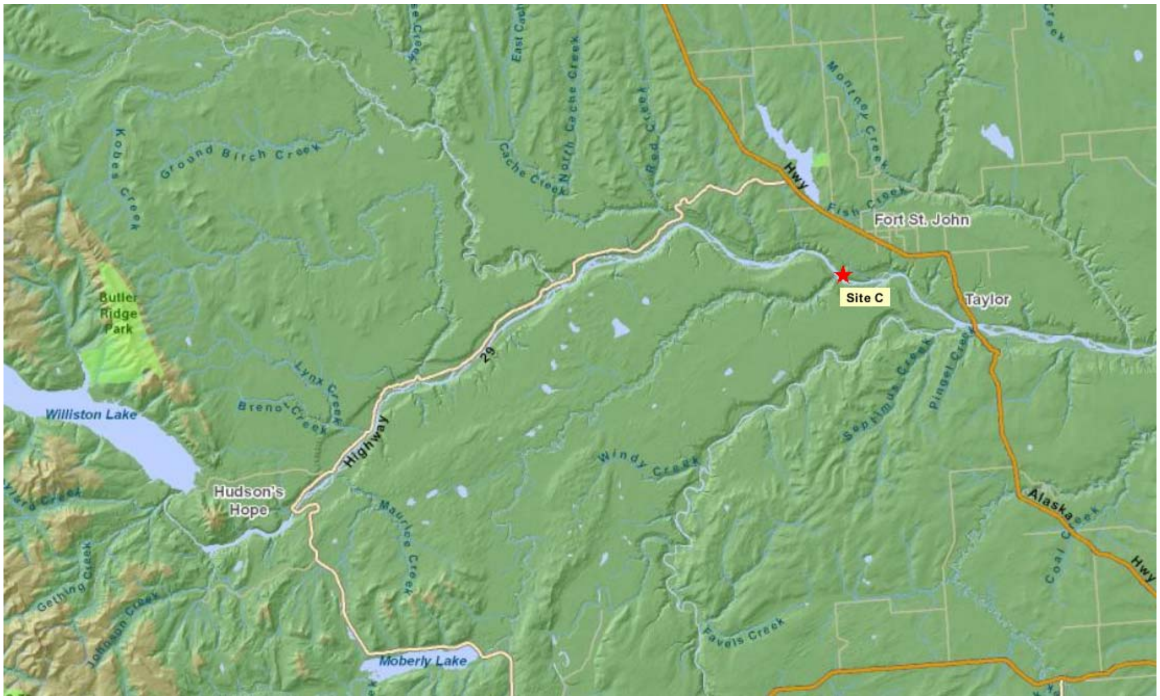


Figure created using imapBC

Site C has been revived three times since it was first shelved in 1976. The first time, in 1982, BC Hydro submitted the Site C Project to the British Columbia Utilities Commission (BCUC). The BCUC then carried out a comprehensive review and consultation with stakeholders before concluding that the project was viable but electricity demand forecasts did not warrant its development. In 1989, the potential need for a new electricity source was identified and Site C was revisited as an option. After two years of studies, demand-side management (electricity conservation) and gas-fired generation were identified as potentially being a better way to meet British Columbia's energy demand. Finally in 2004, the BC Hydro Integrated Electricity Plan (BC Hydro 2004) concluded that Site C should be considered a resource option, and the 2007 BC Energy Plan mandated BC Hydro to renew investigations into Site C.

Site C would have a capacity of 900 MW and be expected to produce approximately 4,600 GWh of electricity annually. It would consist of an earthfill dam, spillways, power intake and powerhouse and two new 500 kV transmission lines. Construction of the project will result in the formation of a 9,440 ha reservoir.

The Upper Harrison Water Power Project

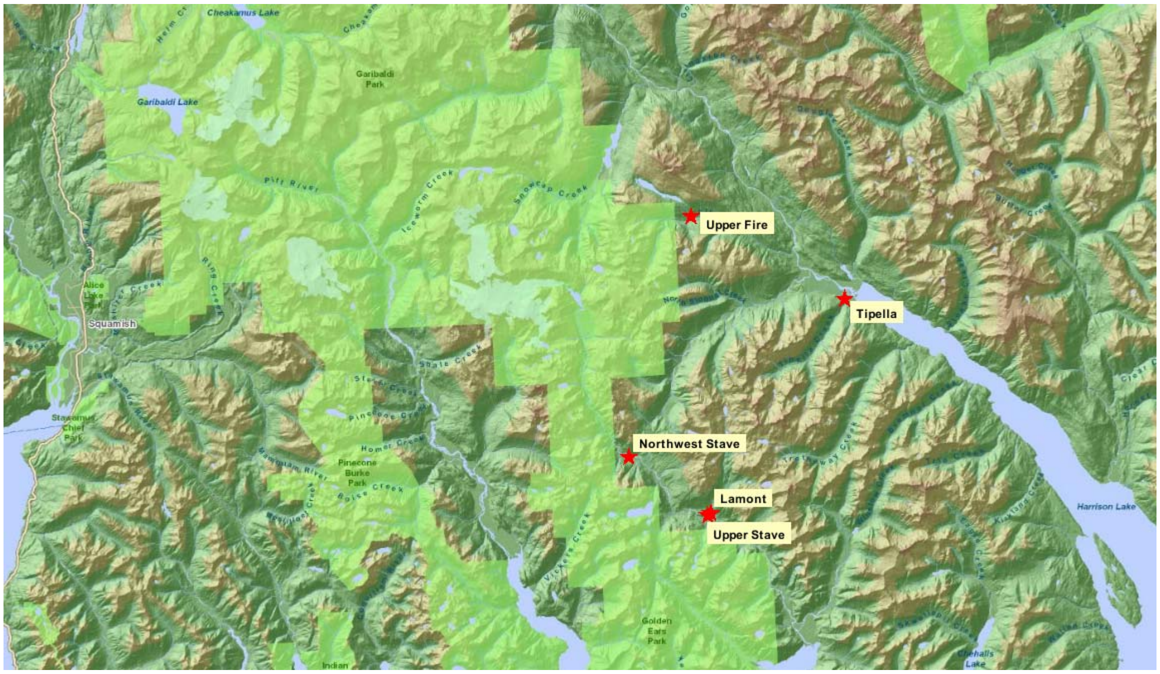
The Upper Harrison Water Power Project (UHWPP) consists of five run-of-river hydroelectric plants near the north end of Harrison and Stave Lakes. Run-of-river means that the projects do not include storage. They divert a portion of the naturally occurring streamflow through the penstock and back into the creek at the powerhouse. As a result, streamflows are not altered downstream of the powerhouse. All information on the UHWPP design is taken from the Upper Harrison Water Power Project's Application for an Environmental Assessment Certificate, which was submitted to the BC Environmental Assessment Office by Cloudworks Energy Inc. (2006).

The five plants that make up the UHWPP are Tipella Creek, Upper Fire Creek, Lamont Creek, Upper Stave River and Northwest Stave River. These facilities' design information is summarized in Table 1 and their locations shown in Figure 3. The combined output of the five facilities is approximately 102 MW. The Upper Fire Creek and Tipella Creek plants began operations in the summer of 2009, and the Lamont Creek plant began operations in late 2009. The Upper Stave and Northwest Stave River plants have not yet begun construction (Pique 2010).

Table 1 : UHWPP facilities summary

Facility Name	Capacity (MW)	Annual Energy (GWh)	Design Flow (m^3/s)	Project Head (m)
Tipella Creek	16.7	64.4	7.2	288.8
Upper Fire Creek	6.0	21.5	1.74	424.1
Lamont Creek	28.0	103.8	8.67	406.8
Upper Stave River	33.5	120.9	43.8	97
Northwest Stave River	18.1	65.4	31.5	65.2
Total	102.3	376.0		

Figure 3: UHWPP plant locations



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1.3 Study Objective

The opposition to both the development of small hydroelectric projects and the potential development of Site C raises questions surrounding the best direction for energy development in British Columbia. More specifically, how do the environmental effects of small hydro compare with those associated with large hydro? Egré and Milewski (2002) state that "when one compares small hydro with large hydropower on the basis of equivalent electricity production, the environmental advantage of small over large hydro becomes much less obvious".

I will consider this subject in light of the recommendations of the WCD (2000) to integrate the environmental assessment with the economic analysis of the project. In order to better inform energy policy decisions, I will calculate a monetary value for the aquatic effects associated with my case study sites. The value of these externalities could then be integrated into an overall cost-benefit analysis to better reflect the true costs of development.

1.4 Study Outline

In order to address my objective, I break the study down into the following sections.

- In Section 2, I review the literature available regarding the effects of hydroelectric projects on the aquatic environment. I also conduct a literature review of similar studies that have been conducted in the past.
- In Section 3, I present the methodology, data sources and parameter assumptions to be used in the study.
- In Section 4, I conduct a qualitative environmental assessment to determine the potential aquatic effects of Site C. I then use benefits transfer to calculate the monetary value of those effects.
- In Section 5, I conduct a qualitative environmental assessment to determine the potential aquatic effects of the UHWPP. I then use benefits transfer to calculate the monetary value of those effects.
- In Section 6, I discuss the results of the environmental assessment and the assessment of the externalities. I also conduct a sensitivity analysis to determine the sensitivity of the results to changes in the parameter assumptions. I then consider the implications of the results on energy policy in British Columbia.

2 LITERATURE REVIEW

In this section, I provide an overview of the social and environment effects of hydroelectric development. I then focus on the aquatic effects identified in Lewis (2005) and a literature review on those effects. Finally, I review previous analyses to determine what comparable studies have been completed.

2.1 Environmental Effects of Hydropower Development

Hydroelectric projects can affect both aquatic and terrestrial ecosystems as well as local communities that rely on those resources. In this section, I provide an overview of these effects. Since the focus of my study is aquatic effects, I then provide a detailed literature review of the aquatic effects associated with hydroelectric development in Section 2.1.1.

The social and environmental effects of hydroelectric developments, particularly large projects, have been studied extensively (e.g., Trussart 2002, Rosenberg *et al.* 1997, Poff *et al.* 1997, Baxter 1977). These studies have shown that there are numerous social and environmental effects associated with large hydroelectric developments that can include, but are not limited to, those effects summarized in Table 2.

Table 2: Social and environmental effects of large hydroelectric projects

Socio-economic Effects
• Involuntary displacement of people from the area to be inundated (Koch 2002) • The creation of a reservoir resulting in land use transformations (Egre and Milewski 2002) • Impacts on minority groups, including encroachment on traditional land and extraction of local resources (Trussart 2002) • Public health risks, including higher incidence of waterborne diseases, particularly in tropical and subtropical areas, and diseases linked to increased population densities (Trussart 2002) • Barriers to river navigation (Trussart 2002)

- Decrease in the aesthetic appeal of the affected river (Svensson 2000)
- Indirect social effects caused by fisheries effects including, loss of livelihood, loss of a source of protein in the diet, or loss of a recreational resource (Koch 2002)
- Revenue generation including possibility of arrangements to share benefits with the local communities, including job creation, infrastructure improvements, recreational facilities, revenue sharing, and payment of local taxes. (Koch 2002, Trussart 2002)
- Hydroelectric power generation (Brismar 2002)
- Structural flood control (Egré and Milewski 2002)
- Reservoir storage for irrigation and drinking water (Brismar 2002, WCD 2000)

Terrestrial Effects

- Flooding of terrestrial and wetland habitats following impoundment of reservoirs (Trussart 2002)
- Loss of biological diversity (Trussart 2002)
- Reduction in the magnitude and frequency of overbank flows due to flow stabilization, which affects riparian plant species and communities. (Poff *et al.* 1997)
- Shoreline modification that is likely to be greater than in a comparable natural lake because the annual drawdown exposes a larger area to the effects of shoreline processes (Baxter 1977)
- Loss of vegetation in the drawdown area (Baxter 1977)
- Reduced soil fertilization on deltas and floodplains (Brismar 2002)

Riverine Effects

- Modifications to water quality (Trussart 2002)
- Changes to the sediment regime (Poff *et al.* 1997)
- Modifications to the natural flow regime, including loss of high flows and natural seasonal variability (Poff *et al.* 1997)
- Major changes in the flow regime may entail modifications in the estuary including increased salt water intrusion and decrease of sediment loading to river deltas (Trussart 2002)
- Deposition of material in the river above the reservoir, if the gradient in the river

is not very steep, which leads to reduction in the capacity of the river channel (Baxter 1977)

- Differing chemistry of the impounded water and the inflow particularly if the amount of soluble material is large and the retention time is long (Baxter 1977)
- Depletion of oxygen in the depth of the reservoir due to the decomposition of submerged vegetation (Baxter 1977)
- Release of toxic substances (such as mercury) into the water from the alteration of the erosion and sedimentation (Baxter 1977)
- Flooding of the existing littoral area and reestablishment of a less productive littoral area (Baxter 1977)

Fisheries Effects

- Barriers to fish migration (Trussart 2002)
- Loss of seasonal peak flows disrupt spawning cues for fish (Naiman *et al.* 2002)
- Alteration of the flow regime causing changes to the established pattern of natural hydrologic variation and disturbance, thereby altering habitat dynamics and creating new conditions to which the native biota may be poorly adapted (Poff *et al.* 1997)
- Perishing of the lotic bethos to be replaced eventually by lentic organisms and development of plankton populations (Baxter 1977)
- Both aquatic and terrestrial organisms adjacent to the periphery of the reservoir are adversely affected (Baxter 1977)
- Dewatering of fish nests in the shallow water near the lake shore when the water level drops (Baxter 1977)

Due primarily to their lack of a reservoir, small hydro projects do not tend to have the same socio-environmental impacts as large storage-type projects. According to Egre and Milewski (2002), “the absence of any sizeable reservoir helps limit considerably both the social and the environmental impacts”.

In British Columbia, the concerns regarding small hydro projects are primarily regarding cumulative impacts and the lack of an overall plan in British Columbia to address acceptable locations for hydroelectric development. In addition, since most projects are developed independently of each other, there is not an overall ranking system in place that determines what projects should be developed first. As a result, more environmentally harmful projects may be developed before their more benign counterparts. The paragraph below is taken from "Green Hydro Power: Understanding Impacts, Approvals, and Sustainability of Run-of-River Independent Power Projects in British Columbia" (Watershed Watch Salmon Society 2007); this paragraph outlines Watershed Watch's concerns regarding independent power production in British Columbia.

> "While small numbers of projects may have acceptable impacts, larger numbers might not, and the degree and types of cumulative impacts are very poorly understood. Concern about cumulative impacts has been prompted because of the large and growing number of projects concentrated in certain areas of the province—areas that are attractive to power producers because of their high densities of suitable rivers and streams, and their proximity to existing transmission grids. BC currently has no strategic planning process to manage the cumulative impacts of these projects, or to ensure that development avoids sensitive areas with high environmental values. While run-of-river power projects can be environmentally sustainable, their green status becomes questionable when entire landscapes are affected by multiple powerlines, roads and water diversions."

2.1.1 Aquatic Effects

Lewis (2005) discusses the impacts of hydroelectric development on aquatic habitat. His report narrows down the aquatic impacts of hydroelectric projects (both large and small) into six catagories. According to Lewis (2005), the aquatic impacts of hydroelectric projects can include:

- Backwater Effects;
- Dewatering;
- Fish passage – upstream blockage;
- Fish passage – entrainment;
- Habitat alteration; and
- Downstream effects.

In Sections 2.1.1.1 through 2.1.1.6, I conduct a literature review on each of these potential aquatic effects.

2.1.1.1 Backwater Effects

The construction of the dam (or weir) associated with hydroelectric projects creates an impoundment in the river or creek behind that structure. In the case of large hydroelectric projects, the dam is built to create head as well as storage. In run-of-river projects, the weir ensures sufficient submergence over the penstock entrance to prevent the formation of vortices; it also typically creates a small headpond used for project operations.

Fish Habitat

The impoundment changes the habitat type from fast-flowing stream environments to more of a lake-type habitat by increasing the depth and reducing the velocity. These changes can reduce the habitat suitability for riverine species (Lewis 2005). Bunn and Arthington (2002), argue that the loss of riverine habitat is not compensated by the creation of lake habitat since reservoirs function differently from natural lakes and wetlands. Because of the fluctuating water levels in reservoirs, productive littoral areas are rarely sustained. Additionally, elevated water levels create a new littoral area with steeper banks, less complex aquatic habitat, and different conditions for aquatic plants and animals (Walker *et al.* 1992). A number of studies have shown the loss of species caused by the creation of large reservoirs. For example, Walker *et al.* (1992) found that populations of riverine crayfish and snails declined, and, in a study of threatened fish of Oklahoma, Hubbs and Pigg (1976) suggested that 55% of human-induced species depletions were due to the loss of free-flowing river habitat, particularly spawning riffles.

Nutrients

Impoundments also change the physical and chemical characteristics of the water body (Friedl and Wüest 2002). According to Friedl and Wuest (2002), one of the main effects of reservoir formation is the decrease in water velocity and associated increased settlement of particles. The increased settlement leads to lower turbidity and increased light transmissivity that results in an increase in primary production. The increase in primary production, in turn, alters the carbon, phosphorus, nitrogen and silicon biogeochemical cycles. A study conducted by Garnier *et al.* (1999) on reservoirs in the Seine River basin found that the reservoirs retained nitrogen, phosphorus and silica. The reservoirs studied retained 40% of the incoming nitrogen, 50% of silica and 60% of phosphate. Similarly, Matzinger *et al.* (2007)

found that for the combined Upper Arrow Reservoir and Lower Arrow Reservoir, located in southeastern British Columbia, nutrient retention by upstream dams (Mica Dam and Revelstoke Dam) reduced productivity by 40 to 50%.

Dissolved Oxygen

The formation of reservoirs can also result in the depletion of dissolved oxygen in hypolimnion. The dissolved-oxygen profile may demonstrate stratification even in the absence of thermal stratification (Petts 1984). In the epilimnion, water mixing through wind and wave action maintains dissolved oxygen levels. However, in the hypolimnion the degradation of organic material in the reservoir can consume oxygen and result in anoxic conditions. This problem is often exacerbated by thermal stratification of the reservoir, which results in low exchange between surface and deep water (Friedl and Wüest 2002).

Greenhouse Gases

If vegetation is flooded during the formation of the reservoir, additional water quality issues can arise. Submerged vegetation decomposing in anoxic conditions is transformed into carbon dioxide (CO_2) and methane (CH_4). Tremblay *et al.* (2004) measured the CO_2 flux of reservoirs and natural lakes. They found that reservoirs older than six years have carbon dioxide emissions that are comparable to the surrounding natural lakes. However, young reservoirs have higher carbon dioxide emissions, which Tremblay *et al.* (2004) attribute to the bacterial decomposition of the labile carbon (carbon that readily undergoes chemical change [Merriam-Webster 2010]) of the flooded soils and the green part of the vegetation.

Mercury

"Reservoir creation has often been inferred as a cause of elevated fish mercury concentrations" (Bodaly *et al.* 1984). Some mercury is present in all soils. In aquatic systems, inorganic mercury is transformed into methylmercury. According to Herrin *et al.* (1998), mercury is methylated by bacteria, and methylation rates are highest when sulphur reducing bacteria are present. Sulphur reducing bacteria are active under anoxic conditions, such as the ones encountered in young reservoirs (Friedl and Wüest 2002). Samples collected by Bodaly *et al.* (1984) from northern Manitoba lakes pre- and post-impoundment demonstrated that mercury levels in fish increased significantly soon after flooding in all three lakes tested. Methyl mercury is also known to bioaccumulate, so concentrations increase as they are passed up the food chain (Hornig 1999).

According to Johnston *et al.* (1991), typically, fish mercury concentrations rise within a few years of reservoir formation and then decline to pre-impoundment levels. The maximum level of fish mercury concentrations varies among reservoirs and the fish species. The decline phase is also variable; some studies, particularly those examining northern reservoirs, predict a very slow decline and that mercury levels may remain elevated for decades. For example, Bodaly *et al.* (2007) found that in the benthivorous lake whitefish (*Coregonus clupeaformis*), mercury levels were usually highest six years post-impoundment and took 10 to 20 years after impoundment to decrease to background concentrations. Mercury levels in the predatory northern pike (*Esox lucius*) and walleye (*Sander vitreus*) were highest two to eight years post-impoundment and required 10 to 23 years to return to background levels.

Bodaly *et al.* (1984) and Bodaly *et al.* (2007) found that peak post-impoundment mercury levels in predatory fish is related to the flooded terrestrial area compared with the pre-impoundment lake area. Further, Bodaly *et al.* (2007) found that the peak muscle mercury increased sharply to approximately 100% flooding (the reservoir area is double the original water surface area); peak muscle mercury then remained relatively constant with increasing flooded area.

2.1.1.2 Dewatering

Dewatering occurs at diversion-type hydro projects, also commonly called run-of-river hydro projects, where flow is withdrawn from the stream at the intake, passed through the penstock and returned to the creek further downstream at the powerhouse. This water diversion results in lower than natural flows between the intake and powerhouse (the diversion reach).

Reduction in stream flow over the diversion reach can reduce fish production. Poff and Zimmerman (2010) found that in their review of papers on ecological responses to altered flow regimes, fish abundance, diversity and demographic rates consistently declined in response to reduced flow magnitude. Other studies have shown that regulating a river can reduce fish populations as well as the complexity of the fish community (e.g., Kingsolving and Bain 1993, Bain *et al.* 1988).

Minimum instream flow releases can protect fish habitat in the diversion reach (Lewis and Mitchell 1995). In British Columbia, a set of guidelines has been established to assist in quantifying the effect of changes in flow on fish habitat (Lewis *et al.* 2004). Relating the quantity fish habitat to flow can help the agencies responsible for habitat protection ensure that habitat is not lost as the result of flow reductions or that it is appropriately compensated.

Reduced flows can also affect benthic macroinvertebrates and riparian vegetation; however, the effect is not consistent between streams. For benthic macroinvertebrates, Dewson *et al.* (2007a) and Dewson *et al.* (2007b) found that reduced discharge could either reduce or increase invertebrate abundance in different situations. Similarly, the response of riparian vegetation did not demonstrate any consistent trends with respect to alteration in flow magnitude (Poff and Zimmerman 2010).

Different techniques for determining the flow required by benthic macroinvertebrates have been proposed (e.g., Gore 1978, Gore and Judy 1981); however, no one technique has become widely accepted. Instead, agencies in British Columbia have focused on monitoring invertebrate drift before and after reductions in flow (Hatfield *et al.* 2007).

Similarly, there is no widely accepted technique to determine the instream flows required to preserve riparian vegetation. However, Merritt *et al.* (2010) found that some of the negative impacts of altered flow regimes can be reversed by restoring components of the natural flow regime (e.g., water availability and fluvial disturbance).

2.1.1.3 Fish Passage – Upstream Blockage

The construction of a dam (or weir) across a river or creek can block the upstream movement of fish. For anadromous fish, the dam can prevent a fish population from reaching spawning grounds upstream of the structure, thus reducing the amount of habitat available to that population. Resident fish migrate for a number of reasons including completing their life cycle, searching for food and avoiding adverse conditions; blocking upstream passage can interfere with all of these activities. For resident fish, the dam can also lead to genetic fragmentation of the population and the divergence of populations of species that live upstream and downstream of the dam (Gehrke *et al.* 2002).

In fish-bearing streams, fish passage can be incorporated into the dam (or weir) structure to allow fish movement upstream of the structure. However, there are some concerns associated with fish passage technology. These concerns include the effectiveness of fishways, particularly on large rivers (Lewis 2005). There may also be concerns related to the energetic costs of migration delays at the fish passage structure (Katopodis 2005). These energetic costs can include the energy used to locate and utilize the fish passage facilities; it can also include the additional energy associated escaping predators or increased exposure to more stressful conditions. In addition, fish passage facilities can affect genetic composition of a fish population. Volpato *et al.* (2009) studied the potential for fish passage selecting particular genetic traits in curimbatá (*Prochilodus lineatus*), which migrate upstream to spawn in the spring and summer. They found that the curimbatá that reached the top of the fish ladder were heavier and longer. Because curimbatá must migrate to reproduce, the ladder reduces the chance for smaller and younger fish to reproduce.

2.1.1.4 Fish Passage – Entrainment

The withdrawal of water at a hydroelectric intake can transport fish through the penstock and turbine. Fish that pass through hydroelectric turbines can be injured or killed by a number of different mechanisms (Cada 2001), including:

- extreme water pressure changes;
- cavitation;
- shear stress;
- turbulence;
- collision with structures; and
- grinding between fixed and moving parts.

Fish mortality due to entrainment can also result indirectly; for example, fish may be more susceptible to predation downstream of the dam or they may be disabled and later succumb to disease (Cada 2001). The severity of the different injury/mortality mechanisms, and the resulting survival rate of fish passing through turbines, is dependent on the size of the fish, the characteristics of the turbine, and the operational characteristics of the plant (Headrick 2001).

Fish screening and can be an effective way of preventing fish entrainment. According to Katopodis (2005), several types of fish screens have been used and widely accepted for decades at water intakes, irrigation canals and hydroelectric dams. For example, Taft (2000) highlights the use of travelling water screens at a number of electric plants throughout the United States. Eicher screens have been used successfully at hydroelectric intakes, including BC Hydro's Puntledge River plant. At the Puntledge intake, survival of chinook (*Oncorhynchus tshawytscha*) and coho salmon smolts exceeded 99%, and survival of steelhead (*O. mykiss*), sockeye (*O. nerka*) and chum (*O. keta*) salmon fry was 100, 96 and 96%, respectively (Smith 1997). Eicher screens consist of a wedge-wire screen installed in a steel penstock at a shallow angle to the flow; the screen directs fish through a bypass pipe branching from the top of the penstock. Other examples of physical barriers to fish entrainment that have been used at power plants include cylindrical wedge-wire screens, porous dikes and barrier nets (Taft 2000).

Behavioural barriers are also used to prevent fish entrainment into the penstock. Behavioural techniques are very species and site specific and must be evaluated on a site-by-site basis. Underwater strobe lights have been shown to repel a number of species (Taft 2000). For example, the Idaho Department of Fish and Game has tested the use strobe lights at turbine intakes; the strobe lights appear to be effective at repelling all size classes of kokanee (*Oncorhynchus nerka*; Brown 2000). Other behavioural barriers that have shown some success at repelling fish include sound, infrasound and mercury light (Taft 2000).

Other behavioural barriers have been tried but yielded less successful results. Air bubble curtains have not been shown to either consistently or effectively repel any species.

Depending on the turbine used, it may also be possible to pass fish downstream safely through the turbine. Cada (2001) discusses advances in turbine design that are increasing the survival rate of fish, predominantly juvenile salmonids, that are passed downstream through the turbines. Large Kaplan turbines on the Columbia and Snake Rivers have an average survival rate of 88%. New, fish-friendly design advances, such as reducing the gap between moving and fixed parts, can further increase that survival rate.

2.1.1.5 Habitat Alteration

Habitat alteration is the replacement of aquatic and riparian habitat with the structures associated with the hydroelectric development. Because the construction of such structures is integral to hydroelectric development, habitat alteration cannot be mitigated. Under the *Fisheries Act*, Fisheries and Oceans Canada (DFO) is responsible for the protection of fish and fish habitat, and their policy dictates no net loss of fish habitat (Fisheries and Oceans Canada 1986). As such, any loss in the productive capacity of fish habitat must be compensated through the restoration of damaged fish habitats or development of new habitats.

In theory, the application of the no net loss (NNL) policy prevents reductions in Canada's fisheries resources. However, when Harper and Quigley (2005) studied the effectiveness of habitat compensation projects across Canada, they found that, based on the review of the files, a NNL determination could only be made in 14% of the 124 *Fisheries Act* Section 35(2) authorizations reviewed. The reasons for the low number of NNL determinations were poor record keeping, poor compliance and lack of monitoring programs. Quigley and Harper (2006) studied the effectiveness of fish habitat compensation further. They found that despite the guidelines stating that DFO should "aim for minimum compensation ratios of 1:1" (DFO 2002) close to 50% of the projects studied would not have achieved NNL with this compensation ratio. Further, while they found that the proportion of projects achieving NNL increased with a compensation ratio of 2:1, a number of entirely compliant habitat compensation projects still did not achieve NNL.

2.1.1.6 Downstream Effects

Hydroelectric projects, and large hydroelectric projects in particular, have the potential to affect downstream aquatic habitat in a number of ways. These effects typically arise from the creation of a reservoir and can include altered flow regimes, water chemistry and geomorphology. These physical changes in turn affect the river's biological systems. The effects can extend as far downstream as the river's estuary and into the marine ecosystem (e.g., Aleem 1972).

Altered Flow Regimes

Altered flow regimes are the result of the water being stored in the reservoir. Dams capture high flows and release the water during periods of naturally lower flow, which results in reduced magnitude and frequency of high flows. Reservoir construction also typically results in higher base flows. These alterations to the natural flow regime have been shown to have a variety of impacts on the ecological integrity of river ecosystems. According to Poff *et al.* (1997), streamflow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems.

Many papers have documented the importance of streamflow regimes to the fish inhabiting those streams. Fish species have evolved to suit the natural flow regime in their habitat, and changes to the streamflow regime can affect their survival. According to Naiman *et al.* (2002), "over millennia, the physical environment has shaped individual population traits related to body size and reproduction". For example, chinook salmon exhibit variations in adult body size related to flow conditions (Roni and Quinn 1995). In powerful rivers, chinook salmon are large bodied, which allows them to move coarse substrate and dig redds. In less powerful rivers, the chinook salmon are smaller bodied yet still sized appropriately for digging redds under those conditions. Another example of the link between physical and biological aspects of a river is that high flows are a cue for a number of species. For example, in southeastern Alaska coho salmon enter many rivers at the onset of autumn rains (and resulting high flows) in September and October, whereas in Washington and Oregon, coho don't enter the river until the rains start in November (Naiman *et al.* 2002). Similarly, Naesje *et al.* (1995) showed that increased water flow during spring induced hatching of vendace (*Coregonus albula*) and whitefish eggs (*C. lavaretus*). This behaviour has likely evolved to prevent hatching prior to ice break-up, because most larvae that hatch before the ice break-up probably die from starvation.

Altering the streamflow regime can result in changes to the fish community that inhabits that stream, including extinction or extirpation of native species, reduced populations and colonization of invasive species (Poff *et al.* 1997). Bain *et al.* (1988) studied the difference in community structure between two tributaries to the Connecticut River: a regulated and a non-regulated river. They found clear differences in the fish communities between the regulated and unregulated rivers. The study conducted by Bain *et al.* (1988) demonstrated reduced community diversity in the regulated river, including the reduction and loss of the most diverse and abundant fish community component (the shallow- and slow-water fishes). Kinsolving and Bain (1993) studied a river downstream of a hydroelectric dam and found a longitudinal gradient of increasing abundance and richness of fluvial specialists (species largely restricted to rivers and streams). They hypothesize that this gradient exists because of the decrease in artificial flow fluctuations with increasing distance from the dam.

Altered streamflows can also affect riparian vegetation. The capture of high flows in a reservoir reduces the frequency, duration and inundation area of riparian vegetation and wetlands. For example, Kingsford (2000) says that the loss of connectivity to the river changes aquatic systems into terrestrial systems. For example, reduced flood flows in the Barmah-Millewa Forest, Australia has changed the composition, growth and regeneration of the vegetation community. Plants that depend on frequent flooding have declined in abundance and are being replaced by species that are tolerant of longer periods without floods (Kingsford 2000).

Water Quality

Water quality effects below a hydroelectric project can include changes to the nutrient loads, mercury concentration, dissolved oxygen and the temperature regime. The impact of reservoirs on nutrients, mercury concentration and dissolved oxygen is described in Section 2.1.1.1; the changes that occur to these water quality parameters in the reservoir are transmitted downstream of the dam.

Temperature Regime

Dams and reservoirs also affect the water temperatures in the river downstream (Baxter 1977). During the summer, solar radiation on the reservoir is converted to thermal energy that will heat the epilimnion (top layer of the lake) but have little effect on the hypolimnion (bottom layer of the lake). Since, hydroelectric projects typically draw water from the hypolimnion, the overall effect is the stream downstream of the dam is typically cooler during the summer and warmer during the winter (less thermal variation than pre-dam construction).

Gas Bubble Disease

Another potential danger for aquatic organisms downstream of hydroelectric facilities is gas-bubble disease. If a fish ingests water that is super-saturated with gases, the excess gas may come out of solution as bubbles that can lodge themselves in the fish's body causing injury or death. Hydroelectric development can result in water becoming super-saturated in one of two ways. The pressure in a turbine can be great enough to force gas into solution. In addition, when water passes over a spillway into a deep basin entrained air bubbles can be carried to a great enough depth that the hydrostatic pressure forces the gas into solution (Baxter 1977).

Sediment Regime and Geomorphology

Reservoirs also alter the sediment regime downstream of a dam. As described in Section 2.1.1.1, the reduced water velocities in a reservoir cause increased sedimentation upstream of the dam and clearer water downstream of the dam. The clearer water can lead to decreased sedimentation and increased sediment transport potential downstream of the dam resulting in increased erosion of the shores and streambed and a coarsening of the streambed (Baxter 1977 and Chien 1985). In addition, since reservoir construction reduces the peak flows downstream of the dam, there are not flushing flows to move the sediment downstream and gravels (spawning areas) can become clogged with fine sediment.

Dam construction can also have negative impacts on the overall geomorphology of a river or creek, which can in turn affect the biota. Ligon *et al.* (1995) described how a reduction in the peak flows of the McKenzie River in Oregon due to the construction of two flood-control dams resulted in channel simplification and the progression from a braided river to a single-thread channel. As the braided river disappeared, so did the areas where spawning gravels could be deposited as well as sloughs and backwaters for juvenile salmon. The lack of spawning gravels resulted in redd superimposition (one redd on top of another), which can lead to damage of the previously deposited eggs.

2.2 Review of Previous Analyses

Comparing the environmental effects of different energy sources is not new. There are a number of scientific studies where the authors have compared the attributes of different energy generation technologies. My literature study revealed that the majority of existing studies regarding the environmental effects of electricity generation focus on fossil fuel generation and comparing its effects, particularly greenhouse gas emissions, to renewable sources of electricity. Most of the studies also include some form of cost comparison with the comparison of environmental effects. I did not find any studies that focused on the aquatic effects of different types of electricity generation. Some examples of previous studies that have examined the environmental effects of different types of electricity generation are described below.

Sims *et al.* (2003) examined the CO_2 production and mitigation costs of different types of electricity generation including fossil fuels, nuclear and renewable electricity generation. They examined the CO_2 production once the plants are in operation and assumed that nuclear power and renewable energy sources (e.g., hydro, wind, biomass and photovoltaic) do not have any CO_2 emissions associated with them. In particular, Sims *et al.* (2003) examined the required price of carbon offsets to make the other generation technologies financially competitive with fossil fuels (with a focus on the American market). They concluded that in areas where both hydro and gas resources exist, building hydropower rather than combined cycle gas turbine (CCGT) technology would be unlikely unless the value of carbon offsets exceeds \$18/tCO_2[1]. Nuclear power requires a slightly lower value of \$13/tCO_2 to make it more financially attractive than CCGT. In addition, the study also showed that wind and biomass, when sited well, can compete with CCGT and coal plants even in the absence of carbon offsets. For comparison, the carbon tax in British Columbia is currently \$20/tCO_2 (MoSBR 2008).

Norton *et al.* (1998) examined a similar question; however, they looked at the CO_2 production of various generation technologies from a life-cycle perspective and thereby incorporate the emissions produced during manufacturing and construction. They found

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[1] In 2000\$US. Converted from tC to tCO_2 using the molar mass of C (12 g/mol) and the molar mass of CO_2 (44 g/mol).

that the life-cycle greenhouse gas emissions for photovoltaic generation (98-167 g CO_2/kWh) are greater than for other renewable energy sources such as small-scale hydro (8.6 g CO_2/kWh) and wind (6.5-9.1 g CO_2/kWh). However, the greenhouse gas emissions for all renewable energy sources are much lower than for fossil fuel generation such as coal (954.6 g CO_2/kWh) or CCGT (429.8 g CO_2/kWh)

Gagnon *et al.* (2002) also examined the impacts of different generation technologies over their life-span; however, their study focused on quantifiable bio-physical impacts associated with electricity generation options as well as CO_2 production (i.e., acid rain, photochemical smog and greenhouse gases). They also focused on the attributes required to provide a reliable electricity supply (e.g., voltage control and load following) and the extent to which each type of generation provides those attributes. Gagnon *et al.* (2002) found that hydropower, wind power and nuclear power perform excellently based on the criteria evaluated. Of the generation technologies they evaluated, coal has the worst performance due to its high emissions. Natural gas performed much better than coal, but it has high emissions relative to renewable sources of energy production.

Hydroelectric effects are highly site and project specific, and the environmental studies relating to different projects are typically completed in support of specific applications. As such, the studies tend to be on a case-by-case basis with the environmental effects being examined by regulators to determine whether they are acceptable rather than whether there are any lower impact alternatives. In British Columbia, prior to a water licence or Crown land tenure being issued, the developer must submit a report summarizing all aspects of the proposed project. Accordingly, studies exist (many publicly available) for each project under construction or operation in British Columbia.

Extensive environmental reviews are also completed when dams are decommissioned. When the Coursier Dam near Revelstoke, BC was decommissioned, BC Hydro was required to obtain a Project Approval Certificate from the Environmental Assessment Office (BCEAO 2010). There have also been studies conducted examining the economic effects of decommissioning dams. For example, Loomis (1996) used a contingent valuation survey to determine the public's WTP to remove two dams on the Elwha River, a salmon bearing river, in Washington State. He found that although the cost estimates for removing the two dams was approximately $100 million, the best estimate of the total non-market benefits to all U.S. households was somewhere between $3 billion and $6 billion. The Elwha Project Human Effects Team (2005) also examined the economic effects of removing the dams on the Elwha River; they concluded that both dams should be removed.

There does appear to be an awareness of the differences between small diversion-type hydroelectric projects and large storage-type hydroelectric projects; however, the articles that I found were not research oriented. They tend to be published by industry groups and focus on the opportunities for developers in different parts of the world (e.g., ABS Energy Research 2009). There are also articles written by environmental groups that question the relative environmental effects of different types of hydro projects (e.g., Garcia 2010).

3 METHODS AND ASSUMPTIONS

3.1 Project Evaluation Methods

There are a number of different tools that can be used to choose the most socially desirable project alternative: cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi criteria decision-making method (MCDM). The most common of these methods (CBA) has been used to help with social decision-making for more than a century (Hanley and Splash 1993), and in many cases, conducting a CBA is mandatory prior to undertaking construction of a project. For example, the Federal-Provincial Fraser River Flood Control Agreement stipulates that dike construction projects must be shown to be economically viable using a CBA prior to beginning construction (Boardman *et al.* 1996).

Part of conducting a CBA is to determine the impacts over the life of a project and to assign dollar values to these impacts (Boardman *et al.* 1996). Many different organizations have recognized the importance of accounting for the environmental effects associated with projects. For example, the European Commission conducted a 10-year long research study to determine the external costs associated with electricity generation. This research showed that the cost of coal and oil generation would double if the external costs were internalized (European Commission 2001). Based on this study, the European Commission decided to encourage its member states to encourage or subsidize cleaner technologies based on the external costs avoided. Similarly, the United Nations Industrial Development Organization (UNIDO; 1972) emphasized the importance of analyzing the indirect costs associated with projects. They went on to say that the inability to quantify many externalities is one of the most serious limitations of social CBA.

An impact analysis, also called an impact assessment, attempts to identify all of the impacts associated with a project. An environmental impact assessment (EIA) focuses on the environmental impacts of a project. According to the United Nations Environment Programme (UNEP; 2002), “EIA is a systematic process to identify, predict and evaluate the environmental effects of proposed actions and projects”. UNEP (2002) also says that particular attention is given in EIA practice to preventing, mitigating and offsetting the significant adverse effects of proposed projects. An EIA does not necessarily quantify (or monetize) the effects determined as part of the assessment, but it could be used as one of the steps leading up to a CBA. The EIA could identify the potential impacts of a project that could then be quantified and used in a CBA.

Evaluation of Energy Projects in British Columbia

As discussed in Section 1.1, prior to construction, energy projects in British Columbia must undergo an environmental assessment (or environmental assessments) to qualitatively determine the effects of the project on the environment and on society. These environmental assessments are variations of an EIA. Each project is evaluated on a case-by-case basis to determine whether regulators believe that the effects are acceptable in light of the benefits provided. Since the environmental assessments do not result in quantitative results, it is difficult to compare one project to another. Also, since a CBA (or similar study) ranking a project and its alternatives according to their social desirability is not conducted, it is impossible to determine whether the most socially desirable projects are being built first.

Given the current limitation on BC Hydro's ability to construct new generation, all new energy projects being constructed in British Columbia (with the exception of Site C) are being developed privately. Prior to building a project, companies conduct their own financial analysis to determine the financial viability of the project. However, since many of the environmental and social costs of a project are not borne by the developers, it is highly unlikely that these costs are ever integrated into the financial analysis for the project. There are not any regulations in place that require developers to integrate the social or environmental costs of a project to the public (externalities) into its financial analysis explicitly.

Considering the social and environmental costs to the public explicitly within a financial analysis is often referred to as internalizing the externalities (Pearce and Moran 1994). If the externalities are not considered, this market failure can result in the goods being under-priced and therefore over consumed. According to OECD (1994), this is particularly true when the supplier does not pay the full cost of providing the good (i.e., does not pay all the social or environmental costs).

One example of a way in which the social and environmental costs are internalized with respect to hydro projects is when there are increases in project costs due to mitigation or compensation measures required by regulators. To a certain extent, these mitigation and compensation measures promote the development of the least environmentally harmful projects first. For example, run-of-river projects with fish in their diversion reaches require a higher minimum instream flow release (IFR) than streams with non fish-bearing diversion reaches. The higher IFR costs the developer money in terms of foregone generation revenue and thus projects in non fish-bearing areas tend to be developed first. My study does not include the costs of the mitigation and compensation measures for my case study sites (e.g., the foregone revenue associated with the IFR). The mitigation costs should be included in an overall CBA for the projects.

In my study, I will conduct a partial impact assessment by determining the aquatic impacts of each of the case study projects. I will then determine the monetary value of these impacts. The aquatic effects determined for each case study site could be integrated into a full impact analysis that would also include terrestrial, heritage, social and cultural effects. Based on the results of the full impact analysis, a CBA could be conducted and, with this information, regulators would be able to make better-informed decisions concerning the most socially desirable projects.

Since the aquatic impacts occur across time, I will also express the aquatic effects as a single present value (PV) that could then be included in a CBA. Present values are based on the concept of discounting. According to Hanley and Splash (1993), both consumers and producers are observed to treat the future as less important than the present. Discounting future costs and benefits reflects this time preference. The PV of a time series of costs is calculated as shown below.

$$PV = \sum_{t=0}^{t=N} \frac{C_t}{(1+r)^t}$$

In the equation above, C_t is the cost in year t, r is the discount rate, and N is the period of the analysis. The parameters used in the calculations are discussed in Section 3.4.

Where the aquatic effects are expressed in terms of the cost per unit of electricity produced (GWh), I based this value on the annual aquatic effects. The value of the annual aquatic effects is calculated by taking the PV of the aquatic effects and then amortizing it over the period of analysis at a rate equivalent to the discount rate, as shown in the formula below.

$$Annual\ Aquatic\ Effects = PV\left(\frac{\left[r(1+r)^N\right]}{\left[(1+r)^N - 1\right]}\right)$$

To get the intensity of the aquatic effects, the value calculated above is then divided by the expected annual electricity generation.

3.2 Valuation Techniques

It is widely recognized that natural resources can have value for many different reasons. The total economic value (TEV) of an environmental attribute includes both the use and non-use value (Pearce and Moran 1994). Use value is the satisfaction that people get from personal utilization of environmental goods or services; it includes direct and indirect use values (Heberling and Bruins 2005). Non-use values are based on the idea that individuals can value environmental goods and services regardless of whether they use them (Freeman 1993). Table 3 shows the taxonomy of benefits that will be used in this study[2] along with river-related examples of each type of benefit.

Table 3: Components of total economic value (TEV) with examples

	Examples for a river
Direct use	Electricity production Recreation and tourism (including fishing and boating) Dilution of wastewater
Indirect use	Transport of nutrients Fish in the river feed other animals
Non-use	Existence value of species inhabiting a river Biodiversity associated with a naturally functioning ecosystem

According to Brouwer (2000), environmental values are measured in monetary terms through the concept of willingness to pay (WTP) or willingness to accept (WTA) in order to

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[2] There are different taxonomies used for classifying environmental benefits. For example, the Millennium Ecosystem Assessment (Millennium Assessment 2003) includes four categories of ecosystem services: provisioning services, regulating services, cultural services, and supporting services.

make the values comparable with other market values. The USEPA (2000) defines the difference between WTP and WTA as follows:

> "Willingness to pay is the maximum amount of money an individual would voluntarily exchange to obtain an improvement (or avoid a decrement) in the environmental effects of concern. Conversely, willingness to accept compensation is the least amount of money an individual would accept to forego the improvement (or endure the decrement)."

A household's WTP can be measured directly by asking people to state a WTP in a contingent valuation survey or through choice experiments. WTP can also be measured indirectly by assuming that it is reflected in the costs incurred to travel to specific sites (travel cost studies) or prices paid to live in specific neighbourhoods (hedonic pricing studies) (Brouwer 2000). Contingent valuation studies have been particularly widely used with respect to environmental services. These studies consist of surveys that ask people what they are willing to pay for a change in the provision of a good or service; econometric techniques are then used in conjunction with the date to determine the mean WTP (Pearce and Moran 1994).

To determine the total benefit of a good, the individual WTP values elicited by the stated preferences study can be totaled or the average value can be multiplied by the total number of affected individuals (USEPA 2000).

Benefits Transfer

A less expensive and time consuming way to determine the WTP of an area may be to utilize existing studies and transfer the benefits to the site being examined. This process is known as benefits transfer. Benefits transfer can take three different forms (Brouwer 2000):

- value transfer, where the values obtained in a study are used directly in another location;
- function transfer, where a WTP function obtained in one study is used in another location with the function variables being replaced with the variables for the new location (e.g., age, education and income); and
- meta-analysis, where a summary findings of empirical studies are used in conjunction with statistical analysis to generate a value function.

While benefits transfer is attractive because it has the potential to provide value estimates at a lower cost than a new study, there are concerns regarding the accuracy of this technique. Present literature provides conflicting results regarding whether benefits transfer is useful (Baskaran *et al.* 2010, Brouwer 2000). To test the validity of benefits transfer, Baskaran *et al.* (2010) studied the validity of value transfer and function transfer with respect to valuing ecosystem services in different wine growing regions of New Zealand. They found that benefits transfer may be adequate for an initial assessment of the policy options; however, the results may not be accurate enough to inform major government policy decisions.

Despite the critiques of benefits transfer, very few studies exist that monetize ecosystem values in British Columbia, and benefits transfer may be the most reasonable option available for aspects of my study. As additional data that is more applicable to the case study sites becomes available, my study could be updated and the results made more certain.

3.3 Data Sources

I chose the projects used for the case study partially for their availability of information. Site C is being developed by BC Hydro (a Crown corporation) and therefore much of the information pertaining to the project is publicly available. The UHWPP obtained a BC Environmental Assessment Certificate and therefore the information that was used in support of the Application for an Environmental Assessment Certificate is available on the BC Environmental Assessment Office's website.

For the qualitative environmental impact assessment, I use the available consultant's reports to determine the aquatic effects of each of the case study sites. I also use scientific literature to supplement this information.

To monetize the aquatic effects, I use benefits transfer, and where possible, I use studies from BC for this purpose.

3.4 Parameter Assumptions

This section outlines the assumptions that I made in order to valuate the aquatic effects of each of the case study sites.

Timeframe

I calculate the value of the aquatic effects over a 40-year lifespan for both projects. I chose this lifespan because 40 years is the term of water licenses in British Columbia and therefore the minimum length of time that the projects would be expected to operate. With maintenance and upgrades, both projects would be expected to last much longer than 40 years. For example, BC Hydro's original Stave Falls plant was in service for 88 years (BC Hydro 2010e).

Base Year

To compare the projects on an equal basis, I assumed that both projects began operations in 2009. Assuming that both projects began operations in the same year ensures that neither project's effects are unfairly discounted.

Real Dollars

I use real (constant) dollars, which means that the values have been adjusted for changes in inflation (Boardman *et al.* 1996). According to Boardman *et al.* (1996), "for CBA it is usually easier and more intuitively appealing to estimate benefits and costs in real dollars". Similarly, the Treasury Board of Canada Secretariat (2007) recommends using real dollars in CBA. In my study, I keep costs constant across the time period, which intrinsically assumes that all costs change at the same rate as inflation.

Discount Rate

Discounting is a concept that is used extensively when dealing with future cashflows; it is used to represent the rate of time preference for consumption or opportunity cost of capital. However, the use of a discount rate is more controversial when dealing with people and environmental effects. According to USEPA (2000), "choosing a discount rate has been one of the most contentious and controversial aspects of [the Environmental Protection Agency's] economic analyses of environmental policies".

I consulted several different publications to help determine the most appropriate discount rate for Canadian projects. The bullets below summarize the discount rates recommended by the different publications.

- The Treasury Board of Canada Secretariat (2007) recommends using a real discount rate of 8%.
- Boardman *et al.* (2010) reviewed the recommendations of the Treasury Board of Canada Secretariat (2007) and determined that the discount rate obtained is too high. They believe that analysts should use a social discount rate of 3.5% if the project is intragenerational.
- Jenkins and Kuo (2007) recommend using a real discount rate of 8%.
- Burgess (1981) recommends a real social discount rate of 7%.
- The USEPA (2000) recommends conducting a sensitivity analysis to determine the effect of the discount rate on the decision with social discount rates ranging from 2 or 3% up to 7%.
- Rabl (1996) examines the potential for utilizing two different discount rates: one for short-term (~30 year) decisions and one for intergenerational decisions. He recommends using a discount rate equal to the growth rate of the economy (approximately 1 to 2%) to discount costs and benefits beyond the generation of the decision-maker.
- Weitzman (1994) examined discounting in long-term CBA. He argued that the social discount rate isn't necessarily a constant and that increasing environmental awareness over time should result in a decreasing discount rate.
- Henderson and Langford (1998) presented evidence for the social discount rate being hyperbolic rather than exponential in nature. They say that although it is clear that the opportunity cost of capital must be exponential in nature, the nature of the social time preference rate it is less clear.

Based on the discount rates suggested by the publications above, I will use a real discount rate of 8% as the base case. However, to reflect the variation in the recommendations and the controversy surrounding discounting of environmental costs, I will conduct a sensitivity analysis on the choice of the discount rate (Section 6.1.1). Although there is evidence to suggest that the assumptions of a constant discount rate and an exponential nature may not be correct, my analysis will be based on these standard assumptions.

Affected Households

To obtain the total WTP, the household WTP is multiplied by the number of affected households; choosing the appropriate number of affected households is essential for accurately estimating the total value. Studies have shown that a household's WTP is related to its distance from the effect. For example, Sutherland and Walsh (1985) used regression analysis to study the effect of distance on a household's WTP to preserve good water quality in the Flathead River and Flathead Lake. They found that WTP decreased with distance from the study area. Similarly, Pate and Loomis (1997) found that a household's WTP for contamination control and wetland improvement programs decreased with increasing distance from the program sites. However, Pate and Loomis (2007) also found that distance did not affect the WTP for a salmon improvement program; they speculated that this may be either species driven or because the WTP for the salmon improvement program was primarily use value driven.

Both case study sites are relatively isolated from the majority of British Columbians, and as such, it does not seem likely that WTP would be constant across the province or even across one region of the province. As such, I limited the number of households who will be considered affected to those within a half-day drive (4 hours or less). All information on the number of dwellings is from the 2006 census population and dwelling counts (Statistics Canada 2010).

Site C is located near the City of Fort St. John and is accessible via highway from the north, south and east. I considered any community located within approximately 320 km to be affected by Site C. In British Columbia, the potentially affected area extended south on Highway 97 to just north of Prince George and north along Highway 97 to near Prophet River. In Alberta, this criterion included residents of the Peace River corridor downstream to the Town of Peace River, and the area also included the villages in the area just south of the Town of Peace River along Highway 2. Table 4 summarizes the number of occupied households within the census subdivisions described above.

Table 4: Number of households affected by Site C

Community/ Census Subdivision	Number of Dwellings
British Columbia	
Fort St. John	6,874
Mackenzie	1,761
Dawson Creek	4,651
Hudson's Hope	1,636
Peace River B	2,076
Peace River D	1,144
Peace River E	163
Fraser-Fort George G	45
Halfway River 168	57
Blueberry River 205	48
Doig River 206	425
Alberta	
Clear Hills No. 21	886
Clear Hills 152C	0
Hines Creek	164
Saddle Hills County	917
Spirit River	447
Spirit River No. 133	236
Rycroft	280
Fairview No. 136	521
Duncan's 151A	42
Peace No. 135	515
Berwyn	214
Grimshaw	984
Peace River	2,399
Smoky River No. 130	734
Girouxville	125
Falher	434
Donnelly	129
Nampa	155
Total	**28,062**

The UHWPP is located in an extremely isolated area at the northern end of Harrison and Stave Lakes; the plants are accessible by logging road from Mount Curry or from Harrison Hot Springs. As well as households within the general UHWPP area, I considered households along Highway 99 as far south as Furry Creek. I also considered households within the census subdivision at the south end of Harrison Lake. Table 5 summarizes the number of occupied households within the area described above.

Table 5: Number of households affected by the UHWPP

Community/ Census Subdivision	**Number of Occupied Dwellings**
Pemberton	943
Whistler	3,909
Squamish	5,614
Harrison Hot Springs	714
Kent	1,937
Fraser Valley C	457
Fraser Valley F	528
Fraser Valley G	749
Squamish-Lillooet C	794
Squamish-Lillooet D	362
Douglas 8	6
Franks 10	0
Skookumchuck 4	25
Sachteen 2A	0
Samahquam 1	0
Baptiste Smith 1A	3
Baptiste Smith 1B	17
Mount Currie 1	40
Mount Currie 2	4
Mount Currie 6	212
Mount Currie 8	21
Mount Currie 10	74
Nesuch 3	41
Seabird Island	162
Tseatah 2	4
Scowlitz 1	4
Chehalis 5	149
Total	**16,769**

4 RESULTS: SITE C

In this section of my study, I determine the aquatic effects of Site C (Section 4.1) and then assign a monetary value to each of these effects (Section 4.2).

4.1 Environmental Impact Assessment

4.1.1 Backwater Effects

The construction of Site C would result in the formation of an 83 km long reservoir that covers an area of 9,310 ha (93.1 km^2), which will include 5,340 ha of flooded land, and extends upstream to the tailrace of BC Hydro's Peace Canyon generating station. The reservoir will flood the Peace River (83 km) and two of its major tributaries: the Moberly River (10 km) and the Halfway River (14 km). Construction of the Site C dam will result in an increase in river depth of 52 m at the dam face and a reservoir volume of 2.31×10^9 m^3. The reservoir will have a residence time of approximately 22 days, which is relatively short compared to other reservoirs.

Fish Habitat

Site C will function as a run-of-river plant (in the technical sense of the term rather than the popular sense). Its reservoir will not be used for storage; all flow regulation will be done using the Williston Reservoir and the G.M. Shrum generating station. Regulated flows released from the Williston Reservoir through the G.M. Shrum generating station will pass through the Peace Canyon and Site C generating stations. These facilities take advantage of the Williston Reservoir and therefore have a smaller reservoir area/GWh than they would otherwise. As such, the Site C reservoir level will not fluctuate as much as a typical reservoir. BC Hydro (2007b) estimates that the Site C reservoir will fluctuate by approximately 0.6 m, subject to environmental review. According to Renewable Resources Consulting Services Ltd. (RRCS; 1979), due to very little fluctuation in Site C reservoir water levels, zoobenthos levels in the littoral area should be comparable to that of natural lakes in the area.

The Peace River at the proposed site of the Site C plant is home to several fish species that could potentially be affected by the Site C generating station. Mainstream Aquatics Ltd. and W.J. Gazey Research (2009) conducted fish sampling in August and September 2008 on the Peace River in the area of the planned Site C reservoir. This study caught fourteen species of fish in the planned reservoir area: arctic grayling (*Thymallus arcticus*) bull trout (*Salvelinus confluentus*), kokanee (*Oncorhynchus nerka*), lake whitefish (*Coregonus clupeaformis*), mountain whitefish (*Prosopium williamsoni*), pygmy whitefish (*P. coulteri*), rainbow trout (*O. mykiss*), burbot (*Lota lota*), northern pike (*Esox lucius*), walleye (*Sander vitreus*), largescale sucker (*Catostomus macrocheilus*), longnose sucker (*C. catostomus*), white sucker (*C. commersoni*), and northern pikeminnow (*Ptychocheilus oregonensis*). The findings during the summer 2008 sampling were generally similar to those from previous sampling conducted between 2001 and 2007. Small fish sampling in October 2006 by Mainstem Aquatics Ltd. (2009) caught 19 different fish species; eight of which were not caught in the August and September 2008 sampling: yellow perch (*Perca flavescens*), lake chub (*Couesius plumbeus*), longnose dace (*Rhinichthys cataractae*), redside shiner (*Richardsonius balteatus*), spottail shiner (*Notropis hudsonius*), trout-perch (*Percopsis omiscomaycus*), prickly sculpin (*Cottus apser*), and slimy sculpin (*Cottus cognatus*). During the 2008 field sampling, the most commonly caught species were mountain whitefish (86.6%), longnose sucker (6.8%), arctic grayling (1.5%) and bull trout (1.4%).

RRCS (1979) discusses the potential effects of Site C construction on the different fish species currently inhabiting that area of the Peace River.

- Northern pike populations are expected to increase as a result of the impoundment because they require aquatic vegetation for spawning and fry rearing; however, adult northern pike are piscivorous and an increase in population could adversely affect other fish populations.
- Mountain whitefish are not expected to be adversely affected by the development of Site C since they have been observed spawning in lakes; they also feed on zooplankton, which are expected to increase in numbers following impoundment.
- Rainbow trout are expected to increase in numbers and in growth rate following inundation due to increases in the zooplankton population.

- Arctic grayling populations are expected to increase following inundation due to an increase in littoral area.
- Bull trout populations are expected to decrease following construction of Site C due to limited spawning habitat in the tributaries.
- Lake whitefish numbers are expected to increase significantly following impoundment, as was the case with the Williston Reservoir.
- Sucker and other non-game fish populations are expected to increase following construction of Site C. If the population of suckers becomes very large, it has the potential to limit the size of sport fish populations (i.e. rainbow trout, bull trout, mountain whitefish and lake whitefish).

In addition, based on the data collected by AMEC and LGL (2009), the walleye population lives predominantly downstream of Site C with only a few individuals (<10%) moving upstream of Site C. As such, walleye are not expected to be adversely affected by project construction.

Construction of Site C will lead to a change in the species composition of the fish population in the Site C area. Based on the fisheries data reviewed, bull trout, a provincially blue-listed species, is the only fish species expected to be negatively impacted by the backwatering associated with construction of the Site C dam. Conversely, species such as lake whitefish and northern pike are expected to increase in numbers following impoundment.

Nutrients

RRCS (1979) considered the effect of the Site C impoundment on nutrients in the water. The predicted macro-nutrient levels in the Site C reservoir are similar to the levels currently found in the Peace River. Due to the short retention time of the proposed reservoir, the contribution of nutrients from decaying vegetation and leaching of soils is thought to be insignificant when compared to other nutrient sources.

Although nutrient levels in the Site C reservoir are expected to remain similar to present levels in the Peace River, total phytoplankton production is expected to increase in response to the greater habitat availability (RRCS 1979). In response to the increase in phytoplankton levels and increased habitat, zooplankton production is also expected to increase. In combination with the influx of zooplankton from the upstream reservoirs (Williston Reservoir and Dinosaur Reservoir), the zooplankton would provide a plentiful food supply for plankton-feeding fish.

Dissolved Oxygen

According to BC Hydro (2007b), the water temperature in the Site C reservoir is expected to be 2-3°C higher than the temperatures currently experienced in the Peace River. The reservoir would reach a maximum temperature of 13.5°C in late July at the end of the reservoir near the dam. Since this temperature is below the British Columbia Approved Water Quality Guidelines (BC Ministry of Environment 2006) maximum temperature threshold for bull trout of 15°C, the most sensitive species present, I will not consider the increase in temperature to be an effect.

Greenhouse Gases

Research conducted by Jacques Whitford AXYS Ltd. (2009) examined the greenhouse gas production that would be expected as a result of the formation of the Site C Reservoir. Based on the methods described by the Intergovernmental Panel on Climate Change, they modeled and evaluated greenhouse gas emissions at Site C. Based on this study, Jacques Whitford AXYS Ltd. determined that the greenhouse gas emissions decrease rapidly with time, and that 35-years post-inundation, the greenhouse gas emissions at Site C will be similar to current conditions. For the first 35 years post-inundation, they calculated that the reservoir's net greenhouse gas emissions will be approximately 32,000 tonnes of carbon dioxide equivalents (CO_2e) annually.

Mercury

BC Hydro has committed to a reservoir clearing program that will clear trees prior to flooding, and vegetation samples collected in the area of the potential Site C reservoir detected very low background levels of inorganic mercury (BC Hydro 2009). Both of these factors will serve to reduce the potential methyl mercury production. According to BC Hydro (2007b):

> "Available evidence from other recently formed reservoirs suggest that methylmercury levels in the Site C reservoir could increase during the initial years after impoundment and then decline over time to levels similar to natural lakes. Due to the relatively small reservoir, there would not be large volumes of standing water in contact with decaying vegetation to cause the accumulation of methylmercury."

The Canadian mercury limit for commercial sale is 0.5 µg/g (Health Canada 2007). Tissue samples were taken from fish in the Site C area by RLL and LGL (1991). As expected, species that are typically piscivorous had the highest mean muscle mercury concentrations: bull trout (0.153 µg/g), walleye (0.157 µg/g), burbot (0.126 µg/g) and northern pike (0.073 µg/g). The lowest mean muscle mercury concentrations were observed in species that are generally not piscivorous: rainbow trout (0.034 µg/g) and arctic grayling (0.034 µg/g).

Additional muscle mercury concentration samples in mountain whitefish and bull trout were collected in 2008 (Mainstream Aquatics Ltd. 2009). The average mean muscle concentrations were 0.078 µg/g in bull trout, 0.033 µg/g in mountain whitefish upstream of Site C and 0.043 µg/g in mountain whitefish downstream of Site C. According to Mainstream Aquatics Ltd., these results showed that the mercury concentration in Peace River bull trout and mountain whitefish may have declined between 1989 and 2008.

The Peace Canyon Dam was built in 1980; according to the data collected by Bodaly *et al.* (2007), mercury levels during the 1989 sampling program would likely have been reflective of methyl mercury formed during the impoundment of the Dinosaur Reservoir. Mercury concentrations sampled during the 2008 field program are likely more reflective of baseline conditions. Since it does not appear that the construction of the Peace Canyon Dam led to fish muscle mercury concentrations exceeding the Canadian limit for commercial sale, it is unlikely that construction of the Site C Dam will result in unsafe mercury concentrations.

4.1.2 Dewatering

The arrangement of Site C is such that there is not any dewatering associated with the project. Water enters the penstock at the upstream face of the dam, and it is immediately passed through the penstocks and turbines. This water re-enters the Peace River immediately downstream of the powerhouse, which is located at the right (south) side of the dam (BC Hydro 2007b).

4.1.3 Fish Passage – Upstream Blockage

The existing design of the Site C plant does not incorporate fish passage (BC Hydro 2009). As such, construction of the dam would result in an impassable barrier on the Peace River.

There are not any diadromous fish in the Site C area of the Peace River, so construction of the dam will not limit the habitat available to a species. However, the dam will prevent resident fish from moving between riverine habitats and may fragment the populations. Fish movement studies were conducted in 1989 and 1990 by RLL and LGL (1991). AMEC and LGL (2009) conducted additional radio telemetry studies in 2005 to 2008. The effects of the Site C dam on Peace River fish are discussed below. Unless stated otherwise, the fish migration information is taken from AMEC and LGL (2009).

- Arctic grayling in the Site C area occur primarily between the Halfway River (upstream of Site C) and the Beatton River (downstream of Site C). They spend most of their time in the Peace River, but they migrate into specific tributaries (mainly the Moberly River) in the spring to spawn; some of the spawning occurs above the inundation zone on the Moberly River. The radio telemetry conducted in 2006 and 2007 showed that arctic grayling are more likely to pass Site C than any other species studied (72% and 29% of the Peace River-tagged arctic grayling in 2006 and 2007, respectively).
- Mountain whitefish are the most widely distributed fish in the Site C area. Based on the radio telemetry data, it appears as though they do not move great distances, and autumn spawning is widely distributed throughout the Peace River mainstem and lower reaches of its tributaries. Movement through Site C was 29% in 2006 and 8% in 2007.
- Rainbow trout occur predominantly upstream of Site C between the Peace Canyon Dam and the Halfway River. They move into the smaller tributaries upstream of the Halfway River to spawn and then move back into the Peace River mainstem to forage and overwinter. Movement through Site C was 15% (4 fish) in 2006 and 3% (1 fish) in 2007.
- Walleye move extensively within and between the Peace River mainstem and two of its major tributaries, the Beatton and Pine Rivers. In 2006, 2007 and 2008,

approximately 50% of the tagged population spawned in the Beatton River and then returned to the Peace River. Approximately 50% of the tagged population remained mostly downstream of the Beatton River and into Alberta, while only a small proportion (<10%) of the tagged fish moved upstream past Site C.

AMEC and LGL (2009) also conducted radio telemetry studies on fish in the Pine River (approximately 15 km downstream of Site C). Based on the data collected, they reached the following tentative conclusions:

- Pine River arctic grayling are resident; they are therefore unlikely to leave the Pine River watershed or pass Site C.
- The majority of the rainbow trout in the Pine River appear to move very little, but some fish do conduct longer migrations.
- Bull trout in Pine Creek are mainly resident; however, approximately 5% of the population is migratory. These migratory fish move seasonally between the Pine, Peace and Halfway Rivers past Site C.

Information collected on fish movements by RLL and LGL (1991) covered a broader range of species than described above. Their findings on these additional species are summarized below.

- Northern pike in the reservoir area appear to be resident, and most individuals observed during the study did not undertake extensive spawning or feeding related movements. As such, northern pike are not expected to be affected by the new barrier on the Peace River.
- The lake whitefish presently in the Site C area are likely recruits from populations in the Williston Reservoir and Dinosaur (Peace Canyon) Reservoir, where these fish are more common than in the Peace River. According to RRCS (1979), "a dramatic increase in the number of lake whitefish occurred in Williston Reservoir [after impoundment]". No movement patterns were observed among this population, and construction of the Site C Dam is not expected to impact lake whitefish movement.

- Suckers are abundant in the Site C area. RLL and LGL (1991) found that suckers exhibited little movement. Suckers were predominantly found at tributary mouths, and they may move into those tributaries to spawn.

Based on the information summarized above, it appears as though arctic grayling will be the most affected by construction of the Site C dam and the resulting barrier on the Peace River. The population would be fragmented by the dam construction, and arctic grayling downstream of the dam would no longer have access to the Moberly River for spawning. The migratory portion of the Pine River bull trout population would also be affected by the Site C dam construction, as their access to the Halfway River would be blocked.

4.1.4 Fish Passage – Entrainment

None of the BC Hydro literature that I reviewed mentions mitigation measures for preventing fish entrainment; as such, I have assumed that no mitigation measures will be implemented. According to BC Hydro (2007b), "the operation of the proposed Site C dam would result in the loss of fish from the reservoir over the spillway or through the turbines".

Entrainment of fish from the reservoir over the spillway is not expected to be a concern because BC Hydro expects to operate the spillway very infrequently due to the flow control upstream at the W.A.C. Bennett Dam. For example, since 1968, the W.A.C. Bennett Dam has spilled an average of once every five years (BC Hydro 2008).

Since neither fish screening nor behavioural barriers are planned for the Site C power intakes, it is likely that fish in the area of the power intakes would be entrained into the penstocks and through the turbines. However, because the majority of fish living in the Site C reservoir will be resident fish with no major downstream migrations (Section 4.1.1), there is no reason to expect mass movements of fish towards the dam.

The Site C generating station will include six 150 MW Francis turbines. Based on the literature reviewed (e.g., Cada 2001, Dedual 2007), fish, particularly small fish, passing through these turbines will have a high survival rate. For example, according to Cada (2001), the survival rate of small fish through Francis turbines is commonly 70% or greater, and in a study of juvenile rainbow trout passing through Francis turbines, Dedual (2007) estimated a long-term survival rate of 93.1%. The presence of lake whitefish in the Site C area of the Peace River supports the idea that at least some fish survive being passed downstream; RLL and LGL (1991) believe that these fish are being recruited from populations in the Williston and Dinosaur Reservoirs. The entrained fish that are passed downstream from the Site C Reservoir into the Peace River will be lost from the upstream population but they will increase the downstream population.

For the purpose of this study, given the site-specific nature of the number of fish that may be entrained and the high survival rate of fish passing through the turbines, I will assume that there will not be any adverse effects on the reservoir fish populations due to fish being entrained into the penstocks.

4.1.5 Habitat Alteration

BC Hydro (2007b) describes the habitat alteration associated with the construction of Site C as follows:

> "Based on initial plans, the dam site, powerhouse, switchyard, access roads and construction camps would affect 280 hectares of land. The realignment of Highway 29 would affect approximately 142 hectares of land. The 500 kV transmission line would affect 179 hectares of Crown land at Peace Canyon and Site C terminations. Additional land would be affected temporarily by borrow and spoil sites (excluding the haul roads), which would be identified following further study."

Most of the habitat alteration described above is not aquatic, and it is therefore outside the scope of this study; however, at least some of the dam site, powerhouse and appurtenant works will be located within both the Peace River channel and the riparian area[3]. BC Hydro data regarding the quantity of riparian vegetation or instream aquatic habitat lost as a result of the Site C project does not appear to be publicly available, so I calculated these losses from the available maps. Based on drawings of the Site C project layout by Klohn Crippen Berger Ltd. and SNC-Lavalin Inc. (KCB and SNC 2006), the earthfill dam and powerhouse access bridge will be the only structures located within the existing Peace River channel. Construction of the Site C Dam in the Peace River channel will cause the permanent loss of

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[3] For the Peace River and its major tributaries, I used a riparian zone width of 100 m (BC Ministry of Forests and Range 2004).

286,400 m^2 of instream habitat (KCB and SNC 2006), and construction of the powerhouse access bridge will result in the loss of 33.0 m^2 (KCB and SNC 2009a). The works at the dam site, including the south bank powerhouse access road[4], will also result in the loss of approximately 587,500 m^2 (58.8 ha) of riparian vegetation.

The existing riparian vegetation along the banks of the Peace River and its tributaries within the inundation zone will be lost. However, new riparian communities will form along the reservoir banks. Because Site C will operate as a run-of-river facility and the reservoir will not experience the large water level fluctuations commonly associated with large hydro projects, I will assume that the post-construction riparian habitat quality will be equivalent to the pre-construction riparian habitat quality. In addition, since the shoreline length following construction of the Site C project will be at least as long as the pre-construction shoreline length[5], I will not consider the loss of the riparian vegetation along the reservoir as a loss of riparian habitat.

The relocation of Highway 29 also has the potential to affect both riparian and aquatic habitat. According to BC Hydro (2009), four segments of Highway 29 totalling approximately 25 km in length would need to be relocated as part of the construction of the Site C project. The relocation would necessitate the construction of four new bridges at Cache Creek, Halfway River, Farrell Creek and Lynx Creek. KCB and SNC (2009b) studied the new bridges and made recommendations regarding the most cost-effective structures. For the Lynx Creek and Farrell Creek bridges, they determined that a short elevated structure in combination with a large fill (causeway) was the most cost effective option, and for the Halfway River and Cache Creek, they determined that a long elevated structure with no causeway was the most cost-effective option. Table 6 summarizes the instream and riparian habitat loss as a result of the Highway 29 relocation. I based the habitat loss calculations on the following parameters:

- a road width of 11 m (KCB and SNC 2009);
- a road clearing width of 25 m;

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[4] The calculation assumes a 25 m clearing width for the south bank powerhouse access road.

[5] Based on a reservoir length of 83 km (BC Hydro 2007b) and a post-impoundment shoreline length of 280 km (KCB and SNC 2009c)

- a riparian zone width of 100 m (BC Ministry of Forests and Range 2004); and
- the conceptual bridge designs presented in KCB and SNC (2009b).

Table 6: Habitat alteration associated with the Highway 29 relocation

	Riparian Habitat Loss: Approaches and Abutments	Instream Habitat Loss: Causeway	Instream Habitat Loss: Piers
Lynx Creek	2,500 m^2	25,525 m^2	3.5 m^2
Farrell Creek	2,500 m^2	12,755 m^2	18.8 m^2
Halfway River	2,500 m^2	N/A	113.1 m^2
Cache Creek	2,500 m^2	N/A	47.1 m^2
Total	10,000 m^2	38,280 m^2	182.5 m^2

As part of Site C construction, an existing 138 kV transmission line corridor will be widened by 34 m to accommodate two new 500 kV powerlines. While transmission lines typically do not affect instream habitat, some riparian vegetation clearing may be required at the two watercourse crossings. If the entire riparian area at these crossings is cleared, the transmission line will result in the loss of 13,600 m^2 of riparian vegetation.

Based on my calculations, in total, the Site C project will result in the loss of approximately 324,900 m^2 of fish-bearing instream habitat and 611,100 m^2 (61.11 ha) of riparian vegetation.

4.1.6 Downstream Effects

Streamflow Regime

Since Site C will operate as a run-of-river plant, the streamflow regime downstream of the Site C generating station will not be incrementally altered by the construction of the plant (beyond the existing streamflow alterations from the Williston Reservoir). According to BC Hydro (2009), the reservoir would typically operate in approximate hydraulic balance over any given day. Since Site C will not have an incremental effect on the downstream flow regime, it will also not incrementally affect the downstream biota or riparian vegetation's response to the flows.

Water Quality

As described in Section 4.1.1, changes in nutrient levels in the Peace River are not expected to result from the construction of Site C. However, the downstream zooplankton populations are expected to increase as a result of increases in the reservoir. An increase in downstream zooplankton numbers would be reflected in increased fish production in the tailrace area (RRCS 1979). Once the zooplankton enter the Peace River downstream of the Site C dam, the population will decrease with distance downstream (Petts 1984). The reduced turbidity of the water downstream of Site C and the increase in zooplankton would likely result in an increase in the downstream populations of rainbow trout and mountain whitefish (BC Hydro 2007b).

Dissolved oxygen measurements taken in 1989 and 1990 below the Peace Canyon generating station, which has a similar configuration to the Site C generating station, showed that dissolved oxygen levels were near saturation and ranged from 11.2 mg/L to 13.2 mg/L (RLL and LGL 1991). For the purpose of this study, I will assume that, similarly, low dissolved oxygen concentrations will not be an issue below the Site C dam.

As described in Section 4.1.1, increased mercury concentrations as a result of the formation of the Site C reservoir are not expected to be a problem in the reservoir. Since mercury is not expected to be a problem within the reservoir, it is also not expected to be an issue downstream of the Site C dam.

Temperature Regime

Site C will change the Peace River water temperature downstream of the project year-round. Due to reservoir stratification, Site C will increase the water temperature in the winter and decrease the water temperature in the summer. Studies regarding water temperature changes downstream of Site C focus on changes to Peace River ice regime. According to modelling done by BC Hydro, this temperature change would result in the ice front reaching the B.C.-Alberta border 25% of the time as opposed to 50% of the time under current conditions (BC Hydro 2009). Although changes to the ice front have both cultural and wildlife implications, these issues are outside the scope of my study.

To determine the effects of the predicted water temperature changes on fish, I consulted RLL and LGL (1991) and the BC Ministry of Environment (2006) water quality guidelines. RLL and LGL (1991) recorded the Peace River mainstem water temperature on six occasions (all seasons) downstream of the Peace Canyon Dam. The temperature ranged from 0.5ºC in February 1990 to 11.5ºC in August 1990. Based on similar depths and expected thermal stratifications, the water temperature regime downstream of the Site C dam is expected to be similar to the current water temperature regime downstream of the Peace Canyon Dam (BC Hydro 2009). It appears that the cooler summer water temperatures expected downstream of Site C will not be detrimental to the bull trout or artic grayling living downstream of the dam

Gas Bubble Disease

As described in Section 2.1.1.6, hydroelectric operations can affect total dissolved gas concentrations. Gas bubble disease at spillways is particularly an issue in rivers where anadromous fish migrations coincide with high flows and the resulting spillway use, such as the Columbia River (Petts 1984). Because of the flow regulation upstream at the W.A.C. Bennett Dam, the spillways at the Site C dam are expected to be operated relatively infrequently; since 1968, the W.A.C. Bennett Dam has spilled an average of every five years (BC Hydro 2008).

The Site C generating station will use Francis turbines, the same type of turbines as the G.M. Shrum generating station (W.A.C. Bennett Dam). Starting in 1968, the BC Ministry of Environment conducted a monitoring program of dissolved gas levels in rivers and lakes throughout BC (Clark 1977). A number of measurements were taken on the Peace River around the W.A.C. Bennett Dam and further downstream through this monitoring program. Of the 43 measurements taken, including eight in the turbine and spillway outflows, only one measurement exceeded the total gas pressure guideline of 110% recommended by Aspen Applied Sciences Ltd. (1994).

Since the spillway is expected to function relatively infrequently and dissolved gases do not appear to be an issue at the existing Peace River generating stations, I will not consider gas bubble disease to be an issue downstream of the Site C dam.

Sediment Regime and Geomorphology

Construction of the Site C generating station would result in the sediment currently contributed to the Peace River by the inundated area and related tributaries being trapped in the reservoir (~3 million tonnes per year). According to BC Hydro (2009), this sediment detention will not have a significant impact on the downstream sediment regime at the Peace-Athabasca Delta or further downstream. Nearly 58% of the sediment in the Peace River at the British Columbia-Alberta border is from the Beatton River, which joins the Peace River downstream of Site C. In addition, the Peace River's sediment regime has already been disrupted by the two upstream facilities, although these disruptions do not appear to be critical to the overall health of the river. Kellerhals and Gill (1973) state that the Peace River's sediment load is small and the effect of the W.A.C. Bennett Dam is probably small, in part because the downstream tributaries are more heavily loaded than the Peace River mainstem.

4.1.7 Summary of Environmental Impact Assessment

Table 7 summarizes Site C's aquatic effects as described in Sections 4.1.1 to 4.1.6.

Table 7: Summary of Site C aquatic effects

	Site C
Backwater Effects	- Change in fish species composition of fish population in the Site C area - 32,000 tonnes CO_2e for the first 35 years
Dewatering	Not applicable
Fish passage – upstream blockage	- Fragmentation of arctic grayling population - Migratory portion of Pine River bull trout population blocked from a portion of their historic habitat
Fish passage – entrainment	Not expected to be detrimental to the population
Habitat alteration	- Loss of 324,900 m^2 of fish-bearing instream habitat - Loss of 61.11 ha of riparian vegetation
Downstream effects	No negative effects

4.2 Aquatic Effects Valuation

In this section of my study, I use the existing literature to assign a monetary value to the Site C aquatic effects (Table 7). The spreadsheet that I used to calculate the present value (PV) of the aquatic effects is included as Appendix C.

4.2.1 Aquatic Life Effects

Both the backwater effects and the migration barrier across the Peace River have the potential to affect aquatic life in the Site C area; however, none of the fisheries studies that I reviewed suggest that any of the species currently inhabiting the Site C area will be extirpated as a result of the project.

Construction of Site C and the resulting changes to the aquatic habitat will result in a change in the species composition of the fish population in the Site C area of the Peace River, particularly in the portion of the river that will become reservoir. Fish species such as northern pike, lake whitefish and suckers are expected to increase in number whereas bull trout are expected to decrease in number.

In addition, blocking the migratory portion of the bull trout population from carrying out their historic seasonal migrations could lead to a reduction in the bull trout population. Similarly, construction of the Site C project will block the downstream population of arctic grayling from reaching their historic spawning rivers upstream of the dam, which could lead to a reduction in the arctic grayling population.

Construction of Site C will also impact the aquatic habitat present in the project area, including the direct loss 324,900 m^2 of fish-bearing habitat.

The aquatic life in the Site C area has both use and non-use values. The fish have a direct use value because the Site C area is used by anglers, and they have an indirect use value because they contribute to overall ecosystem functioning (e.g., they provide food for larger animals). Studies have shown that aquatic life also has non-use values (e.g., Kataria 2009 and Weber and Stewart 2009).

Direct Use Value

According to LGL (2009), sport fishing is very important to the communities and the economy of the Peace Area. In an effort to establish baseline recreation data, LGL conducted a creel survey to monitor recreational use of the Peace and Pine River areas between mid-May and the end of December 2008. The study determined that the estimated angling effort in the Site C reservoir area over the study period was 13,276 angler-hours. This can be compared to the angling pressure of approximately 42,208 angler-hours[6] per year determined by RRCS (1979). The decline in angling pressure in the Site C area is consistent

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[6] Based on the value of 10,552 angler-days given in the report and an assumption of 4 angler-hours per angler day.

with the trends observed province-wide. According to G.S. Gislason & Associates Ltd. (2003), the number of angler-days in B.C. declined by 30% between 1985 and 2000.

In an earlier study, RRCS (1979) used the morphoedaphic index[7] to calculate that post-impoundment the Site C reservoir would be capable of supporting approximately 16,800 to 34,160 angler-hours[8]. Though the morphoedaphic index has since been shown to have dubious statistical validity (e.g., Jackson *et al.* 1990), it is the best available estimate of the effect of Site C construction on angling. The calculations by RRCS (1979) show that the Site C area will be able to support the current angling pressure following project construction. For my study, I will assume that angler pressure has stabilized and that the reservoir area will be able to sustain the angler-pressure over the 40-year period being analyzed.

The desirability of the fish being caught in the Site C area is expected to decrease following project construction. Fish that are highly desirable to anglers like arctic grayling and bull trout are expected to decrease in abundance whereas less desirable fish like northern pike and mountain whitefish are expected to increase in abundance (RRCS 1979). As a result, anglers will be less likely to catch desirable fish and more likely to catch undesirable fish. The decrease in desirability of the angling available in the Site C area could result in a decrease in the angler effort. In a survey conducted as part of RRCS (1979), members of the Peace River Rats Association completed a survey regarding recreation in the Site C area. One of the survey questions related to how frequently the respondents would fish on the reservoir as compared to that stretch of the Peace River. The answers by the 18 respondents were as follows:

- eight would fish the same amount;
- six would fish less; and
- four would fish more.

Though the sample size is very small and the survey results are more than 30 years old, this survey provides some insight into whether anglers in the Peace River area prefer riverine or reservoir habitat. Because of the large degree of uncertainty associated with angler

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[7] The morphoedaphic index is total dissolved solids (ppm)/mean depth (ft).

[8] Based on the assumption that there are 4 angler-hours in an angler-day.

preferences, I will test the effect of the change in angler effort on the study results as part of the sensitivity analysis.

Based on survey results, I will assume that the four anglers who said that they will fish more often are offset by four of the anglers who said that they will fish less often. Further, I will assume that the two remaining anglers who say they will fish the Site C area less frequently decrease their fishing effort by 50%. Thus, the angler effort will decrease by half of the net proportion of survey respondents who said they would fish in the Site C area less frequently (1/18 or 5.6%). Given these assumptions, the annual angler effort following project construction will decrease to 12,546 angler-hours (a decrease of 730 angler-hours or 183 angler-days annually).

I use the concept of consumer surplus to measure the fishing value that would be lost as a result of the construction of Site C. The latest research available relating to the value of recreation on Crown land in BC is the "Outdoor Recreation Survey 1989/90" (BC Ministry of Forests 1991). In the Prince George Forest District, which encompasses the Site C area, I calculate that the consumer surplus is \$25.75[9] per day of fishing. Using this value, the consumer surplus relating to fishing that is lost as a result of Site C is \$4,712 annually.

The data contained in BC Ministry of Forests (1991) is more than two decades old, and the study needs to be updated to be more reflective of the current consumer surplus for a day of fishing; the value appears to be low in comparison to more recent studies. For example, Chizinski *et al.* (2005) used the travel cost method to calculate an average consumer surplus of \$61-\$122 per day for angling at the relatively small (6,310 ha) Lake Kemp reservoir in Texas, USA. The fish species commonly targeted by Lake Kemp anglers include blue catfish (*Ictalurus furcatus*), channel catfish (*I. punctatus*), largemouth bass (*Micropterus salmoides*), spotted bass (*M. punctulatus*), striped bass (*Morone saxatilis*), white bass (*M. chrysops*) and white crappies (*Pomoxis annularis*) Although the Chizinski *et al.* (2005) study is more recent, I use the data from BC Ministry of Forests (1991) in my study. The consumer surplus data from Texas relates to reservoir fishing as opposed to river fishing, and the species targeted by anglers in

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[9] I calculated this value based on the BC Ministry of Forests (1991). I then used the Bank of Canada inflation calculator to convert the 1990 dollars into 2009 dollars.

that study are very different from those targeted in the Site C area. The effect of the value of the consumer surplus for day of fishing on the study results is tested in Section 6.1.2.

Some consumer surplus may also be lost as a result of the change in the species composition, which will increase the probability of catching an undesirable fish and decrease the probability of catching a desirable fish. If a decrease in consumer surplus occurred, it would be extremely difficult to predict the magnitude because it would be highly site-specific and time dependent. For the purpose of my study, I will assume that consumer surplus does not change as a result of the change in species composition; however, I test the effect of changes in consumer surplus in Section 6.1.2.

Indirect Use Value

Given that the quantity of fish in the Site C area will not change (just the species composition), I will assume that the indirect use value will also not change. It is possible that (as with humans) bears and other animals have a preference regarding what type of fish they catch; however, the indirect effects that would arise as a result of these preferences would be extremely difficult to quantify and even more complex to monetize.

Non-use Value

The fish that would be affected by construction of Site C may also have non-use value in addition to the use value calculated above. Some studies that have examined the public's WTP to protect fish species are described below.

Collins *et al.* (2005) used multi-attribute choice experiments to derive the economic value of restoring a 23.7 mile (38.1 km) long creek in West Virginia. This study examined the WTP for restoration of three different creek attributes: aquatic life, swimming and scenic quality. They calculated the WTP to restore aquatic life separately for the anglers and non-anglers, and I will assume that the non-anglers' WTP represents non-use value. Collins *et al.* (2005) found that the mean WTP was US$61.08 annually (C$85.51[10]) to restore the creek from very limited areas of fish habitat to stream habitat that is capable of supporting reproducing fish populations.

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[10] Based on the Bank of Canada Conversion Rate of 1.40 (2003 average).

Unlike the study conducted by Collins *et al.* (2005), the Site C area will remain a functioning (but significantly altered) aquatic ecosystem following construction. As such, utilizing the full WTP value from their study seems overly high[11]. For the purpose of this study, I will use a WTP of C$30 per year per household. Given that there are 28,062 households affected by Site C, the total WTP is $841,860. I will examine the effect of the WTP selected on the value of the aquatic effects in Section 6.1.2.

Instream Habitat

The value of instream habitat is primarily related to the contributions that it provides to the fisheries resources in the area (i.e., fish habitat and fish food production). Since I have already accounted for the effects of Site C on fisheries resources, I will not assign a value to the lost instream habitat. By doing so, I avoid double counting the effects of Site C on fisheries resources in the Peace River.

4.2.2 Carbon Dioxide Production

Construction of Site C will produce 32,000 tonnes CO_2e annually for the first 35 years post-impoundment. After 35 years, the greenhouse gas emissions of the Site C area will be similar to baseline conditions (Jacques Whitford AXYS Ltd. 2009).

Tol (2005) conducted a review of 103 estimates of the marginal damage costs of carbon dioxide emissions from 28 published studies. He found that if all the studies are considered, the best guess for the marginal damage costs of carbon dioxide emissions is US$5/tC (US$1.36/tonne CO_2) but the mean is US$104/tC (US$28.38/tCO_2). The difference between the best guess and the mean reflects the large uncertainty. Tol (2005) concludes that climate change impacts may be very uncertain, but it is unlikely that the marginal damage costs of CO_2 emissions exceed US$50/tC (US$13.65/tCO_2).

The boundaries relating to the effects of carbon dioxide are different from those used elsewhere in the report. The increasing concentration of atmospheric carbon dioxide is a global concern with global consequences; therefore, the costs of carbon dioxide production

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[11] Richardson and Loomis (2008) reviewed the available literature regarding the WTP to protect threatened and endangered species. They found a large range in the WTP to protect different species, from US$241 per household per year to protect Washington State anadromous fish populations down to US$8 per household per year to protect striped shiners.

extend far beyond the affected populations used for the other aquatic effects, and the studies used consider the worldwide effects.

For the purpose of this study, I will use a value of C$65/tC (C$17.73/tCO$_2$), which is approximately equivalent to the US$50/tC from Tol (2005)[12]. Using this value, the cost of emitting 32,000 tonnes of CO$_2$e in 2009 is C$567,360, and the PV of the emissions produced by Site C is C$6,612,336. Since there is a large degree of uncertainty associated with the value of carbon emissions, I will test a range of values as part of the sensitivity analysis.

4.2.3 Riparian Habitat Loss

As with many of the other potentially affected aquatic attributes, riparian vegetation can have direct use value, indirect use value and non-use value: the direct use value can include the aesthetic appeal of intact riparian vegetation; the indirect use value can include the shade and water purification that riparian vegetation provides to the stream; and the non-use value would consist primarily of the existence value. A number of studies have been conducted to determine the value of riparian vegetation (e.g., Weber and Stewart 2009 and Holmes *et al.* 2004). Select studies that value riparian habitat are summarized below along with the WTP determined by the study.

Weber and Stewart (2009) conducted both a choice experiment and a contingent valuation study on a 17-mile (27 km) reach of the Middle Rio Grande River, New Mexico. The choice experiment allowed them to determine the greater Albuquerque's WTP for a number of environmental attributes connected with a planned river restoration. The most important attribute to survey respondents was restoring native vegetation. Restoring native vegetation had a WTP of US$60 annually for the 1,619 ha area (approximately C$67.80[13]), which is equal to C$0.042/ha/year/household (in 2006 dollars).

Holmes *et al.* (2004) conducted a contingent valuation experiment for different levels of river restoration on the Little Tennessee River. They found that the scale of riparian restoration affected the public's WTP for riparian restorations. The study showed that the mean annual

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[12] Based on the Bank of Canada Conversion Rate of 1.21 (2005 average) and the Bank of Canada inflation rate for 2005 to 2009.

[13] Based on the Bank of Canada conversion rate of 1.13 (2006 average)

household WTP for restoring two miles of riparian habitat was US$2.68 (C$4.21[14]), whereas restoring six miles of riparian habitat had a mean annual household WTP of US$27.26 (C$42.80). Through unit conversion, we find that this is equal to between C$1.31/km/year/household to C$4.43/km/year/household.

Colby and Orr (2005) conducted a contingent valuation study on preserving riparian vegetation in the Upper San Pedro Basin, Arizona. The study determined the willingness of visitors to the Upper San Pedro riparian area to make a one-time donation to protect riparian vegetation in the 22,662 ha San Pedro Riparian National Conservation Area. They found that the mean WTP was US$78.50/household (C$121.68/household[15]).

Loomis *et al.* (2000) conducted a contingent valuation survey to determine the WTP of households to restore ecosystem services along a 45 mile (72 km) section of the Platte River. They found that households would be willing to pay an average of US$252 per year to restore natural vegetation and increase instream flows in order to increase five ecosystem services: dilution of wastewater, natural purification of water, erosion control, habitat for fish and wildlife, and recreation. Because this study does not separate the WTP for increased flows from the WTP to restore natural vegetation, it is difficult to know what proportion of the WTP should be assigned to restoring natural vegetation.

Due to the similar size of the riparian areas being affected, I believe that Weber and Stewart (2009) will be the most applicable study. According to Pearce and Moran (1994), the economic values captured by WTP studies typically elicit a mix of potential use and non-use values; therefore, I will consider the values calculated by Weber and Stewart (2009) to be the TEV. Based on the study value of C$0.044/ha/year/household in 2009[16], the mean expected value of the riparian vegetation that would be lost as a result of construction of the Site C project (61.11 ha) will be $2.73/year/household. Based on the number of affected households, the value of the riparian vegetation that would be lost due to the construction of Site C would be $68,595 annually.

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[14] Based on the Bank of Canada conversion rate of 1.57 (2002 average)

[15] Based on a conversion rate of 1.55 (2001 average)

[16] In 2009 dollars. Calculated using the Bank of Canada inflation values.

4.2.4 Summary of Aquatic Effects Valuation

Table 8 summarizes the PV of Site C's aquatic effects at an 8% discount rate over 40 years.

Table 8: Present value (PV) of Site C aquatic effects at an 8% discount rate over 40 years

Aquatic Effect	Site C
Aquatic Life: direct use value	$56,192
Aquatic Life: non-use value	$10,038,855
Carbon dioxide	$6,612,336
Riparian vegetation	$899,762
Total aquatic effects	$17,607,145

5 RESULTS: UPPER HARRISON WATER POWER PROJECT

In this section of my study, I first examine the potential aquatic effects associated with the UHWPP (Section 5.1). I then use the existing literature to assign a monetary value to these aquatic effects (Section 5.2).

5.1 Environmental Impact Assessment

In the subsections below, I examine each of the potential aquatic effects associated with hydro projects (Lewis 2005) in respect to the UHWPP.

5.1.1 Backwater Effects

Each of the plants comprising the UHWPP has a different intake configuration designed to suit the site conditions. Sections 5.1.1.1 to 5.1.1.5 describe the weir configurations for each site and the extent of backwatering associated with each of the headponds. The information regarding the weir configuration for each plant is taken from the UHWPP application for an Environmental Assessment Certificate (Cloudworks Energy Inc. 2006). In each of these sections, I also calculate the estimated volume of each headpond and the flushing time based on the information available. Section 5.1.1.6 then relates the headpond descriptions to the potential backwatering effects described in Section 4.1.1.

5.1.1.1 Tipella Creek Plant

The diversion weir for the Tipella Creek Plant is a low-level ogee crest weir; the headpond surface area associated with the construction of the weir will be 0.1 ha (1,000 m^2) in area. The elevation of the creek bed at the intake is 315.6 m above mean sea level (AMSL) and the normal operating level is 316.3 m AMSL, thus the depth of water inundated by the weir will be less than 1 m above the creek bed.

Based on the headpond area and a depth of 0.7 m at the weir, the volume of the headpond is estimated to be approximately 42 m^3.

5.1.1.2 Upper Fire Creek Plant

Since the Upper Fire Creek Plant draws water from Fire Lake, there will not be a weir or backwatering associated with this plant.

5.1.1.3 Lamont Creek Plant

The diversion weir for the Lamont Creek Plant is a concrete overflow weir with an ogee-crest, and the surface area of the headpond associated with the weir is 1.0 ha (10,000 m^2). The creek elevation at the intake is 605 m AMSL, and the full supply level is 609 m AMSL.

Based on the headpond area and a depth at the weir of 4 m, the headpond volume is estimated to be approximately 20,000 m^3.

5.1.1.4 Upper Stave River Plant

The diversion weir for the Upper Stave River Project will be a concrete overflow weir; the surface area of the headpond associated with this weir will be 3.0 ha (30,000 m^2). The creek bed elevation at the intake is 303.6 m AMSL, and the full supply level is 308 m AMSL.

Based on the headpond area and a depth at the weir of 4.4 m, the headpond volume is estimated to be approximately 66,000 m^3.

5.1.1.5 Northwest Stave River Plant

The diversion weir for the Northwest Stave River Project will be a concrete overflow weir; the surface area of the headpond associated with this weir will be 0.5 ha (5,000 m^2). The creek bed elevation at the intake is approximately 493 m AMSL and the full supply level will be 494 m AMSL.

Based on the headpond area and a depth at the weir of 1 m, the headpond volume is estimated to be 2,500 m^3.

5.1.1.6 Summary

The construction of the weirs associated with the project will result in 4.6 ha of lotic habitat being converted to lentic habitat. Of this 4.6 ha of lentic habitat, approximately 1.5 ha will be located in non fish-bearing reaches of the streams. According to Lewis (2005), headponds can be beneficial to riverine species by providing deepwater habitat that provides secure holding and feeding areas.

As part of the instream flow analysis for the UHWPP conducted prior to construction, OnStream Environmental Inc. (2005) stratified the diversion reaches into seven different mesohabitats: canyon, cascade, chute, falls, pocket water, pool and riffle (Table 9). As can be seen in Table 9, pool habitat is a small percentage of the diversion reaches at all the plants except for the Northwest Stave River, which is non fish-bearing in the intake area. In particular, rainbow tout in Tipella Creek, which only has 0.8% pool habitat, may benefit from the creation of new pool-type habitat through construction of the weir.

Table 9: UHWPP diversion reaches mesohabitat composition

	Tipella Creek Plant	Upper Fire Creek Plant	Lamont Creek Plant	Upper Stave River Plant	Northwest Stave River Plant
Canyon	20.9%	0.0%	0.0%	0.0%	0.0%
Cascade	75.7%	89.9%	76.0%	6.6%	34.4%
Chute	0.0%	0.0%	0.0%	3.0%	10.2%
Falls	1.2%	5.5%	5.9%	1.4%	0.6%
Pocket water	0.0%	0.0%	0.0%	79.0%	0.0%
Pool	0.8%	4.6%	2.8%	10.0%	30.8%
Riffle	1.4%	0.0%	18.1%	0.0%	24.0%

As described in Section 4.1.1, the negative effect of reservoirs on water quality is due to their long residence times and resulting stratification, which can lead to anoxic conditions at the bottom of the reservoir. The flushing times of the UHWPP headponds at the streams' mean annual flows (MAF) are summarized in Table 10. As can be seen in Table 10, the flushing times vary from 10 seconds to approximately 1 hour. These flushing times can be compared to Williston Lake, the reservoir formed by W.A.C. Bennett Dam that has a residence time of approximately two years (BC Hydro 2007b).

Table 10: Flushing times of the UHWPP headponds

	Tipella Creek Plant	Lamont Creek Plant	Upper Stave River Plant	Northwest Stave River Plant
Headpond volume	42 m^3	20,000 m^3	66,000 m^3	2,500 m^3.
MAF	4.50 m^3/s	5.42 m^3/s	27.38 m^3/s	19.68 m^3/s
Flushing time at MAF	0.2 min	61.5 min	40.2 min	2.1 min

Because of the short flushing times, none of the water quality concerns typically associated with large reservoirs (nutrient retention, anoxic conditions and methyl mercury) are expected to be a concern with the UHWPP.

5.1.2 Dewatering

As part of the permitting process for the UHWPP, OnStream Environmental Inc. undertook an instream flow assessment adopted from Lewis *et al.* (2004) for each of the project sites. Sections 5.1.2.1 to 5.1.2.5 describe the fish presence in each of the diversion reaches and the minimum instream flows required to maintain habitat for these fish. All information relating to fish presence and instream flows for the UHWPP, except where referenced otherwise, is taken from the "Upper Harrison Water Power Project fisheries and instream flow report" (OnStream Environmental Inc. 2005).

Since reduced flows through the diversion reach can result in reduced maintenance flows and connectivity flows, the preservation of these flows is also discussed in the sections below. Channel maintenance flows recruit gravel and large organic debris to the stream channel; connectivity flows link stream channel habitats with off-channel and riparian habitat (Lewis *et al.* 2004).

5.1.2.1 Tipella Creek Plant

There is a fish barrier on Tippela Creek 100 m upstream of the powerhouse, which blocks fish movement upstream beyond that point. Fish sampling on Tipella Creek caught six species of fish downstream of the barrier falls: coho salmon (*Oncorhynchus kisutch*), bull trout, coastal cutthroat trout (*O. clarki clarki*), rainbow trout, coastrange sculpin (*Cottus aleuticus*) and slimy sculpin (*C. cognatus*). Sampling upstream of the falls caught only rainbow trout.

An instream flow assessment was conducted for the 2 km long diversion reach of the Tipella Creek plant. This analysis examines the habitat available to the rainbow trout prior to plant construction and ensures that habitat is maintained during plant operations when flow is being diverted from Tipella Creek. The report proposes different instream flows to maintain each of summer rearing, spawning and overwintering habitat for rainbow trout. According to OnStream Environmental Inc. (2005), if these flows remain in the diversion reach, rainbow trout habitat will not be negatively affected. The instream flow assessment concentrates on rainbow trout because the other species only have access to 100 m of the 2 km long diversion reach.

Based on mean daily flow data, channel maintenance flows (400% mean annual flow) occur in Tipella Creek approximately 1.56% of the time before plant construction and 0.72% of the time after plant construction. Similarly, based on mean daily flow data, connectivity flows occur 36% of the time before plant construction and 7% of the time after plant construction. According to OnStream Environmental Inc. (2005), these events will continue to occur sufficiently frequently to maintain their function.

5.1.2.2 Upper Fire Creek Plant

Chinook and coho salmon are present in the bottom reach of Fire Creek, possibly as far upstream as an impassable barrier. Rainbow trout, coastal cutthroat trout, mountain whitefish, both resident and migratory bull trout, coastrange sculpin and river lamprey (*Lampetra ayresii*) have also been recorded below the barrier. Rainbow trout were stocked in Fire Lake in 1938, and they have since colonized Fire Creek downstream to the barrier. The plant powerhouse will be located 50 m downstream of the barrier.

An instream flow assessment was conducted for the 2.1 km long diversion reach. This analysis examines the habitat available to the rainbow trout prior to plant construction and ensures that habitat is maintained during plant operations, when flow is being diverted from Fire Creek. The report proposes different instream flows to maintain each of summer rearing, spawning and overwintering habitat for rainbow trout. According to OnStream Environmental Inc. (2005), if these flows remain in the diversion reach, rainbow trout habitat will be maintained. The instream flow assessment focuses on rainbow trout because the other species only have access to 50 m of the 2.1 km long diversion reach.

Based on mean daily flow data, channel maintenance flows (400% mean annual flow) occur in Fire Creek approximately 1.67% of the time before plant construction and 0.16% of the time after plant construction. Similarly, based on mean daily flow data, connectivity flows occur 31% of the time before plant construction and 4.5% of the time after plant construction. According to OnStream Environmental Inc. (2005), these events will continue to occur sufficiently frequently post-construction to maintain their function.

5.1.2.3 Lamont Creek Plant

Fish sampling was conducted on Lamont Creek by both OnStream Environmental Inc. (2005) and Ecofish Research Ltd. (2005). This sampling concluded that Lamont Creek is non fish- bearing above a barrier 0.7 km upstream of the powerhouse. Below these falls, fish sampling determined that bull trout, coastal cutthroat trout and rainbow trout are present.

An instream flow assessment was conducted for the 3.2 km long project diversion reach on Lamont Creek. The study examined the fish habitat available prior to flow diversion and recommended minimum flow releases for summer rearing, spawning and overwintering to ensure that habitat in the fish-bearing reach of Lamont Creek is maintained following project construction.

Based on mean daily flow data, channel maintenance flows (400% mean annual flow) occur in Lamont Creek approximately 1.29% of the time before plant construction and 0.40% of the time after plant construction. Similarly, based on mean daily flow data, connectivity flows occur 34% of the time before plant construction and 11% of the time after plant construction. According to OnStream Environmental Inc. (2005), these events occur sufficiently frequently post-construction to maintain their function.

5.1.2.4 Upper Stave River Plant

Fish sampling on the Upper Stave River was conducted by OnStream Environmental Inc. (2005) and Ecofish Research Ltd. (2005). This sampling showed that bull trout, coastal cutthroat trout and rainbow trout are present in the Upper Stave River below a set of falls located 1 km upstream of the powerhouse. Rainbow trout were the only species captured upstream of the falls.

OnStream Environmental Inc. also conducted an instream flow assessment for the 1.8 km long project diversion reach on the Upper Stave River. The study examined the fish habitat available prior to flow diversion and recommended minimum flow releases for summer rearing, spawning and overwintering to ensure that habitat in the Upper Stave River is maintained following project construction.

Based on mean daily flow data, channel maintenance flows (400% mean annual flow) occur in the Upper Stave River occur approximately 1.47% of the time before plant construction and 0.63% of the time after plant construction. Similarly, based on mean daily flow data, connectivity flows occur 36% of the time before plant construction and 6% of the time after plant construction. According to OnStream Environmental Inc. (2005), these events occur sufficiently frequently post-construction to maintain their function.

5.1.2.5 Northwest Stave River Plant

Fish sampling on the Northwest Stave River was conducted by OnStream Environmental Inc. (2005) and Ecofish Research Ltd. (2005). This sampling showed that rainbow trout are present at the powerhouse of the Northwest Stave River Plant. There is an impassable falls approximately 520 m upstream of the plant powerhouse. No fish were caught near the plant intake, and the Stave River is thought to be non fish-bearing above the falls mid-way through the diversion reach.

OnStream Environmental Inc. conducted an instream flow assessment for the 1,375 m long diversion reach associated with the Northwest Stave River Plant. They examined the fish habitat available prior to the construction of the plant and recommended instream flows to maintain summer rearing, spawning and overwintering habitat. Ecofish Research Ltd. (2006) conducted additional field studies regarding instream habitat. They found that the Northwest Stave River Plant's diversion reach appears to have low suitability for fry rearing and spawning; however, it is suitable for juvenile and adult rearing.

Based on mean daily flow data, channel maintenance flows (400% mean annual flow) occur in the Stave River at the Northwest Stave River Plant approximately 1.56% of the time before plant construction and 0.76% of the time after plant construction. Similarly, based on mean daily flow data, connectivity flows occur 36% of the time before plant construction and 7% of the time after plant construction. According to OnStream Environmental Inc. (2005), these events occur sufficiently frequently post-construction to maintain their function.

5.1.2.6 Summary

As described in Sections 5.1.2.1 to 5.1.2.5, minimum instream flows were prescribed for each of the plants in the UHWPP. According to OnStream Environmental Inc. (2005), these minimum instream flows mitigate the potential for reduced fish habitat due to reduced flows through the diversion reaches. In addition, the minimum flow releases and the maximum diversion flows selected will ensure that the streams maintain their natural functions post-construction. As such, I will consider that all potential aquatic impacts have been mitigated and that there are no residual dewatering impacts associated with the UHWPP.

5.1.3 Fish Passage – Upstream Blockage

Each of the plants making up the UHWPP has a different intake configuration designed to suit the site conditions. Sections 5.1.3.1 to 5.1.3.5 describe how the intake weir configurations for plant could affect upstream fish passage in that stream. The information regarding the weir configuration for each plant is taken from the UHWPP application for an Environmental Assessment Certificate (Cloudworks Energy Inc. 2006).

5.1.3.1 Tipella Creek Plant

The weir associated with the Tipella Creek Plant intake will have a height of approximately 0.7 m above the existing creek bed. Adult rainbow trout have a maximum jump height of up to 1.5 m (Omtzigt and Tobler 2008); construction of the weir and integrated Coanda screen intake should therefore not restrict the upstream movement of adult rainbow trout. The ogee shaped spillway rather than a straight drop may also allow smaller fish to swim up the low weir during appropriate flow conditions.

5.1.3.2 Upper Fire Creek Plant

The intake for the Upper Fire Creek Plant is a siphon-type intake located in Fire Lake. Since there is no diversion weir associated with the intake, construction of the plant will not affect upstream fish passage on Fire Creek.

5.1.3.3 Lamont Creek Plant

Lamont Creek is non fish-bearing in the Lamont Creek Plant intake area; the weir will therefore not affect upstream fish passage.

5.1.3.4 Upper Stave River Plant

The crest of the intake weir for the Upper Stave River Plant will be approximately 4 m above the elevation of the creek bed. An obstacle of this height will create a barrier to upstream passage for rainbow trout present in the intake area. There is an existing barrier approximately 400 m downstream of the intake, and the channel between the barrier and the intake is incised in bedrock (poor habitat quality).

Based on the fish sampling conducted on the Stave River, the rainbow trout population in the intake area is believed to originate from a stocked population in Thomas Lake (Ecofish Research Ltd. 2006). Ecofish Research Ltd. caught rainbow trout fry upstream of the Upper Stave River Plant intake, despite Thomas Lake last being stocked in 1999 (Ministry of Environment 2010), which suggests that the population is sustaining itself in the accessible 10.8 km reach of the Stave River upstream of the plant intake.

Given the close proximity of the intake to the existing natural barrier, there is not expected to be any incremental effect on upstream fish passage to the rainbow trout population. Fish passing over the intake weir and the natural falls will be lost to the upstream population but gained by the rainbow trout population downstream of the natural barrier.

5.1.3.5 Northwest Stave River Plant

The Stave River is non fish-bearing in the Northwest Stave River Plant intake area; the weir will therefore not affect upstream fish passage.

5.1.3.6 Summary

As described in Sections 5.1.3.1 to 5.1.3.5, the weirs will not affect fish passage at four of the five intakes. As described in Section 5.1.4.4, the intake for the Upper Stave River Plant (and resulting barrier) will be located 400 m upstream of an existing natural barrier and is not expected to have an incremental effect on upstream fish passage.

5.1.4 Fish Passage – Entrainment

Since the intake for each plant is designed to suit the site conditions, the intakes and the steps that have been taken to avoid fish entrainment are discussed below. All information on the UHWPP is taken from the project application for an Environmental Assessment Certificate (Cloudworks Energy Inc. 2006).

5.1.4.1 Tipella Creek Plant

The Tipella Creek Plant intake utilizes a Coanda type water intake. With this type of intake, water flows over a wedge wire screen and falls into a collection box that runs across the creek (perpendicular to the flow). The screen will have openings of 1.1 mm. Due to the intake design selected, fish cannot be entrained into the penstock.

5.1.4.2 Upper Fire Creek Plant

The intake for the Upper Fire Creek Plant is a siphon-type intake located in Fire Lake. It is screened using a cylindrical wedge wire screen with a maximum design opening of 2.54 mm to exclude fish with a fork length of 25 mm or larger. The screened area is large enough that approach velocities do not exceed 0.11 m/s to avoid fish impingement on the screen, which complies with DFO guidelines (Fisheries and Oceans Canada 1995).

5.1.4.3 Lamont Creek Plant

The intake for the Lamont Creek Plant is located in a non fish-bearing reach of Lamont Creek. Fish entrainment into the penstock is therefore not a concern.

5.1.4.4 Upper Stave River Plant

Fish screens are considered cost-prohibitive, and they will not be incorporated into the intake of the Upper Stave River Plant. According to Cloudworks Energy Inc. (2006), the mitigation measures that will be implemented to prevent entrainment are very low inlet velocities and a gated sluiceway to allow fish to be bypassed around the intake.

The Upper Stave River Plant has rainbow trout present in the intake area, and despite the mitigation measures, it is still possible that these trout will be entrained into the penstock and passed through the turbines. The plant uses three 11.2 MW Francis turbines to generate electricity (maximum flow of 14.6 m^3/s). In his study of juvenile rainbow trout passing trough the similarly sized, but lower head, Hb Dam in New Zealand, Dudual (2007) found that the immediate survival rate was approximately 95.6% and the 96-hour survival rate was 93.1%.

The combination of the mitigation measures lessening the number of fish that are entrained and the expected high survival rate of fish that are entrained means that the rainbow trout mortality expected as a result of penstock entrainment is very low. For the purpose of this study I will consider the mortality negligible.

5.1.4.5 Northwest Stave River Plant

The intake for the Northwest Stave River is located in a non fish-bearing reach of the Stave River; fish entrainment is therefore not a concern.

5.1.4.6 Summary

Design measures, including intake siting and design, will prevent fish entrainment at four of the five plants. At the Upper Stave River Plant, fish screens are not considered viable; however, rainbow trout mortality is considered negligible due to the combination of entrainment prevention measures and high expected turbine survival. No entrainment effects are expected due to the construction of the UHWPP.

5.1.5 Habitat Alteration

The construction of any hydroelectric plant will result in the loss of both instream and riparian habitat due to the placement of the structures associated with the plant (intake, weir and powerhouse/tailrace). For run-of-river hydro projects, such as the UHWPP, there is instream habitat loss associated with the construction of the in-channel weir and intake. There is also some instream habitat alteration at the junction of the tailrace[17] and the creek, which is typically armoured with rip-rap. Cloudworks Energy Inc. (2006) estimates that the habitat alteration associated with the tailraces will be less than 200 m^2 for all five plants combined.

Construction of the project structures also requires some riparian vegetation clearing. Since the width of the riparian zone is not a specific with, I am considering it to be 50 m, as shown on the UHWPP riparian habitat balance drawings (Cloudworks Energy Inc. 2006).

5.1.5.1 Tipella Creek Plant

Construction of the Tippella Creek Plant intake resulted in the permanent loss of 930 m^2 of instream habitat in a section of the creek that supports rainbow trout. It also resulted in the permanent loss of 0.327 ha of riparian vegetation.

5.1.5.2 Upper Fire Creek Plant

Construction of the Upper Fire Creek Plant resulted in the loss of 30 m^2 of lake bottom outside of the littoral area. It also resulted in the permanent loss of 0.232 ha of riparian vegetation.

5.1.5.3 Lamont Creek Plant

Construction of the Lamont Creek Plant intake resulted in the permanent loss of 270 m^2 of non fish-bearing instream habitat. It also resulted in the permanent loss of 1.563 ha of riparian vegetation.

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[17] The channel that directs flows from the plant back to the creek.

5.1.5.4 Upper Stave River Plant

Construction of the Upper Stave River Plant will result in the permanent loss of 860 m^2 of instream habitat in a section of the Stave River that supports rainbow trout. It will also result in the permanent loss of 1.739 ha of riparian vegetation.

5.1.5.5 Northwest Stave River Plant

Construction of the Northwest Stave River Plant will result in the permanent loss of 1070 m^2 of instream habitat in a non fish-bearing section of the Stave River. It will also result in the permanent loss of 0.813 ha of riparian habitat.

5.1.5.6 Summary

The construction of the five plants comprising the UHWPP will result in the loss of 1,340 m^2 of instream habitat in non fish-bearing reaches and 1,790 m^2 of instream habitat in reaches with rainbow trout. It will also result in the loss of 30 m^2 of non-littoral lake bottom, as well as 200 m^2 of habitat alteration from the construction of the tailraces.

As described in 5.1.5, DFO has a policy of no net habitat loss. If DFO determined that a fish habitat loss occurred as a result of project construction, this habitat loss would need to be compensated (since it cannot be mitigated). However, since habitat compensation is not always effective, I will consider the potential loss of instream habitat in this study.

The UHWPP will also result in the loss of 4.674 ha (46,740 m^2) of riparian vegetation.

5.1.6 Downstream Effects

Streamflow Regime

One of the characteristics of run-of-river hydroelectric projects is that all of the diverted water re-enters the creek at the powerhouse, and the flow regime downstream of the powerhouse is not affected. The unaltered streamflow regime means less effect on downstream biota, such as fish, benthic invertebrates and riparian vegetation; spawning cues are not interrupted and riparian vegetation continues to be inundated with the same frequency.

Changes to the quantity of water being diverted at the intake can lead to water level fluctuations downstream of the powerhouse, particularly during plant shut-down, due to the difference in travel time between water in the penstock and water in the creek. Ramping rates (maximum change in water level per unit time) were developed in consultation with DFO prior to the issuance of the *Fisheries Act* Authorizations for the UHWPP. These ramping rates are intended to ensure that fish are not stranded.

Water Quality

Due to their lack of a reservoir, run-of-river projects have a low potential to affect water quality downstream of the projects, as supported by the high flushing rates summarized in Table 10. The UHWPP may result in some localized, short-term nutrient trapping similar to debris retention behind a natural log jam (Cloudworks Energy Inc. 2006); however, this nutrient retention is not considered significant for the purpose of the cost-effectiveness analysis. Since vegetation is not inundated and the high flushing rates mean that stratification is unlikely, methylmercury and low dissolved oxygen are not concerns.

Temperature Regime

Water temperatures can be affected by diversion-type hydro projects in two different locations: in the diversion reach and downstream of the powerhouse. Reduced flows lead to lower velocities through the diversion reach, which allows for more time for thermal transfer. Water in the diversion reach will tend to warm faster in the summer and cool faster in the winter. Because the streams involved in the UHWPP are mountain streams with cool temperatures that are sub-optimal for fish, increased temperatures are not expected to have a negative impact on aquatic life (Cloudworks Energy Inc. 2006). In the winter, if water temperatures are above air temperatures more heat may transfer to the air than under baseline conditions, which could lead to the formation of frazil and anchor ice. Flows are naturally low during winter on the creeks in the project area, so the reduction in flows is less during the winter. If creek flow falls below the sum of the instream flow release and the minimum turbine flow, the plant will be shut down.

The water temperature downstream of the powerhouse is affected by (and under most operating conditions, dominated by) water from the powerhouse re-entering the creek. Two different processes can alter the water temperature of diverted flows. Firstly, water travelling through the penstock is insulated from heat transfer between it and the air, particularly in buried pipe. The result of the insulating effect on the water temperature is dependent on whether the air is warmer than the water or vice versa. Secondly, water can gain heat from friction in the pipe and inefficiencies in the turbine. The result of both thermal effects is a small temperature difference between natural conditions and post-construction conditions.

Gas Bubble Disease

Gas bubble disease is usually not an issue with small hydroelectric plants because of their configuration. The maximum weir height at the UHWPP plants is approximately 4 m, which is equivalent to many of the naturally occurring falls in the project areas; consequently, there are not any deep plunge pools and entrained air is not carried to depth. In addition, the intakes are designed with adequate submergence to prevent air entrainment into the penstock and subsequently into the turbines. Three of the five facilities making up the UHWPP use Pelton turbines. With Pelton turbines, water hits the turbine runner and then drops to the powerhouse foundation. The water then flows back out to the creek under gravity; it is not pressurized and any supersaturated gases can be released. The Upper Stave River Plant uses Francis turbines that require the tailrace to be kept backwatered (under pressure). Due to the higher potential for gas bubble disease at the Upper Stave River plant, Cloudworks Energy Inc. (2006) monitored the baseline total gas pressure in the plant area and found that the excess gas pressure (ΔP) was 11 mmHg as compared to the guideline limit of 76 mmHg for freshwater aquatic life. Since the baseline excess gas is well below the guidelines and the intake is designed to prevent air entrainment, Cloudworks Energy Inc. determined that gas bubble trauma is not likely at any of the UHWPP plants.

Sediment Regime

Anytime a structure is built across a stream, it has the potential to interrupt the supply of sediment to the downstream portion of the stream. Four of the five plants in the UHWPP have weirs associated with them that have the potential to block sediment passage; the Upper Fire Creek Plant does not include a weir. The mitigation measures implemented at each of the other intakes are described below.

- The intake type selected for the Tipella Creek Plant allows sediment to pass over the weir; there will be a short-term reduction in sediment input to the creek downstream of the weir while the volume behind the weir is filled.
- The Lamont Creek Plant, Upper Stave River Plant and Northwest Stave River Plant will all have sluice gates incorporated into their intakes. The sluice gates will be opened periodically to allow sediment to pass downstream. Since the majority of sediment movement occurs during high flows naturally, the natural sediment regime will be maintained.

Because the streamflow regime downstream of the powerhouse is unaffected in run-of-river projects and the sediment regime will be maintained at the UHWPP (as described above), the geomorphology of the river downstream of the powerhouse is also unaffected by the construction of these hydroelectric projects.

For the reasons outlined above, it is unlikely that the UHWPP will have a negative effect on the aquatic habitat in the creeks downstream of the plants.

5.1.7 Summary of Environmental Impact Assessment

Table 11 summarizes the aquatic effects associated with the construction of the UHWPP.

Table 11: Summary of UHWPP aquatic effects

	UHWPP
Backwater Effects	Mitigated
Dewatering	Mitigated
Fish passage – upstream blockage	Mitigated
Fish passage – entrainment	Mitigated
Habitat alteration	- Loss of 1,790 m^2 of fish-bearing instream habitat - Loss of 1,340 m^2 of non fish-bearing instream habitat - Loss of 4.67 ha of riparian vegetation
Downstream effects	Mitigated

5.2 Aquatic Effects Valuation

The expected aquatic effects associated with the UHWPP are the loss of riparian and instream habitat. In Section 5.1, I determined that the UHWPP should not have an effect on fisheries resources in the area nor will its headpond produce CO_2. I calculate the costs associated with the unmitigated UHWPP aquatic effects in the sections below.

5.2.1 Habitat Loss

Riparian Vegetation

As described in Section 4.2.3, the mean expected value for riparian habitat is C$0.044/ha/year/household. 4.67 ha of riparian habitat will be permanently lost as a result of the UHWPP, so the value of riparian habitat lost will be C$0.21/year/household. Based on the number of households affected by the UHWPP, the total value of the riparian vegetation lost as a result of UHWPP construction will be $3,446 annually.

Instream Habitat

In the case of the UHWPP, the plants will result in the loss of a total of 3,130 m^2 of instream habitat; however, they are not expected to result in any changes to the fish populations. As described in Section 4.2.3, the value of instream habitat relates primarily to the fish population. If the fish population in any of the creeks were affected by the UHWPP then this aquatic effect would be accounted for by that calculation.

Table 12: Present value (PV) of the UHWPP aquatic effects at 8% discount rate over 40 years

Aquatic Effect	UHWPP
Aquatic Life: direct use value	Not applicable
Aquatic Life: non-use value	Not applicable
Carbon dioxide	Not applicable
Riparian vegetation	$41,089
Total aquatic effects	$41,089

6 DISCUSSION AND POLICY IMPLICATIONS

In this section of my study, I first examine the effect of the chosen parameters on the results of the aquatic effects valuation conducted in Sections 4.2 and 5.2. I then discuss the results of the study, and finally, I examine my study results in the context of British Columbia energy policy.

6.1 Sensitivity Analysis

The results of the aquatic effects valuation are subject to uncertainty due to the uncertainty in the parameters used. The valuation studies used in my study were often from very different parts of North America than the study areas, and when BC data was available, it was out-of-date (see Section 6.2 for more details). Sections 6.1.1 to 6.1.4 determine how the present value of the aquatic effects changes depending on the value of the parameters selected. For context, I also provide the intensity of the aquatic effects per unit of electricity produced (i.e., \$/GWh).

6.1.1 Discount Rate

The discount rate is likely the most controversial parameter chosen for my study (as discussed in Section 3.4). In the base case, I used a real discount rate of 8%, which is consistent with several of the Canadian publications that I reviewed (e.g., The Treasury Board of Canada Secretariat 2007 and Jenkins and Kuo 2007). However, other publications (e.g., EPA 2000) recommend much lower discount rates. Table 13 shows the effect of the discount rate on the PV of the aquatic effects for the case study sites.

Table 13: Sensitivity of the PV of aquatic effects to changes in the discount rate

Discount Rate	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
2%	$39,405,693 ($313/GWh)	$94,259 ($9/GWh)
4%	$28,839,017 ($317/GWh)	$68,200 ($9/GWh)
6%	$22,098,809 ($319/GWh)	$51,845 ($9/GWh)
8%	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)

As expected, the present value of the aquatic effects decreases as the discount rate increases (an increased discount rate gives less weight to future effects). Regardless of the discount rate used, the present value of the Site C aquatic effects is much greater than the present value of the UHWPP aquatic effects on both a total and a per GWh basis.

6.1.2 Aquatic Life

Direct Use Value

The direct use fisheries value is based on the angler effort that is expected to be lost as a result of construction of Site C and the conversion of that section of the Peace River from free-flowing river to reservoir. I based the estimated reduction in angler effort (5.5%) on a survey conducted by RRCS (1979). Due to the small sample size and the assumptions that I made, it is possible that the change in the angling opportunities available will have either a greater or a lesser effect than my estimate. Because of the large degree of uncertainty, I tested the effect of both halving (2.8%) and doubling (11%) the reduction in angler effort used in the base-case. I test the effect of changes in the angler effort on the PV of aquatic effects in Table 14.

Table 14: Sensitivity of the PV of aquatic effects to changes in angler effort

Reduction in Angler Effort	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
-2.8%	$17,579,049 ($320/GWh)	$41,089 ($9/GWh)
-5.5%	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)
-11%	$17,663,337 ($322/GWh)	$41,089 ($9/GWh)

Changing the reduction in angler effort (the direct use value of fish) has very little effect on the value of the aquatic effects. This insensitivity is because the fisheries direct use value is much less than the other aquatic effects. The PV of the UHWPP aquatic effects is unaffected by the changes because it is not expected to affect fisheries resources.

There is also uncertainty surrounding the value of consumer surplus for a day of fishing used in my study and thus in the amount of consumer surplus that will be lost as a result of the reduction in angler effort. The most recent data available is BC Ministry of Forests (1991) and the data contained in the report is more than two decades old. The study needs to be updated to be more reflective of the current consumer surplus for a day of fishing. For the base-case, I used a consumer surplus value of $25.75 per day. This value can be compared to a more recent study by Chizinski *et al.* (2005) where they calculated an average consumer surplus of $61-$122 per day for angling at a reservoir. I test the effect of changes in the consumer surplus on the PV of aquatic effects in Table 15.

Table 15: Sensitivity of the PV of aquatic effects to changes in the consumer surplus for a day of fishing

Consumer Surplus for a Day of Angling ($\day)	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
$15	$17,583,686 ($321/GWh)	$41,089 ($9/GWh)
$25.75	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)
$50	$17,660,064 ($322/GWh)	$41,089 ($9/GWh)
$100	$17,769,174 ($324/GWh)	$41,089 ($9/GWh)

As can be seen in Table 15, the consumer surplus value for a day of fishing has a relatively small effect on the total value of the aquatic effects. This insensitivity is because of the small contribution of the fisheries use value to the overall aquatic effects.

Non-Use Value

The non-use value of the aquatic life that will be reduced by the construction of Site C is based on the affected households' WTP to protect that life. For the base case, I selected an annual WTP of $30 per household based on Collins *et al.* (2005). As shown in Richardson and Loomis (2008), there is a large variation is WTP depending on the species being protected.

Table 16: Sensitivity of the PV of aquatic effects to changes in WTP to protect aquatic life

WTP to Protect Aquatic Life ($\household\year)	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
$10	$10,914,575 ($199/GWh)	$41,089 ($9/GWh)
$30	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)
$50	$24,299,715 ($443/GWh)	$41,089 ($9/GWh)
$70	$30,992,285 ($565/GWh)	$41,089 ($9/GWh)

As can be seen in Table 16, changing the WTP to protect aquatic life has a large effect on the value of the aquatic effects of Site C since it is the most highly valued effect. The value of the UHWPP aquatic effects is not affected by changes in the non-use value of fisheries resources.

6.1.3 Carbon Dioxide

Tol (2005) developed a probability density function based on his review of one hundred and three estimates of the marginal damage costs of carbon dioxide emissions from 28 published studies. He found that the probability density function is strongly right skewed, which reflects the large uncertainty combined with the notion that negative surprises are more likely than positive ones (Tol 2005). Table 17 tests the sensitivity of the PV of aquatic effects to the marginal damage costs of carbon dioxide emissions over the range of values from Tol (2005).

Table 17: Sensitivity of the PV of aquatic effects to changes in the cost of CO_2

Cost of CO_2 Emissions ($\t$CO_2$)	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
$5	$12,859,540 ($234/GWh)	$41,089 ($9/GWh)
$18	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)
$30	$22,183,195 ($404/GWh)	$41,089 ($9/GWh)
$100	$48,289,428 ($880/GWh)	$41,089 ($9/GWh)

As shown in Table 17, the cost of a tonne of CO_2 used in the analysis has a very large effect on the value of the Site C aquatic effects. It is important to note that the lower values tested are the most realistic values based on Tol (2005); I tested the effect of using $100/t$CO_2$ because it corresponds to the 95th percentile of the probability density function.

6.1.4 Riparian Vegetation

The value of the riparian vegetation used in the aquatic effects valuation is based on other studies (e.g., Weber and Stewart 2009) that have elicited people's WTP to restore riparian vegetation. Holmes *et al.* (2004) showed the WTP to restore riparian habitat varied widely with the scale of the restoration. In addition, all contingent valuation studies are affected by the income and values of those surveyed. To test the effect of these uncertainties on the value of the aquatic effects I substituted different values of WTP to protect riparian habitat (Table 18).

Table 18: Sensitivity of the PV of aquatic effects to the WTP to protect riparian vegetation

WTP to Protect Riparian Vegetation ($\ha\household)	Site C Aquatic Effects PV	UHWPP Aquatic Effects PV
$0.022	$17,157,264 ($313/GWh)	$20,544 ($5/GWh)
$0.044	$17,607,145 ($321/GWh)	$41,089 ($9/GWh)
$0.088	$18,506,908 ($337/GWh)	$82,177 ($18/GWh)

Both the value of the Site C and the UHWPP aquatic effects change with changes in the WTP to protect riparian vegetation. The value of the riparian vegetation is a small component of the Site C aquatic effects so it does not have much effect on the PV of these effects. Conversely, riparian vegetation is the only effect of the UHWPP and consequently the WTP to protect riparian vegetation has a large effect on the PV of its aquatic effects.

6.1.5 Range of Possible Results

Since there are large uncertainties associated with the parameters that I used in this study, I examined two different scenarios to bound the reasonable range of study results. For simplicity, I refer to the scenarios as the best-case scenario (the combination of all parameters giving the smallest aquatic effects) and the worst-case scenario (the combination of all parameters giving the greatest aquatic effects). The parameters used in the analysis along with the results for each case study site are summarized in Table 19.

Table 19: Range of possible case study site aquatic effects

	Best-Case Scenario	Worst-Case Scenario
Discount Rate	8%	2%
Reduction in Angler Effort	2.8%	11%
Consumer Surplus for a Day of Fishing ($/day)	$15	$100
WTP to Protect Aquatic Life ($/household/year)	$10	$70
Cost of CO_2 Emissions ($/t$CO_2$)	$5	$100
WTP to Protect Riparian Vegetation ($/household/year)	$0.022	$0.088
PV of Site C Aquatic Effects	$5,677,264 ($103/GWh)	$138,860,428 ($1,104/GWh)
PV of UHWPP Aquatic Effects	$20,544 ($5/GWh)	$188,517 ($18/GWh)

As can be seen in Table 19, there is a very large range in the possible results of my study. If additional data that is more relevant to the case study sites was collected, the range of aquatic effects could be reduced. With more certainty surrounding the aquatic effects (and other effects), policy makers will be able to make better decisions regarding energy policy in British Columbia.

6.2 Synthesis

Study Results

Site C is a much larger project than the UHWPP; it would be capable of producing 4,600 GWh of electricity annually as opposed to the 376 GWh produced annually by the UHWPP. However, along with the larger amounts of energy produced come a greater variety of aquatic impacts and a much larger costs associated with these aquatic effects. The aquatic impacts associated with Site C would be on an ecosystem level (e.g., shifts in fish species composition) and thereby far wider reaching than the more localized effects associated with the UHWPP. As shown in the sensitivity analysis (Section 6.1), the larger value of aquatic impacts for Site C (both in total and per GWh of electricity generated) persists over the full range of scenarios tested. With any reasonable set of parameter assumptions, Site C's aquatic effects are far greater than those of the UHWPP per GWh of electricity generated.

In the base case scenario, I calculate that Site C would cause $1,476,538 of aquatic impacts annually, which is $321 per GWh of electricity produced, and the UHWPP would cause

$3,446 of aquatic impacts annually, which is $9 per GWh of electricity produced. These aquatic impact values can be compared to the current residential rates for electricity in BC of $62,700/GWh (Step 1 rate) and $87,800/GWh (Step 2 rate). In both cases, the value of the aquatic effects is minimal compared to the value of the electricity produced. The aquatic effects of Site C represent approximately 0.5% of the Step 1 rate, and the aquatic effects of the UHWPP represent approximately 0.01% of the Step 1 rate.

One caveat is that my study assumes that a GWh is simply a GWh, which does not wholly reflect the reality of the electricity market. Site C does have one major advantage over the UHWPP: it is firm power. Firm power means that Site C produces electricity on demand whereas the UHWPP electricity generation is subject to the natural stream fluctuations. Because of the multi-year storage in the Williston Reservoir, BC Hydro can change the energy generated by the Peace River system on an as-needed basis. Within a certain authorized range, BC Hydro can adjust the water being discharged from the Williston Reservoir to meet the BC Hydro grid's load and that means generation can be increased during peak demand times.

While not taken into account in my study firm vs. non-firm electricity is an important consideration in meeting customer demand and for BC Hydro's operations. To be reflective of BC Hydro's planning requirements, future studies would need to consider the differences between the firm and non-firm electricity supplied by the case study projects. The consequence of relying on non-firm energy is that BC Hydro may be obliged to purchase electricity from the energy market if production does not meet demand. One way that this energy shortfall could be taken into consideration would be in the overall CBA of the different project options. The projected electricity generation could be calculated for a number of different hydrologic scenarios, and then the projected electricity shortfall under that scenario could be determined. The cost of meeting this projected electricity shortfall through electricity purchases could then be integrated into the overall CBA.

Site Specific Nature

Gagnon *et al.* (2002) caution readers about the highly site-specific nature of hydropower. As previously mentioned, there is no such thing as a standard hydroelectric project and the case study sites selected will affect the results of the study. Due to the site-specific nature of hydroelectric effects, it is difficult to extrapolate my study results to hydroelectric projects in general.

Site C has one particularly unique characteristic that reduces its aquatic impacts in relation to other large hydroelectric projects. Its location downstream of the W.A.C. Bennett Dam, which controls flows in the Peace River, allows the Site C generating station to operate as a run-of-river plant and maximizes its generation to reservoir area ratio. This configuration means that many of the negative aquatic effects typically associated with large storage-type projects are not a concern with the Site C project. For example, the fact that Site C does not incrementally affect Peace River flows eliminates one of the main concerns associated with large hydroelectric projects. Similarly, Site C's run-of-river configuration limits the water level fluctuations in the reservoir thereby allowing a littoral area to form that is more similar to a natural lake littoral area than many other hydroelectric projects. The relatively small reservoir volume, which leads to a short flushing period, also eliminates some of the water quality issues often associated with large hydroelectric projects.

If my study had used the W.A.C Bennett Dam and G.M. Shrum Generating Station as the case study, there would have been far more aquatic impacts associated with the project. The multi-year storage contained in the Williston Reservoir due to the flow control at the W.A.C. Bennett Dam has changed the natural flow regime in the Peace River. The large reservoir area and 143,000 ha of forested area that was flooded (Baker *et al.* 2000) also means that issues such as methyl mercury formation, CO_2 formation, and nutrient retention would need to be examined carefully. The extensive drawdown on Williston Reservoir makes the reservoir's littoral area far less productive than a natural lake's littoral area. However, the W.A.C. Bennett Dam does generate an extensive amount of electricity and its flow control vastly increases the electricity that can be produced at the downstream Peace Canyon Generating Station and at Site C.

The UHWPP demonstrates that, with appropriate mitigation measures, the aquatic effects of small hydroelectric projects can be minimized. The lack of aquatic effects at the UHWPP is partially as a result of the plants being run-of-river plants, which means that they only affect the streamflow regime within the diversion reach. The lack of a sizeable reservoir is also very helpful in reducing the aquatic impacts associated with small run-of-river plants in general.

However, the aquatic effects of small plants are also highly dependent on the plant location and the characteristics of the creek that is being diverted. As such, the case study site that I selected has the potential to impact the study results. For example, if I had selected small hydro projects located on salmon bearing streams[18], it would have increased the aquatic effects associated with the small hydro projects. Small hydroelectric projects located near major population centres would also have the potential to have much larger aquatic effects due to the larger population willing to pay to protect the aquatic life.

Cumulative Effects

In my study, I divide the value of the aquatic effects by the amount of electricity produced to get an intensity of aquatic effects. If the value of the intensity of aquatic effects for a small hydro project is scaled up to determine the value of aquatic effects for multiple small hydro projects in one area, a key concept is missed: cumulative effects. One of the worries associated with multiple small hydro projects is that the effects may not be additive. There may be considerably more effects associated with a project that is added to a basin already containing hydro projects than are associated with the first hydro project in the area. My study does not address the issues associated with cumulative effects of small hydro projects; however, it is an extremely important issue that should be addressed in future research.

Indirect Aquatic Effects

I limited my study to direct aquatic effects; however, the potential also exists for indirect aquatic effects. For example, the construction of roads, borrow areas and spoil areas, which are all terrestrial effects, can lead to increased sediment input to streams. Anderson and Potts (1987) found that in the first year following forestry road construction suspended sediment yields increased 7.7 fold. If sediment is introduced into a stream in high enough concentrations, the sediment can be detrimental to aquatic life and its habitat. Some of the effects of high suspended sediment loads include a reduction in primary productivity, changes in channel morphology, a reduction of habitat available for benthic invertebrates and a decline in the quality of fish spawning habitat (Wood and Armitage 1997).

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[18] Salmon have access to very short sections of the Tipella Creek and Upper Fire Creek Plants' diversion reaches, 100 m and 50 m respectively, but are not the species of primary concern in either case.

The input of sediment to watercourses can be partially mitigated by following best management practices during construction; however, it is unlikely that the potential effects could be completely mitigated. Since there will be clearing and some road construction associated with both Site C and the UHWPP, I would expect that both projects would have indirect effects on the aquatic environment. These effects would need to be taken into consideration in an overall CBA.

Non-Aquatic Effects

Although limiting the scope of my study to the aquatic effects of the case study sites made it an appropriate size for a research project, limiting the scope also forced me to ignore many of the impacts associated with hydro projects (both large and small). My study did not consider terrestrial, socio-economic, First Nations or heritage effects. All of these impacts have the potential to be as important as the aquatic effects considered in my study. Limiting the scope of my study to aquatic effects is not intended to minimize the importance of the other types of effects but simply to maintain a reasonable scope.

Terrestrial effects can include impacts to both wildlife and vegetation. Hydroelectric development necessitates vegetation clearing; this clearing can be significant both in terms of the vegetation itself and the wildlife habitat that it provides. The impacts are highly site specific and can be reduced through project siting (e.g., locating the project within a recently logged area and using existing infrastructure). In particular, concerns have also been raised regarding the networks of powerlines and access roads that can be associated with clusters of small hydroelectric projects.

There are large socio-economic effects associated with all major construction projects. These effects can have a positive impact on the surrounding community. For example, according to BC Hydro (2010f):

> "the creation of Site C will provide economic benefits for northern B.C., First Nations and the entire province. The project is estimated to create 7,650 person-years of direct construction employment during the construction period and up to 35,000 direct and indirect jobs through all stages of the project."

However, there can also be negative socio-economic effects associated with hydroelectric development, particularly projects with large reservoirs. The newspaper article "BC Geographers Link Big Dams with Topocide" (Northeast News 2009) describes the loss of a place and sense of place as a result of construction of large dams and the resulting irreparable changes to the landscape. According to Windsor and McVey (2005), First Nations people are particularly affected by hydroelectric projects because of the intimate relationship between them and their ancestral lands.

Hydroelectric developments can have a particularly profound impact on First Nations. These impacts can be to rights and title as well as to traditional rights such as hunting and fishing. An example of such an impact is the displacement of the Cheslatta T'En (Carrier First Nations) from their homes and traditional territory during the construction of the Kenney Dam and Nechako Reservoir by Alcan in the 1950s (Windsor and McVey 2005).

Constructing any large project can also result in the destruction of heritage sites. To a certain extent, heritage effects can be mitigated through siting of the project; however, with large projects this may not be possible. For example, BC Hydro has identified four types of heritage resources that could be impacted by construction of the Site C project: historic sites, prehistoric (archaeology) sites, paleontologic (fossil-bearing) sites and ethnographic sites (BC Hydro 2009a).

Data Sources

One of the biggest difficulties associated with my study was finding relevant valuation studies to apply to the aquatic effects of each project. None of the WTP studies that I used in my research was from British Columbia (or even from Canada). Due to the lack of Canadian data, I was obliged to use WTP data that was collected in the United States for very different ecosystems than those in my study. For example, the Collins *et al.* (2005) study that I used to assign a non-use value to aquatic life was conducted for a creek in West Virginia.

Where data from British Columbia was available, it was very outdated. For example, the "Outdoor Recreation Survey 1989/90" (BC Ministry of Forests 1991) is the most recent data available relating to the use value of Crown land in British Columbia, and it is more than

20 years old. When I compared this data to more recent studies from the United States, I found that using the data from the BC Ministry of Forests (1991) may severely underestimate the use value of Crown land in the province.

Using old data in combination with data from other parts of the country has undoubtedly introduced uncertainties in the valuation of the aquatic effects (as demonstrated in Section 6.1.5). To better understand the province's options with respect to electricity production, researchers need access to relevant, up-to-date data.

6.3 Policy Implications

In the past decade, a number of controversial decisions have been made concerning BC energy policy. The first such decision, in 2002, was to limit the construction of new energy projects to the private sector. This decision led to the proliferation of water licences for small hydro projects across BC and raised concerns surrounding the cumulative effects of such projects. Then, the 2007 Energy Plan mandated BC Hydro to renew investigations of Site C. Site C would be the first large hydro project built in BC in more than 25 years; it has been divisive because of the scope of the project and the magnitude of the impacts. Most recently, the *Clean Energy Act* was passed in June 2010; it allows BC Hydro to pursue energy exporting opportunities. My study is a step towards informing these contentious decisions. Further studies regarding the other impacts (e.g., terrestrial and cultural effects) of different types of energy projects would provide additional information on these decisions from another perspective.

With regards to the aquatic effects of small hydro projects and how these effects compare to the proposed Site C project, my study showed that the UHWPP has less effect on the aquatic environment per GWh of electricity produced than Site C. If the aquatic effects were the only consideration in deciding what form of new hydro projects to build, the UHWPP is the clear winner. However, as previously discussed, there are large uncertainties associated with the data that I used for my study. In addition, there are other factors (e.g., firm vs. non-firm) energy that can influence a utility's preference for different electricity sources.

When dealing with public policy, the issues are never simple. The main criticism of small hydroelectric projects is that they are privately owned whereas all of BC Hydro's heritage assets are publicly owned. The ownership issue often gets mixed up with the environmental issues during public debates on electricity policy. Before any truthful discussions can occur, the environmental effects and the question of ownership must be separated into two distinct debates.

Despite the fact that many industrial activities in Canada (e.g., logging and mining) focus on the export market, the idea of constructing energy projects intended for the export market has been very controversial in British Columbia. BC Hydro is heavily involved in the energy trading market through their subsidiary, Powerex Corp., but until recently, it was not mandated to pursue energy exporting opportunities. My study is a first step in deciding whether building power projects for energy export is a socially desirable choice. By understanding the full social costs and benefits associated with producing electricity, regulators would be in a better position to determine whether the benefits outweigh the costs and whether this part of the *Clean Energy Act* is socially desirable.

Another policy implication of my study is that it could be used to help set electricity prices that are more reflective of the true social costs of energy production. Currently, BC Hydro electricity prices are regulated by the BCUC. To request an increase in their electricity rates, BC Hydro must submit a request to the BCUC demonstrating their revenue requirements for the upcoming fiscal year (e.g., BC Hydro 2010g). Since electricity rates are based on BC Hydro's operations, these rates do not reflect the true social costs and thus consumers' electricity usage is not socially optimal. BC Hydro has large heritage hydro projects (e.g., the Peace and Columbia systems) that produce inexpensive electricity and keep electricity rates in BC artificially low. These low rates lead to a greater electricity demand than is socially optimal. If the BCUC were to consider the social and environmental costs associated with energy development when setting electricity rates, the rates would be more reflective of the true social costs and therefore consumers' energy consumption would be closer to optimal.

6.4 Conclusions

Without energy conservation initiatives, B.C.'s electricity shortfall in 20 years is expected to be approximately 25,800 GWh/year (BC Hydro 2009a). BC Hydro has a target of meeting 9,900 GWh/year of this demand through energy conservation, which leaves a shortfall of

15,900 GWh annually. According to BC Hydro (2002), the BC mainland has the potential for about 2,450 MW (10,700 GWh/year) of small hydroelectric development. Small hydro projects alone cannot meet BC's electricity demand; however, the large amount of small hydro potential means that it, along with other electricity sources (e.g., wind power), could play an important role in fulfilling BC's electricity demand. My study looked to inform the decisions that policy makers will need to make regarding the best ways to meet British Columbia's energy demands. One of the main findings of my study was that before the aquatic effects of different energy sources can truly be evaluated more up-to-date British Columbia specific data is required.

Using the available data, my study showed that the UHWPP has much less effect on the aquatic environment than Site C. The aquatic effects associated with Site C are at the ecosystem level (e.g., changes to fish species composition) whereas the aquatic effects associated with the UHWPP are more localized. However, Site C does have one distinct advantage over small hydro projects (and wind power). Site C would produce firm power, which is typical of large hydroelectric projects. Firm power means that it is available on demand rather than being subject to natural streamflow variations. According to BC Hydro (2009a), Site C has the unique characteristics of "high energy capability, high capacity and excellent flexibility". These attributes make it a very attractive option for meeting BC's increasing electricity demand.

In deciding whether to proceed with the construction of Site C or to pursue more small hydro development, regulators will need to determine whether the requirement for firm power is sufficient to justify the construction of Site C. It may be possible for BC Hydro to do a risk analysis and accept the inherent risk that if it uses less dependable (non-firm) sources of electricity it may end up purchasing electricity during low water years. If BC Hydro can accept the risk of having to purchase electricity during low water years, it will be able to capitalize on the lower aquatic impacts associated with small hydro projects.

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APPENDICES

Appendix A

Site C would be BC Hydro's third hydroelectric facility on the Peace River. It would be located downstream of the W.A.C. Bennett Dam and the Peace Canyon Dam, and it would take advantage of the water stored in Williston Reservoir and the regulation of flows at the W.A.C. Bennett Dam.

The configuration of the Site C plant, as it is currently proposed, is described below. All information on the project design is taken from BC Hydro (2007b) and is subject to review during Stage 4 (detailed design) of the development process. As currently conceived, the Site C project would include an earthfill dam, spillways, power intakes, penstocks and a powerhouse.

The zoned earthfill dam will be 60 m high and approximately 1,120 m long. The gated spillways will be located adjacent to the earthfill dam and will have a concrete lined chute that leads to submerged energy dissipaters. Due to the upstream flow regulation at the W.A.C. Bennett Dam and flood forecasting, BC Hydro expects that the spillways will rarely be operated.

The power intake will be located adjacent to the spillways on the south bank of the Peace River; it will be 400 m long and 45 m high. The power intake will have six separately gated openings that each lead to a 9.35 m diameter penstock. The water in the penstocks will drive six Francis turbine/generator units each with a capacity of 150 MW (total of 900 MW). Electricity will be delivered to the Peace Canyon generating station via two new 500 kV transmission lines that would be built within an existing BC Hydro right-of-way.

The reservoir created by the Site C dam would have a normal operating level of 461.8 m (BC Hydro 1980). Since the majority of the flow control on the Peace River will be done using Williston Reservoir at the W.A.C. Bennett Dam, the fluctuations in the water level of the Site C reservoir would be small (approximately 0.6 m to 1 m). At normal operating level, the reservoir would have a surface area of about 9440 ha, approximately 4840 ha (51.3%) of which would be within the existing river channel. To form the reservoir approximately 3560 ha of tree-covered land would be inundated.

Appendix B

The UHWPP will involve the construction of the five plants as well as the associated infrastructure including access roads and transmission lines. Overall, a total of 134 ha of land will be cleared for the project. Of the land cleared, 116 ha will be replanted with native vegetation. The UHWPP will require 52 km of wood-pole transmission line. Of this, approximately 47 km will be installed within or adjacent to existing road or powerline right-of-ways and approximately 6 km of new rights-of-way will be required. 3 km of new access roads from existing main forestry roads to access the intake or powerhouse sites, and upgrades to 12 km of existing roads. Total length of permanent new linear rights-of-way (roads, penstocks and powerline) for all facilities will be approximately 11 km. The UHWPP interconnects to the existing BC Hydro 360 kV transmission line that runs between Bridge River and Rosedale.

Tipella Creek Plant

The Tipella Creek Plant is located on Tipella Creek, a tributary to the Lillooet River. The 16.7 MW plant includes an intake structure, 2.3 km long penstock and a powerhouse containing two Pelton turbines.

The Tipella Creek Plant intake is a Coanda screen-type intake incorporated into a 30 m long ogee crest weir. Water flows over the weir and Coanda wedge-wire screen, where it falls into the collection box. Water from the collection box will flow into a deep drop box. The drop box includes an outlet pipe that will discharge the minimum instream flow release into Tipella Creek downstream of the intake.

From the drop box, water enters the penstock. The penstock is 2348 m long and is made up of high-density polyethylene (HDPE) and steel pipe ranging from 1.7 to 1.1 m in diameter.

The plant powerhouse will be a steel building on a concrete foundation. The powerhouse will contain the two vertical Pelton turbines each coupled to a generator. A rip-rap lined tailrace will deliver diverted flows back into Tipella Creek.

Upper Fire Creek Plant

The Upper Fire Creek Plant is located on Fire Creek, a tributary to the Lillooet River. The 6.0 MW plant includes a lake intake, 2.1 km long penstock and powerhouse.

The intake for the Upper Fire Creek Plant is located on Fire Lake. A screened sump was installed on the lake bed of Fire Lake. A siphon-type intake lifts water out of the sump and into the 2100 m long steel and HDPE penstock that varies from 1.0 m to 0.5 m in diameter.

The plant powerhouse is a steel building on a concrete foundation. The powerhouse will house the single 6.0 MW Pelton turbine and generator. A rip-rap lined tailrace delivers the diverted flows back into Fire Creek.

Lamont Creek Plant

The Lamont Creek Plant is located on Lamont Creek, a tributary to the Stave River. The 28 MW plant includes an intake, 3.3 km long penstock and powerhouse.

The intake for the Lamont Creek Plant is located at a split in the creek and includes two separate weirs. The concrete intake channel (desilting basin), sluiceway and overflow weir are located on the right branch of the creek, and a concrete overflow weir is located on the left creek branch. Water will enter the sluiceway through submerged rectangular orifices and then pass from the sluiceway through a trashrack into the desilting basin. The sluiceway will incorporate a sluice gate to pass sediment and other debris around the weir. The desilting basin will incorporate an outflow pipe that will discharge the instream flow release and sediment into Lamont Creek downstream of the intake. Water will pass from the desilting basin into the penstock. The Lamont Creek Plant penstock is 3378 m long and made of steel pipe varying in diameter from 1.9 to 1.1 m.

The plant powerhouse will be a steel building on a concrete foundation. The powerhouse will house two 14.0 MW vertical Pelton turbines each coupled to a generator. The diverted water will re-enter Lamont Creek through a concrete box culvert.

Upper Stave River Plant

The Upper Stave River Plant will be located on the Stave River approximately 19 km upstream of Stave Lake. The 33.5 MW plant will include an intake, 1.8 km long penstock and powerhouse.

The Upper Stave River Plant intake will include a concrete overflow weir, sluiceway and intake channel (desilting basin). The intake configuration is similar to the Lamont Creek Plant. From the desilting basin, water will enter the 1891 m long HDPE and steel penstock that varies from 3.6 to 2.7 m in diameter.

The Upper Stave River Plant powerhouse will be a steel building located on a concrete foundation. It will house three 11.2 MW Francis turbines each coupled with a generator. Diverted flows will re-enter the Stave River through a rip-rap lined channel.

Northwest Stave River Plant

The Northwest Stave River Plant will be located on the Stave River approximately 30 km upstream of Stave Lake. The 18.1 MW plant will include an intake, 1.3 km long penstock and powerhouse.

The Northwest Stave River Plant intake will include a concrete overflow weir, sluiceway and intake channel (desilting basin). The intake configuration is similar to the Lamont Creek Plant and Upper Stave River Plant. From the desilting basin, water will enter the 1318 m long HDPE and steel penstock, which varies from 3.2 to 2.7 m in diameter.

The Northwest Stave River Plant powerhouse will be a steel building on a concrete foundation. It will house three 6.0 MW Francis turbines each coupled with a generator. Diverted flows will be returned to the Stave River through a rip-rap lined tailrace.

Appendix C

List of Parameters

Discount Rate	8%
Site C	
Project Capacity (MW)	900
Annual Electricity Generation (GWh)	4,600
Number of Affected Households	28,062
CO_2 Emissions (tonnes)	32,000
Value of CO_2 Emissions ($/tonne)	$17.73
Use Value of Fish ($)	$4,712.25
Non-Use Value of Fish ($/household)	$30.00
Value of Riparian Veg ($/ha/household)	$0.04
Value of Riparian Veg ($/household)	$2.69
UHWPP	
Project Capacity (MW)	102
Annual Electricity Generation (GWh)	376
Number of Affected Households	16,769
Value of Riparian Veg ($/ha/household)	$0.04
Value of Riparian Veg ($/household)	$ 0.21

Aquatic Effects Summary

	Site C	UHWPP
Total Present Value of Aquatic Effects	$17,607,145	$41,089
Value of Aquatic Effects per GWh	$321	$9

Aquatic Effects

		Site C				UHWPP
	Year	Fish: Use Value	Fish: Non-Use Value	Carbon Dioxide	Riparian Vegetation	Riparian Vegetation
1	2009	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
2	2010	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
3	2011	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
4	2012	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
5	2013	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
6	2014	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
7	2015	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
8	2016	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
9	2017	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
10	2018	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
11	2019	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
12	2020	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
13	2021	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
14	2022	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
15	2023	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
16	2024	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
17	2025	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
18	2026	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
19	2027	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
20	2028	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
21	2029	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
22	2030	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
23	2031	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
24	2032	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
25	2033	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
26	2034	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
27	2035	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
28	2036	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69
29	2037	$4,712.25	$841,860.00	$567,360.00	$ 75,454.23	$3,445.69

		Site C				UHWPP
	Year	**Fish: Use Value**	**Fish: Non-Use Value**	**Carbon Dioxide**	**Riparian Vegetation**	**Riparian Vegetation**
30	2038	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
31	2039	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
32	2040	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
33	2041	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
34	2042	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
35	2043	$4,712.25	$841,860.00	$567,360.00	$75,454.23	$3,445.69
36	2044	$4,712.25	$841,860.00	-	$75,454.23	$3,445.69
37	2045	$4,712.25	$841,860.00	-	$75,454.23	$3,445.69
38	2046	$4,712.25	$841,860.00	-	$75,454.23	$3,445.69
39	2047	$4,712.25	$841,860.00	-	$75,454.23	3,445.69
40	2048	$4,712.25	$841,860.00	-	$75,454.23	$3,445.69
Present Value		**$56,191.76**	**$10,038,854.98**	**$6,612,335.82**	**$899,762.49**	**$41,088.57**