Climate Change Implications for the Operation of Called Upon Flood Control in the Columbia River Basin

by

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Abstract

Negotiated over 60 years ago and ratified in 1964, the Columbia River Treaty (CRT or "the Treaty"), is often looked to as the standard for cross-jurisdictional water management. A crucial aspect of the Treaty is the governance of water flows to minimize downstream flooding. Climate change directly impacts the hydrology of the Columbia River, which has implications for activities such as power generation and flood control management. The Treaty needs to be modernized to incorporate the effects of climate change. Current discussions between Canada and the United States over the Treaty provide an opportunity to incorporate potential impacts of climate change on measures Canada could be asked to take to reduce downstream flooding. This study looks at the effects of climate change on flood risk within the Columbia River Basin and analyzes the costs and benefits associated with the operation of a provision in the current treaty known as ‘Called Upon’ flood control. This study then presents the information that may be helpful for the Canadian Entity to frame negotiation options given the potential impacts of climate change.

Keywords: Climate change; flood control; Columbia River Treaty; adaptation; hydroelectricity generation

Dedication

To my parents, without whom I would not be where I am today.

To my friends who listened to me complain listlessly about life.

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I would like to express my gratitude for Dr. Nancy Olewiler, whose guidance and support made the completion of this capstone possible.

My friends in the MPP program who helped me along the way and made this two year journey together. EC, you've been amazing and I could not possibly have done this without you, I am extremely honored and grateful to be your friend.

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List of Acronyms

AOP	Assured Operating Plan
APFC	Assured Primary Flood Control
BAU	Business as Usual
BC	British Columbia
CBIP	Columbia Basin Irrigation Project
CFS	Cubic Feet per Second
CRB	Columbia River Basin
CRT	Columbia River Treaty
CUFC	Called Upon Flood Control
EG&S	Environmental Goods and Services
FCOP	Flood Control Operating Plan
GCM	Global Circulation Model
IPCC	International Panel on Climate Change
KCFS	Thousand Cubic Feet per Second
MAF	Million Acre Feet
MW	Megawatt
MWh	Megawatt Hour
PEB	Permanent Engineering Board
SFU	Simon Fraser University
SWE	Snow Water Equivalent
PCIC	Pacific Climate Impacts Consortium
TEV	Total Economic Value
US	United States
USACE	United States Army Corps of Engineers
WTP	Willingness to Pay

Glossary

Benefit Transfer	Method often used to estimate the value of an ecosystem good or services (EG&S). It aims to estimate the benefits for one EG&S by adapting an estimate of benefits from another, often similar, EG&S.
Million acre feet	Unit of measurement. 1 Maf of water equals approximately the volume of water held in 11 Olympic-sized swimming pools.
Snow Water Equivalent	Measurement of how much water is present within a snowpack. Available water is the amount of water that would be released if the snow pack melts.

Executive Summary

Our climate is changing and the weight of scientific evidence is that the ever rising levels of greenhouse gases from human activity are the major cause. Climate change will affect all aspects of our lives, from increasing temperatures and extreme weather events to the security of everyday life and the availability of food. In an age of rapid globalization, the solution to minimizing the impacts of climate change will stem from countries working with each other. Cross-jurisdictional cooperation is vital if the effects of climate change are to be addressed effectively and efficiently.

Such an opportunity for international cooperation presents itself in the case of the Columbia River Treaty renegotiation between the United States and Canada. Policy-makers must find a way to incorporate climate change into the negotiations of the Treaty. Important in their deliberation is an assessment of the trade-offs between acting to minimize the negative impacts of climate change and the full cost of doing so.

Within the scope of this study, the analysis focuses on the flood control mechanisms outlined within the Treaty. The current mechanisms outlined in the Treaty do not detail how flood control operations will continue post 2024. As a result, the specifics of flood control post 2024 will need to be negotiated between the two Entities. This study analyzes the options for negotiation of the flood control objective to be set in the Treaty, as well as how compensation would work as Canada provides the US with flood control benefits. Included in the analysis is also a qualitative description of the distribution of the incremental costs and benefits across the Canadian-US border.

The study finds that the re-negotiation of the Treaty must define in clear terms the operational procedures of the Treaty, including aspects such as what the flood management objective is, when a Called Upon request can be made, and what denotes the start of a Called Upon action in Canada. Called Upon Flood Control (CUFC) is a form of flood control wherein the US Entity may call on Canada to provide flood management storages should conditions be met.

The analysis shows that in terms of flood control benefits directly resulting from CUFC, the US receives benefits valued between approximately $2.1 billion to $14 billion in the 50 year period between 2024 and 2074.

With the added effects of climate change, it is expected that the Columbia River would see an increase of water flow between 3% and 19%. The incremental benefits that the US would obtain from flood control in Canada at a level of 600 cubic feet per second (kcfs) to a more stringent level of 450 kcfs (as measured at the Dalles) ranges from a low of $63 million to a high $1.18 billion over the period 2024 to 2074. This estimate includes avoided direct costs that have market-determined prices. When indirect costs arising from externalities whose prices have to be imputed are included, there would be an additional $24 million to $0.23 billion in avoided costs providing benefits to people and property in the US portion of the Columbia River Basin. In general, having the flood control objective at the Dalles to be more stringent brings about larger benefits to the US, while a more relaxed flood control objective brings fewer benefits.

The Entities must clarify the compensation models to be used for Called Upon management. This includes detailing the components of the compensation as well as how the compensation is to be calculated. The analysis shows that the potential values of ecosystem goods and services is quite large in the Columbia River Basin and the exclusion of these values when calculating compensation for Canada could result in significant losses for Canadians.

It has become clear in the course of this study that both the United States and Canada need to better understand climate change and ecosystem services within the Basin. This includes continued facilitation of information access as well as continued support of academic and engineering studies of the implications of climate change in the Basin. In addition, more information is needed on the interconnectedness of ecosystem services within the Basin in order to fully understand how they are affected by climate change. Both countries also need to continue to monitor and document the hydrology of the Columbia River, as well as make clear any reasoning behind decisions made on the operation of the Treaty.

Chapter 1.

Introduction

Our climate is changing and the weight of scientific evidence is that the ever rising levels of greenhouse gases from human activity are the major cause. Climate change will affect all aspects of our lives, from increasing temperatures and extreme weather events to the security of everyday life and the availability of food. In an age of rapid globalization, the solution to minimizing the impacts of climate change will stem from countries working with each other. Cross-jurisdictional cooperation is vital if the effects of climate change are to be addressed effectively and efficiently.

The Columbia River (or "the River") is the fourth largest river in North America. While its mountainous origins and numerous tributaries make the river ideal for hydropower production, the same factors exposes the Columbia River, especially the lower Columbia, to higher risks of flooding.

15% of the Columbia River Basin (CRB or the Basin) lies in Canada, all of which is located in British Columbia (BC Ministry of Energy and Mines, June 25, 2013). The remaining 85% of the CRB is located in the United States spread across seven states (Osborn, 2012). Although Canada only accounts for 15% of the CRB, Canadian water accounts for 38% of the average annual flow volume, and up to 50% of the peak flood waters (BC Ministry of Energy and Mines, June 25, 2013). Approximately 50% of the electricity generated in British Columbia comes from the Columbia River. In addition, the River plays an important role in the traditional way of life of Aboriginal communities who live within the Basin and depend on the resources of the River. The River also offers transportation and recreational benefits to Canadians.

Negotiated over 60 years ago and ratified in 1964, the Columbia River Treaty (CRT or "the Treaty"), is often looked to as the standard for cross-jurisdictional water management. At the time of its negotiation over half a century ago, the CRT was only meant to regulate means of hydropower production and flood control between British Columbia (BC) and the US in its scope. In the 1960s when the CRT was first negotiated, there was little information available on the science of climate change. As a result, the effects of climate change on the Basin were not considered in the implementation of the Treaty. As more knowledge is being uncovered on the science of climate change in recent years, it is becoming more imperative to consider the effects of climate change on the hydrology within the Columbia River Basin and how that might affect a future treaty.

Climate change is altering the hydrology of the Basin, and will continue to do so in the next century. Both the timing of peak flow and the amount of water available for usage in the Basin has been changing, and will keep changing as climate change impacts become more pronounced. Climate change also will increase the frequency and intensity of floods in the region. The increased risks of flooding does not directly impact the Canadian portion of the Basin, but does mean significantly increased risks of flooding for the US portion of the CRB. In order to address these changes and other issues that climate change may bring to the CRB, the management of the Basin needs to be revised to reflect current knowledge.

While the CRT has no end date, it does have the option of termination for either country after 60 years when given at least 10 years advance notice. This means that the CRT can be terminated in 2024 by either party should notice be given in 2014. Consequently, 2014 provides an important opportunity for the renegotiation of. With the impending impacts of climate change, a potential renegotiation provides a good opportunity to explore the implications of climate change impacts on the CRB and what role the treaty can play in minimizing the negative effects of climate change.

1.1. The Policy Issue

The issue that policy-makers face is finding a way to incorporate climate change into the negotiations of the CRT. Important in their deliberation is an assessment of the tradeoffs between acting to minimize the negative impacts of climate change and the full cost of doing so.

Within the scope of this study, the analysis focuses on the flood control mechanisms outlined within the Treaty. The current mechanisms outlined in the Treaty do not detail how flood control operations will continue post 2024. As a result, the specifics of flood control post 2024 will need to be negotiated between the two Entities. This study analyzes the options for negotiation of the flood control objective to be set in the Treaty, as well as how compensation would work as Canada provides the US with flood control benefits. Included in the analysis is also a qualitative description of the distribution of the incremental costs and benefits across the Canadian-US border.

Chapter 2 of the capstone provides the background information on the Treaty and projected climate change impacts on the basin. Chapters 3 to 5 focus on the issue of negotiating a flood control objective that maximizes benefits for both countries. The chapters provide the method of analysis, results, and recommendations respectively. Chapters 6 to 8 focus on the issue of Canadian compensation that allows flexibility and considerations for mitigation and adaptation to climate change scenarios, these chapters are similarly structured to chapters 3 - 5. Chapter 9 details the final recommendations and next steps, and finally chapter 10 outlines the limitations of the study.

Chapter 2.

Background

2.1. Development of Successful Cross-Jurisdiction Water Management

The literature identifies a number of significant requirements for adaptive governance in complex common resource systems. In the context of the CRT, the two most important requirements are to provide information and be prepared to change (Dietz, Ostrom, & Stern, 2003).

Information that helps parties to understand resource systems is a key input for creating alternatives and developing political will for action. Due to the long time horizon of the CRT, many components are prone to changes in the future. Thus it is vital that the Treaty implement adaptive strategies that are flexible and respond to altering conditions.

In addition, one of the most significant ways to promote cooperation is to have parties pay for the services they receive, as some examples illustrate. In allocating water use in the Nile, Egypt compensates Uganda for the loss of hydroelectric power at the Owen Falls Dam, so the dam could operate to benefit flows in lower Nile for Egyptian irrigation (Grzybowski, McCaffrey, & Paisley, 2010). In 2000, Kazakhstan signed an agreement in which they have agreed to reimburse a part of Kyrgyzstan's expenses for operation, maintenance, and rehabilitation of a number of dams and reservoirs located in Kyrgyzstan but that supply water to Kazakhstan.

Another aspect of a successful international Treaty is the flexibility of the mechanisms. The Colorado and Rio Grande model of management allows for significant decisions to be made by the International Boundary and Water Commission through the creation of Minutes, which have legal standing.[1] For Farakka Barrage, located across the Ganges River in India, the management strategy allows "immediate consultations to make adjustments on an emergency basis, in accordance with the principles of equity, fair play and no harm to either party" (Hearns, 2010).

2.2. The Columbia River Treaty

The Columbia River (The River) originates from the Columbia Lake in British Columbia and is a total of 1,243 miles long (Pacific Climate Impacts Consortium (PCIC), 2006). The Columbia River is the largest in the Pacific Northwest in both length and drainage area, and the fourth largest river in North America. The River's discharge rate ranges from 120,000 cubic feet per second (cfs) to 260,000 cfs, making the Columbia River one of the most powerful rivers in the world (Osborn, 2012).The mountainous origins of the River along with the tributary streams are what contributes to the Columbia River's size and power. About 15% of the basin lies in Canada, all of which is located in British Columbia (BC Ministry of Energy and Mines, June 25, 2013). The remaining 85% of the CRB is located in the United States spread across seven states (Osborn, 2012). Although Canada only accounts for 15% of the CRB, Canadian water accounts for 38% of the average annual flow volume, and up to 50% of the peak flood waters (BC Ministry of Energy and Mines, June 25, 2013).

The Columbia River is ideal for hydropower development due to the elevation of the River's origin, its size, and its power. The average annual generation of hydroelectricity within the CRB has been 16,500 megawatts (MW), though the basin has a total of 36,400 MW of installed hydropower generation capacity over 214 hectares (Payne et al., 2004). The same reasons that make the Basin ideal for hydropower make it flood prone due to the river’s high volatility of flow volume during the year (Osborn, 2012).

[1] See Article 25 of the Treaty between the United States of America and Mexico relating to the utilization of the Waters of the Colorado and Tijuana Rivers and of the Rio Grande, signed February 3, 1944. 59 Stat. 1219; Treaty Series 994. (1944)

The Columbia River Treaty (CRT) is a treaty negotiated between the US and Canada. Ratified in 1964, the treaty optimizes flood management and power generation in the CRB through the coordinated operations and management of reservoirs and water flows. In 1963, the Canada-British Columbia Agreement allocated the rights, benefits and obligations of the Treaty to the province of BC. BC Hydro serves as the Canadian Entity responsible for managing the daily operations of the reservoirs and hydroelectric facilities in cooperation with the US Entity, which is made up of the Bonneville Power Administration and the United States Army Corps of Engineers (USACE) (US Army Corps of Engineers Northwestern Division, 2011).

Under the CRT, BC agreed to build three dams and coordinate water flows with the US, and in return received a one-time payment from the US of $64 million for 60 years of assured flood control. In accordance with Treaty provisions, BC Hydro constructed and continues to operate 15.5 million acre-feet (MAF) of reservoir storage at the Mica (7MAF), the Hugh Keenleyside (7.1 MAF), and the Duncan (1.4 MAF) projects in coordination with the US (United States Envrionmental Protection Agency, 2013). The total power generation at these facilities provides approximately 44% of the low-cost electricity that BC Hydro delivers to BC residents and businesses (Penfold, 2012).

In addition to direct power generation, BC also receives the Canadian Entitlement, which is payment based on the benefits of additional power generation potential downstream resulting from the water flow management implemented through BC reservoirs.[2] The Canadian Entitlement includes the annual delivery of 1320 MW capacity and 4540 gigawatt hours of energy to BC border over the last 10 years, which is worth $120 to $300 million annually (BC Ministry of Energy and Mines, June 25, 2013).

Under the CRT, the US receives both benefits of hydropower production and flood control. To reduce flood damage, as noted above, the US agreed to pay Canada $64.4 million for the use on an annual basis of 8.45 Maf of reservoir space for US flood management needs during the first 60 years of the Treaty. BC Hydro has estimated that the cumulative value of flood damage prevention in the Columbia River Basin has

[2] Downstream powers benefits are modeled and calculated using procedures set out in the Treaty and are defined six years in advance. They are not calculated based on actual amount of downstream power generated.

totaled nearly $32 billion, the benefits of which have been entirely on the US side of the border (BC Ministry of Energy and Mines, June 25, 2013). In 2024, assured flood control that the US receives will end and unless otherwise negotiated, the US will begin to receive and have to pay for "called-upon" flood control (CUFC). Through this process the US Entity may request additional flood storage drafts or delayed refill operations in Canada to supplement US operations and reservoir storage required to meet flood risk management needs for the duration of a flood period (US Army Corps of Engineers Northwestern Division, 2011).

2.3. Climate Change Impacts on the CRT

While the provisions in the Treaty target hydropower production and flood control, the CRT does not address a number of issues that also arise in the Basin. One of the issues that the Treaty does not take into account is the impact of climate change on hydrology within the CRB.

Between the years of 1985 and 2000, all glaciers within the CRB have experienced a net loss in area due to the increasing temperatures as a result of climate change. The average loss over this period for all glaciers in the CRB was 16%, while some have lost as much as 60% (PCIC, 2006). Annual precipitation has increased by 26%, composed of an increase of 32% in rainfall and a 6% decrease in snowfall (PCIC, 2006). Climate projection scenarios have predicted that mean temperature is expected to rise within the Basin by 1.1 to 1.3 °C by the 2020s, 2.4 to 3.0 °C by the 2050s, and 3.3 to 5.0 °C by the 2080s (PCIC, 2006).

The existing CRT's focus was on hydropower production and flood control. While management practices have changed over time, the treaty has not been updated to reflect potential impacts of climate change, or any of the advances in the understanding of hydrology, glaciations, and weather patterns. The current and forecast hydrology within the watershed due to climate change will have direct impacts on the management of the Basin. These impacts will not only affect the costs associated with implementing flood control by BC, but also the benefits of flood control received by the US. In addition, climate change will affect industries such as agriculture, recreation, and transportation.

The changes in the water storage capacity of the CRB and the timing of the runoff will have serious consequences for the competing interests of water resources between flood control, energy production, commercial navigation, agricultural production and fisheries management.

One of the main impacts of climate change for both the US and Canada is on the ability to predict future scenarios. Current modeling is based on historic data, which will no longer be valid for predictions of future hydrological events. Thus, the ultimate impact of climate change will be the loss of stationarity. The concept of stationarity applies to ecosystem functions in dynamic equilibrium fluctuating within a predictable envelope of variability, which allows modeling and predictions of future scenarios (Osborn, 2012). The "predictable envelope" is the scientific understanding of historic weather patterns. Due to climate change, however, historic weather patterns can no longer be used to predict the future.

The hydrology of the CRB is dominated by snow accumulation and melt, which is highly sensitive to temperature changes. Climate change will cause the loss of glacial mass and winter snowpack, which results in changes in the basin's hydrology. In addition, there will be seasonality shifts in water runoff associated with reduced winter snow accumulation, earlier peak snow melt, higher winter runoff, and higher evapotranspiration (Cohen, Miller, Hamlet, & Avis, 2000). River flows will peak higher and earlier in the spring, and lower and warmer river flows will occur in the summer. As a result of climate change, there will be lower stream flow during low precipitation months of summer and autumn.

The US portion of the CRB will see more water from mountains in the winter and spring months as a result of climate change, this means reduced summer flows in those tributaries.[3] As temperatures rise, precipitation in the mountains will increasingly arrive as rain instead of snow. This shift leads to decreases in snowpack accumulation. Correspondingly, there will be an increase in water supply resulting from melting glaciers for a period of years. This incremental water supply will, however, disappear once the

[3] A predictions of the increase in mean annual temperature of the US portion of the basin will increase is 6 - 7 degrees Fahrenheit by the 2090's (Osborn, 2012).

glaciers have melted and result in permanent reduction in flows of glacier-dependent rivers (Osborn, 2012). The transition from precipitation in the form of snow to rain also leads to potential increases in intensity of flood events. In addition, the combination of higher flows and increased likelihood of extreme weather events will increase the frequency of flood events in the US portion of the CRB as well as conditions for other activities taking place in the CRB such as fishery management, recreational uses, or agriculture...

In the Canadian side of the Basin, the effects of climate change are predicted to be less severe compared to those in the US, but will nonetheless have significant impacts. By 2050, temperatures in the Canadian basin may rise by up to 2.7-5 °C. The glaciers will retreat as a result of climate change, and the ice fields will have completed disappeared by 2050 (PCIC, 2006). The glacier melt will have a 2-phase impact. The first phase is the increase in water flows resulting from the melting glaciers, the second phase results in retreating glaciers and declining stream flow. Data shows that the initial phase of increased stream flow has already ended in southeastern BC (Osborn, 2012). In addition to changes in water flow, the cold water fisheries will suffer due to temperature increases of water as well as disturbances due to earlier drafting of reservoirs due to flood control requirements.

2.4. Identified barriers for adaptation to climate change within the CRB

Adaptation to climate change means preparing and responding at the local level to potential impacts due to climate change. Adaptation in the CRB means that the community has to be prepared for a future that is different from the past experiences of the region. The activities necessary for climate change adaptation differs between various communities and regions. Adaptation activities can include enhancing sustainable practices and standards in the region, building capacity or upgrading existing infrastructure to accommodate climate change impacts on weather.

There are only a handful of other cross-boundary water management treaties, and none are quite to the scale of the Columba River Treaty. This is mainly due to the complexity of the development, negotiation and implementation of a Treaty of such a scale, which poses significant barriers for many jurisdictions. In fact, most of the world's 263 international basins lack any type of joint management structure, and certain fundamental management components are noticeably absent from many of those that do (Giordano & Wolf, 2003) (Wolf, Stahl, & Macomber, 2003). The CRT has been successfully operated for the last 60 years, which demonstrates the effectiveness of the original Treaty. However, as we now uncover more information about climate change, it is important for the Treaty to be updated to reflect the new knowledge we have regarding climate science and potential future scenarios.

This section of the chapter identifies the main barriers for the CRB to adapt to climate change successfully. While the policies options may have certain qualities that address some of these issues, the barriers listed in this section are more applicable to the policy implementation stage.

2.4.1. Inertia prevents movement away from the status quo

Due to the size of organizations involved in dealing with the CRT, such as the BC Hydro, the USACE, the Columbia River Trust, etc., there may be inertia when trying to implement changes to the status quo. All implementation of policy should keep in mind that changes will take time to occur when dealing with large organizations (IPCC, 2014).

In addition, the development of the Columbia River emphasized the need for collection of data prior to any agreement, setting the stage for more efficient hydrological planning and laying the foundations for continued cooperation in data exchange (Paisley & Hearns, 2006). However, acquiring the data takes time and significant effort, and the overall process may be slow due to inherent inertia and resistance to change.

2.4.2. Legal and political considerations may limit the range of adaptation options

The CRT has warranted much media scrutiny, and both the US and Canadian Entities have opened up channels for the public to comment on the Treaty re-negotiation (U.S. Entities, 2013). Because of the economic and social diversity of the Columbia River Basin, there may be many political considerations that will limit the options available. In addition, the legal framework of the existing Treaty may also limit the range of options that can be considered.

For example, the existing Treaty only deals with the power generation and flood management. These two areas only reflect a portion of what management of the Columbia River can impact. Fishery management is an important economic activity within the CRB, and is directly dependent on the hydrological flows of the Columbia River and will be impacted by the effects of climate change (Government of British Columbia, 2012). Yet the current Treaty does not have the scope to fully address this issue. Similarly, the Treaty does not have the capacity in its current state to deal with agricultural water needs, which is another significant source of economic productivity within the CRB.

2.4.3. Jurisdictional conflicts may hinder due to various agencies having differing mandates and mission statements

The US Entities and the Canadian Entity have different mandates in terms of who their stakeholders are and what their scope of analysis is. This could result in different objectives in terms of adaptation priority and adaptation policy. The re-negotiation process is one in which these differences may be resolved, but the jurisdictional differences could potentially result in friction as policies are implemented.

2.4.4. Upfront cost versus future benefits may not be recovered

Climate change impacts are based on forecasts that give rise to differing scenarios of what could happen, so the net impact on each country under different treaty obligations is highly uncertain. In addition, some of the adaptation policies may involve upfront costs that need to implemented now in order to realize any future benefits at all. The uncertainties attached with the analysis may discourage adaptation from being carried out (Lane, Cohen, Murdock, & Eckstrand, 2011).

2.5. Flood Control in the CRT

The Columbia River system is comprised of both run-of-river and storage reservoirs that are authorized or licensed for multiple purposes, including power generation, flood control, navigation, irrigation, recreation, and fish operations. Run-of-river reservoirs have very limited storage and therefore simply pass inflows through the hydroelectric project by generating power or by spilling. Storage reservoirs can accommodate significant changes in inflow volume, which can be utilized to modify the timing and quantity of runoff through the river system. While many dams and reservoirs in the system provide some contribution, the core of the system flood risk management in the Columbia River Basin is formed by seven U.S. storage reservoirs (Libby, Hungry Horse, Dworshak, Brownlee, Kerr, Albeni Falls, and Grand Coulee) and the three Canadian Treaty projects (Arrow, Mica, and Duncan).

Under the Treaty provisions, Canadian reservoirs can only be requested by the US Entities for storage if the US reservoirs do not have the ability or effectiveness to manage flooding risks. This means first it is important to establish which US reservoirs can be considered effective. Following the Treaty terms, it can be established that in order to be considered a flood control facility, a project or reservoir must be authorized by the US government for system flood control in the CRB, and it must be effective at reducing the flow at the Dalles during a flood event. Table 1 below breaks down the various types of US projects in the Columbia Basin and the storage space offered by each type[4]. Table 2 offers a summary of the Canadian storage types and capacity that offer system flood control.

One of the main benefits that the Treaty offers is downstream flood control through reservoir management. However, the current practice will end on September 16th, 2024 and regardless of the whether the Treaty is continued, the Canadian flood control obligations will automatically change from a pre-determined annual operation to a "Called Upon" operation (CUFC). Thus regardless of whether the Treaty continues after 2024, the default flood control operations as set out in the Treaty will change

[4] For operational purposes, runoff of the Columbia River is usually measured at The Dalles, which is a dam located in Oregon in the US portion of the CRB.

significantly. In the called upon scenario, the US will no longer have a dedicated amount of flood storage to be used in Canada. Instead, the US Entity may request flood storage drafts or delayed refill operations in Canada to supplement flood control management operations in the U.S. This means that the U.S. can only call on Canadian for flood management if it can demonstrate that it has exhausted its own storage. Canada will be compensated by the US for any operating costs incurred by Canada and economic losses arising directly from Canada forgoing alternative uses of the storage used to provide the flood control in the US.

Even if the Treaty is terminated, Canada will continue to operate the called upon mechanism within the limits of the project sites. Canada is obligated to offer Called Upon flood control for as long as the dams built under the original CRT exist, thus regardless of Treaty termination, Called Upon flood control would be implemented. However, there is no provision in the Treaty that obligates Canada to maintain the current dams or prevent BC Hydro from reducing or eliminating storage capability should the Canadian Entities want to. In addition, if the Treaty terminates, then Canada is no longer obligated to share their power draft plans with the US, which has the potential to make coordination across the borders much more difficult.

Therefore, the termination of the Treaty would increase uncertainty. Decisions regarding how the space is acquired, the uncertainty of how it is distributed, and how Canada would be compensated for the flood risk management operations they provide will be difficult because Canadian operations could be unknown to the US and would operate independently from the US without any coordination. Thus, in the scenario that the Treaty is terminated and with no other agreements for coordination of the Columbia River operations, the US would have greater uncertainties in planning for Called Upon flood risk management requests because there may not be a Canadian power operating plan available to the US Entities.

Within the defined terms of the Treaty, the US is only able to initiate the Called Upon mechanism if potential floods in the US could not have been adequately controlled by all the related storage facilities in the US. However, it is stipulated that the US is able to call for flood control based on forecast needs or to control "potential floods". This is to say that the US Entities do not require pressing or actual occurrence of a flooding event before calling on Canadian reservoir space.

An important point to note is that under current protocols, Canada is not obligated to provide any greater degree of flood control under the Called Upon mechanism than required prior to 2024. The Permanent Engineering Board (PEB) was established by the CRT to handle such tasks as assembling flow records, assisting in settling differences that may arise between the Entities, and creating annual reports of the results being achieved.

The Called-Upon flood control calls are made only if the Canadian Entity has agreed that the US flood control facilities cannot fully meet the flood control needs in the US. The Canadian Entity will have 10 days after receiving the initial request to provide its acceptance, rejection, or modification. If the Canadian and US Entities do not agree, the PEB is consulted. The PEB may then modify or reject the original request made by the US. However, if the PEB does not give any instructions within 10 days, then the US Entity may renew the request, and the Canadian Entity must comply with the request regardless of its objections (The Governments of the United States of America and Canada, 1961).

Article VI, Sections 4 and 5 of the Treaty provides that Canada would be compensated their operating costs and economic losses for the use of Called Upon flood control operations (The Governments of the United States of America and Canada, 1961). It is also stated in the Treaty that Canada may elect to receive, in electric power, the whole or any portion of the compensation representing loss of hydroelectric power to Canada. Currently, there is no agreement between Canada and the US as to what constitutes as economic losses resulting from the operation of Called Upon flood control, nor how those losses are to be calculated.

Called Upon requests would change the reservoir levels in Canada, resulting in disturbances to planned power operations in Canada. As such, it has been outlined in the Treaty and agreed on by both countries that compensation to Canada will be necessary for this type of financial loss resulting from Called Upon requests. In order to quantify this impact, the operations for power and flood risk management would have to be optimized and the difference between the two determined to assess compensation requirements. This would largely rely on Canadian operations to provide the necessary modeling and information.

Given the layouts of the reservoirs in Canada and the US, the BC government has determined that most of the Called upon draft from the Canadian reservoirs will be drafted from Arrow reservoir. Arrow is the most effective Canadian reservoir for reducing flows because the response time from Arrow to the Dalles is shorter than that from Mica and Duncan, and because Arrow controls a much larger basin. As a result, Called Upon flood management are expected to have limited impacts on both Mica and Duncan reservoirs.

It was noted by the BC government's review that Called Upon operations would not only manage flooding in the US, but also provide incidental power benefits to the US. At the same time, the stipulation of Called Upon flood control limits the flexibility of Canadian hydro production operations.

The BC Report on the US benefits received from the Treaty stated that cumulative flood damages prevented by the CRT have totaled almost $32 billion in 2012, and these benefits fall entirely on the US side of the border (BC Ministry of Energy and Mines, June 25, 2013). However, given the change in flood management practices, the BC Government has stated that Called Upon flood control has been shown to increase the flood risk within the CRB and increase the risk of reservoirs not being able to refill, with likely negative consequences for other aspects of interest for stakeholders in the CRB such as fisheries management, ecosystem functions, power production and water supply for industries including agriculture and transportation.

2.6. Necessary structures for implementation of the CRT

In order for the CRT to continue operating smoothly, regardless of the policy options implemented, there are certain items that need to be accomplished. This section lists a number of identified best practices to ensure the smooth operation of a cross-jurisdictional water management treaty in the face of climate change.

Given the requirement of consultation between the US and Canada and the limited timeline between requests, it would be in both Entities' interest to set forth a preliminary assessment for when a request for flood storage is appropriate. An overall agreement setting forth the hydrologic and operational metrics could help outline the general conditions when a call for storage may be made. This would help the US and Canada establish a basic agreed upon approach for the consultation obligation requirement, and possibly for describing the runoff conditions when a call for storage would be made.

2.6.1. Continue to develop and improve hydrological forecasting and modeling tools

As our knowledge of climate change has greatly improved in the last 60 years, the models for hydrological forecasting and the tools that are available to analysts need to be constantly updated in order the best represent our understanding of climate change and the way it interacts with hydrology. The assumptions and models that scientists use in their forecasts are still evolving as new information is constantly being uncovered regarding

2.6.2. Incorporate better coordination between hydroelectric operations and other water projects sharing the watershed

Much of the focus of the CRT is on hydroelectricity generation. Given that the original Treaty only mandates power generation and flood risk management, it is easy for other interests to be overlooked in the process of Treaty operations. However, it is important to keep in mind that there are other activities within the watershed that needs hydrological resources just as much as hydroelectricity generation. These projects may include fishery management, transportation, recreation, or environmental conversation. Despite the projects' presences not being outlined explicitly in the Treaty, they must be considered when making decisions towards Treaty operations in order to best represent the interest of the CRB.

2.6.3. Consistent monitoring and documentation of hydrological conditions

Consistent monitoring allows analysts to make timely observations about how hydrological conditions may be changing, and provide a strong basis upon which forecasts for flood conditions may be made. Consistent documentation of hydrological conditions allows analysts to observe past trends, which would help in gaining a better understanding of the interactions between climate change and hydrological conditions.

2.6.4. Documentation of tested, retained and discarded hypotheses and management practices

Due to both the time horizon of the Treaty and the size of the organizations that are managing the Treaty, it is easy for information to get lost within vast data streams. Given that this is the case, it is important to provide clear and accurate documentation of any hypotheses and management practices that have been tested, retained, or discarded so that there is a clear flow of logic for any decisions made, and no duplication of analysis.

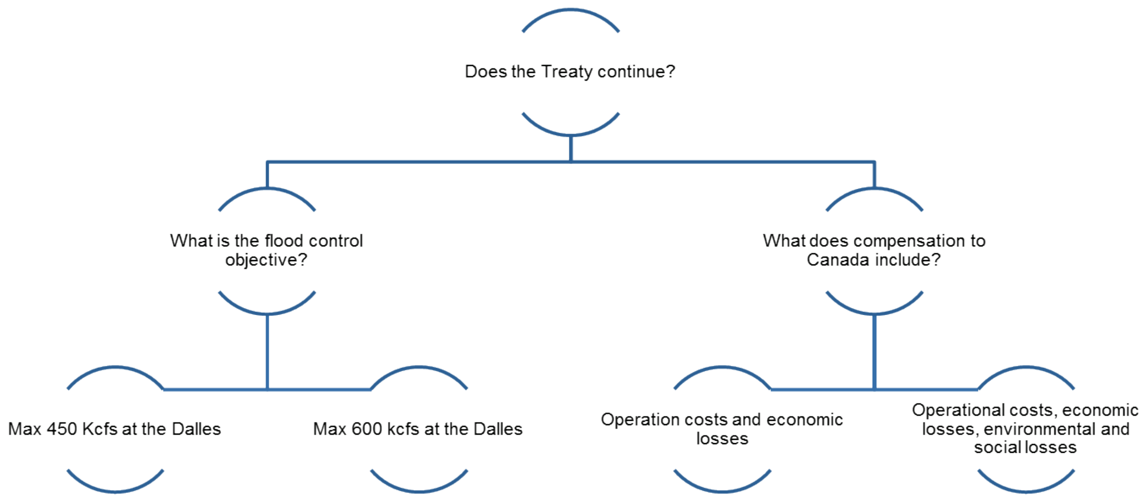
2.6.5. Clear documentation of motivation of each decision to facilitate trust and communication between stakeholder groups

Again, given the time and scope of the Treaty, there will be many stakeholder groups who would be interested in its operation and management. These groups of stakeholders may not share a level of trust among them to facilitate sound discussion and sharing of information. In addition, some of the stakeholder groups may have inherent mistrust of those managing the Treaty due to various historic reasons. The clear documentation of motivation of every decision would help in building trust between stakeholder groups by demonstrating transparency.

2.7. Decision Making Process

Due to the complex nature of the Treaty and the decision-making, there are several layers of decisions that must be made sequentially in order to determine the ultimate policy outcome. Figure 2.1 below shows the decision tree and the potential policy options given each decision.

Figure 1. Decision tree outlining policy options



One of the first policy decisions that need to be made is whether the Treaty will be terminated. Either party may choose to terminate the Treaty starting 2024, so long as they give a 10-year advanced notice. However, regardless of whether the Treaty terminates, Canada is expected to provide flood risk management for the US at the same level as is currently outlined in the Treaty (pre-2024), as the flood control is to be provided by Canada so long as the infrastructures built under the Treaty still exist regardless of the actual status of the Treaty. However, should the Treaty terminate, Canada would no longer be under obligation to share power draft plans with the US. Due to the fact that power drafts offer the US additional flood control benefits, the US has traditionally been able to take this into consideration when planning flood management operations. Should the Treaty be terminated, the US would no longer be able to take into consideration Canadian power drafts when making called-upon decisions. This increased uncertainty means the US would likely have to access Called Upon more often and with a larger magnitude.

Both the US Entities and the Canadian Entity have published documents on their positions of the Treaty. Both entities have stated that the Treaty should not be terminated, as the management of the Columbia River has brought great benefits to both the US and Canada. On BC's part, it was decided that Canada would continue the CRT and "seek improvements within existing Treaty framework" (Government of British Columbia, 2012). Correspondingly, the US Entities have published their support for the "modernization of the Treaty" (U.S. Entities, 2013).

Given this decision, the next step would be to determine what type of flood control the Entities would undertake post 2024. The currently flood management scheme of Assured Primary Flood Control (APFC) will end in 2024 as is stated in the Treaty, and will switch to Called Upon flood control. However, the Entities do have the option of negotiating a continuation of APFC if both parties are willing.

The other option would be to let flood management switch over to the Called-Upon mechanism. This would require both Entities negotiating the details of the operation, as it is something that has not been done previously. This study focuses on what would happen if CUFC is implemented, and the various tradeoffs in terms of deciding on the mechanisms of implementation of CUFC.

The major decisions that need to be made are setting the flood control objective and the method of compensation for Canada. Setting the flood control objective would clarify the occasions on which the US may invoke the use of CUFC. In addition, although the Treaty says Canada should be compensated for economic losses associated with the operation of CUFC, it does clarify how the compensation is to be calculated. These choices can be made independent of each other as one does not affect the outcome of the other.

2.8. Other Areas of Interest for the Treaty

2.8.1. Energy Production in the Basin

The hydropower capacity of the Columbia River Basin is immense. There are more than 200 hydro projects within the Basin, most located within the United States. In the Canadian portion, BC Hydro has a total of 4,620 MW production capacity.

In order to distinguish the effects of the climate change on hydropower production, the changes to regional hydrology need to be clearly identified and energy prices must be predicted. Generally Global Circulation Models (GCMs) are used to predict changes in water flow as a result of weather changes. GCM is a mathematical representation of the behavior of the atmosphere in which a horizontal and vertical grid structure is used to track the movement of air parcels and the exchange of energy and moisture through parcels. It is prohibitively costly to run a GCM at the scale of specificity needed to identify the impacts within the CRB. This, combined with the uncertainty in electricity pricing, indicates a need for further calibrations to reflect the conditions specific to the CRB.

However, existing studies show that the hydrology within the CRB would be affected by climate change. Firstly, because the volume of water flowing through the Columbia River is highly dependent on glaciers and melting snow packs, the increased temperature due to climate change would result in larger water flows but smaller snow water equivalent (SWE).[5] As a result even though the volume of water flow would increase in early years of temperature increase, once the snow-packs have melted completely the water flow in the Columbia River would diminish greatly, thereby limiting the amount of electricity that can be produced.

Additionally, the effects of climate change would result in wetter springs and drier summers due to increased precipitation. This combined with the earlier melting of snow packs would result in earlier annual peak flow. The shift in timing of peak flow may

[5] Snow Water Equivalent is the measurement of how much water is present within a snowpack. Available water is the amount of water that would be released if the snow pack melted.

result in more scheduled spills at Arrow, which would result in a loss of hydroelectricity generation capacity. This is analyzed in detail in section 4.4 below.

It is important to keep in mind that BC Hydro's ability to adapt will be strongly constrained by current reservoir storage capacity. In addition, BC Hydro operations may need to be modified in order to mitigate the effects of climate change on aquatic ecosystem health, with possible trade-offs concerning power generation. Thus, while the impact on energy production can be analyzed independently, the results should be interpreted with consideration regarding other aspects of the Treaty.

2.8.2. Agriculture in the Basin

One of the competing interests for water use within the CRB is irrigation for agriculture. The Columbia Basin Irrigation Project (CBIP) diverts 3 MAF of water per year to 671,000 acres of farmland in the US portion of the Columbia River Basin (CRB). The CBIP was started in the early 1930's to provide irrigation water to lands in the CRB; it is currently being managed by the US Bureau of Reclamation. Water for the CBIP comes from Lake Roosevelt, the reservoir formed behind the Grand Coulee dam. The CBIP's need for water combined with the effects of climate change on the hydrology within the Basin implies that the demand for water will increase during the times where climate change reduces water flow.

The total amount of the Columbia flow that is diverted into the CBIP at Grand Coulee varies a little from year to year, but is generally stabilized around 3 Maf. This is about 2.3% of the average flow on the lower river as measured at the Dalles. While the amount of water is sufficient for irrigating 671,000 acres of farmland, the original plan of the CBIP was to irrigate 1,100,000 acres of farmland, which would result in more than double the amount of water being currently used (Bloodworth & White, 2008).

In addition, higher temperatures resulting from climate change will lead to higher levels of evapotranspiration. This means that there will be more water lost to the atmosphere through plants and soil. This will increase demand for irrigation in the winter when water flows are least available.

A study using data from 72 counties in Washington and Oregon was conducted to determine the cost of climate change on irrigated agriculture. It used the effects of reduced runoff during the low snowpack years of 1992 and 2001 as potential models for the impacts of climate change. The study assumes that there would be proportional reductions in surface water availability for irrigation as a result. The study uses three potential prices of water ($50, $100, and $150) as well as three snowpack reduction scenarios (50%, 60% and 70%). The conclusion of the study indicates that the damages to irrigate agriculture ranged from $456 million annually to $2.4 billion annually depending on the water price and snowpack reduction scenario (Goodstein & Matson, 2004). The majority of agricultural activities within the Columbia River Basin are located in the U.S. portion of the Basin, of which the states of Washington and Oregon account for over half. The Goodstein and Matson study represents a low estimate of what the total loss in the CRB may be. This value represents the cost to government to retain a given level of irrigation given the effects of decreased snowpack runoff directly caused by climate change, but does not take into account the direct impacts of changes in temperature or precipitation.

2.8.3. Ecosystem Goods and Services in the Basin

Ecosystems produce a variety of goods and services (EG&S) that we all depend on. These include goods we directly consume such as food and water, but also services that affect us indirectly such as pollination services and water filtration services. In recent years, a drastic loss of EG&S has been documented worldwide. The Millennium Ecosystem Assessment states that about 60% of the services delivered by ecosystems are degrading, and in most cases, the rate of degradation is accelerating (UNEP, 2005). This results in a need to invest heavily in substitutes and restoration of EG&S. In many cases the cost of addressing environmental degradation once damage has already occurred is significant, and in some cases the restoration of EG&S benefits is not possible. Many EG&S are fundamental to human life and wellbeing; the health and wellbeing of human populations heavily depend upon the services provided by ecosystems and their components – organisms, soil, water, and nutrients.

In Canada, the Supreme Court of Canada has recognized that the project impacts to the economic benefits of EG&S need to be considered in the decision-making processes, and that the suitable method of doing so is through the Total Economic Value (TEV) framework, which takes into account both market values and non-market values of an EG&S (2004 SCC 38). The Supreme Court states that the benefits of EG&S need to be given full consideration to balance other economic considerations. This will allow for better trade-offs to be made between competing demands related to the environment.

Fifteen percent of the Columbia Basin lies within Canada. Four mountain ranges deeply dissect the Canadian Basin, creating an incredible range of ecosystems - including grasslands, wetlands, dry pine forests, interior rainforests, alpine meadows and glaciers. The Basin is home to over 700 species of birds, mammals, fish and reptiles as well as many large and small human communities. The wetlands, streams, rivers and lakes are the lifeblood of the Columbia River system - providing habitat for a rich diversity of species and bringing water to its human inhabitants (Columbia Basin Trust, 2006).

The Columbia River Basin encompasses numerous EG&S, many of which will be impacted by climate change. Due to the lack of literature on climate change and its interactions with ecosystem services, data was only available for estimation of the values associated with the existing EG&S within the basin, but not what the incremental impacts of climate change would be.

Chapter 3.

Methodology

A mixed method of literature review, quantitative analysis, and cross-jurisdictional analysis were applied to address the policy problem identified.

The literature review identifies the potential effects of climate change on the hydropower production and flood management within the CRB. This includes a scan of the literature on the potential effects of climate change on weather and temperature patterns within the CRB, which gives the background on what climate change scenarios may look like in the CRB. The physical impacts of the changes in temperature and water flow are then outlined through literature, the majority coming from CRT Entities such as BC Hydro, the Bonneville Power Administration, and the US Army Corps of Engineers. Given the uncertainty of climate science, there are an abundant number of models used in the literature to forecast climate change implications. A scan of the models used within the literature determines the plausible scenarios to use in this analysis to best reflect the range of possible climate scenarios in the CRB in the medium and long term.

3.1. Identification of Climate Change Scenarios

The analysis will first underline the distinct differences between scenarios in which the Treaty continues and the Treaty terminates.

If the Treaty continues after 2024, the US will receive an assured operating plan for Canadian storage, which will benefit American flood control and power generations through removal of uncertainty. In turn, Canada will benefit from continued Canadian Entitlement (though the size of the Entitlement is to be determined) and have increased flexibility to optimize generation in Canada.

Both the US and Canadian will enjoy assured power drafts should the Treaty continue. Power drafts will bring large benefits to the US, as it also offers substantial flood control benefits in addition to power production. Being able to access coordinated power drafts means that the US will have more certainty and less volume of Canadian storage required during a Called Upon flood control request.

On the other hand, if the Treaty terminates, Canada will lose the Canadian Entitlement. However, Canada will no longer be obligated to coordinate its operations with the US, and therefore will gain flexibility in its operations both for power generation and other interests such as agriculture and fishery management.

In a joint study conducted by the U.S. Army Corps of Engineers (USACE) and the Canadian entity (Phase 1 study), the average volume of Called Upon storage required to meet US flood control needs increased substantially when the models compared the Treaty Continues scenario to the Treaty is Terminated scenario, ranging from an average of 1Maf to 11Maf respectively, resulting in an average difference of 10 Maf (Canadian and U.S. Entities, July, 2010).[6] The relative certainty of Canadian operations in the Treaty continues scenario was the main driver of Called Upon volumes as well as the duration of Called Upon events.

The three options were analyzed using a number of different scenarios that were designed to test and compare a range of possible situations with varying study time horizons, various water supply forecasting procedures. The modeling was completed by both entities in their Phase I study of the Columbia River Treaty and post 2024 operations. However, the Phase I study did not include any calculation of the economic benefits or costs of the scenarios for hydropower, and flood control operations were described in terms of the effects on reservoir storage but did not calculate flood damages prevented or the economic losses (opportunity costs) associated with flood control storage operation under the scenarios. This analysis adds to the Phase I study by evaluating, where possible, the economic implications of each of the 13 scenarios under the policy options.

[6] 1 Maf equals approximately the volume of water held in 11 Olympic-sized swimming pools.

3.2. Analytical Timeframe

The analysis was performed for the 50-year period between 2024 and 2074. This time frame begins in the first year of Called Upon flood control operations and continues for 50 years in order to give a representative demonstration of what post-2024 flood control operations may look like.

The 50-year time frame was chosen partially due to the fact that climate change occurs slowly over long period of time, thus in order to accurately reflect the potential impacts of climate change, a longer than usual timeframe was needed for the analysis.

3.3. Quantitative Analysis Methodology

Using the identified climate change scenarios, the economic impacts of climate change on the CRB were highlighted through a simple analysis of costs and benefits of operating flood risk management in addition to a description of the distribution of impacts. The analysis, while using principles of cost-benefit analysis, should not be interpreted as a full CBA as it only looks at quantifiable costs and benefits. The analysis is not meant to demonstrate a bottom-line net present value, but is instead meant to inform policy options and give a general view of what the potential financial implications could be for the policy scenarios.

The quantitative analysis used a combination of replacement cost method, change in economic productivity method, and benefits transfer using data from existing contingent valuations. Impacts that were not quantifiable were described qualitatively.

The replacement cost method was used to estimate the climate change impacts on energy production. The analysis looked at what the cost would be to update the current reservoirs and water management practices and tools in order to accommodate the increased water volume resulting from climate change so that energy production potential can be maximized without the danger of over-spilling the reservoirs, which would result in catastrophic losses downstream.

The change in economic productivity method was used in combination with replacement cost method to illustrate the potential value of flood control within the CRB. Changes in economic productivity before and after a possible flood, as well as the replacement cost that would be incurred by damaged to infrastructure were both considered in the analysis. The combination of the two types of costs would give a very conservative estimate of the costs of floods, given that they do not take into account people's security and welfare.

Benefit transfer was used as an illustration of the values of ecological goods and services and agriculture within the CRB to demonstrate the trade-offs that would be faced by the CRT and competing demands of for water and to inform the analysis of policy options.

3.4. Qualitative Analysis Methodology

Finally, a cross-jurisdictional review of international management practices in combination with literature from CRT stakeholders informed the selection of policy options available to incorporate into the Treaty negotiations. These options were assessed based on criteria identified through a mix of literature and best practices.

Chapter 4.

Setting the Flood Control Objective

4.1. Analysis background

The standard metrics for communicating the costs and benefits of flood risk management can be reported in a variety of ways that include: net present value, benefit-cost ratios, internal rate of returns, and avoided costs. However, given data limitations that prevent a full cost-benefit analysis, the approach taken here is to estimate the benefits to the US associated with each flood risk management scenario. The objective of the analysis is to inform the negotiation process of the incremental benefits that Canada provides to the US given future climate change scenarios as well as the costs to Canada of providing those benefits. This information would inform the negotiation process for the Canadian Entity.

The incremental impact of climate change on flood risk is estimated through hydrological and climate data from the Pacific Climate Impacts Consortium (PCIC). Note that due to a lack of engineering models at the scale of the watershed, the estimated results are not meant to be an exact prediction of what would happen in the CRB in the future given climate change. Instead, these estimates are meant to illustrate how climate change could potentially impact hydrological flows within the Basin.

PCIC reports that due to climate change, the Canadian dams within the CRB would expect to see an increase of 3% to 19% annual water flow at various dams within the CRB between the years of 2041-2070 due to increased snowmelt and precipitation resulting from climate change, with the median increase in annual stream flow across all projects to be about 10% (Shrestha, Berland, Schnorbus, & Werner, 2011). This increase is relative to the baseline data from the period of 1961-1990. This projection was taken to represent the estimated increase in flood risk in the US portion of the CRB due to climate change post 2041. Studies show consistent monthly increases during the late fall and winter period, an earlier onset of the spring melt and a substantially higher discharge during spring and early summer. In addition, monthly flow in the late summer and early fall periods will be lower in the future due to decreased precipitation and earlier melting of snow packs and glaciers. This section outlines the various impacts of potential flooding that are analyzed. The specific methodology and results can be found in sections 4.2 and 4.3 respectively.

First I analyze the extent of the flood damage on economic activities. The analysis focuses mainly on quantifiable direct economic damage, but it is also important to recognize the indirect effects of floods. For example, flooding damage to transportation systems such as highways or roads could result in significant loss of productivity, but such effects are difficult to predict and measure. Because the indirect effects on the economy are not monetized in this analysis, it is expected that the final results of the economic impacts of floods will be an under-estimation of the costs of flooding.

Other impacts of floods include human casualties. Although there are points of contention regarding the economic valuation for loss of life, this analysis uses the value of a statistical life to illustrate the significant benefits that flood prevention could bring. The value of a statistical life is not an attempt to specify a financial amount for a specific life, but instead shows the overall societal willingness to allocate resources to decrease the probability of loss of life. Environmental damage also occurs in floods and includes damages to the ecosystem in general as well as damages resulting from release of polluted substances.

The CRT policies and climate change impacts occur over long time horizons and lead to costs and benefits that are realized at different times. Thus the discount rate selected in dealing the analysis could play a key role in how the policy options compare to each other. In accordance with both the US EPA and the Canadian Treasury Board Secretariat guidelines, this analysis uses a 3% discount rate, with sensitivity analyses using the discount rates 0% and 7%.

4.2. Scenarios Analyzed

To be consistent with the modeling undertaken by the US Army Corps of Engineers (USACE) and BC Hydro in the Phase 1 study, the scenarios are named in accordance with documents published by the Canadian and US Entity.

A total of 11 scenarios were analyzed by the Phase 1 report in the joint study by the Canadian and US Entities, these were screened in my analysis using various modeling strategies as well as different flood control objectives. Five of these scenarios were modeled under the assumption that the Treaty would continue, 6 were modeled under the assumption that the Treaty would terminate. As discussed previously in section 2.1, the Treaty is highly unlikely to be terminated because both parties have expressed a high level of interest in renegotiation and continuation of the Treaty. Due to this, the six termination scenarios modeled in the Phase 1 Report are not analyzed in my study.

Of the five scenarios that were modeled in the joint study by Canadian and US Entities, 3 were modeled with the flood control objective of the maximum flow at the Dalles being no higher than 600 thousand-cubic-feet-per-second (kcfs), 2 were modeled with the flood control objective at 450 kcfs. The Dalles is used as the site of the metric for maximum flow as it is the site listed in the Treaty for determination of Called Upon need. The reason for the different flood control objectives modeled is due to the lack of agreement between the two countries about what the appropriate flood control objective should be to initiate Called Upon. According to the current Flood Control Operating Plan (FCOP), flooding begins in the lower Columbia when flow reaches around 450 kcfs at the Dalles, while major damages begin when flow at the Dalles is around 600 kcfs. The Canadian Entities have expressed their assumption that the flood control objective would be set at 600 kcfs, while the US Entities have outlined strategies for both 450 kcfs and 600 kcfs in the past.

The second aspect distinguishing the scenarios is whether the study was conducted in observed or forecast (simulated) mode. The difference between the observed mode and the simulated mode comes into play in two periods of the modeling: 1) during the drawdown period in order to provide reservoir space for the anticipated spring runoff, and 2) during the reservoir refill period to reduce runoff peaks and provide for assured refill of the reservoirs.

Under Observed mode, reservoir regulation decisions are assumed to be made with perfect foresight of all future runoff volumes and inflows across the entire Columbia Basin. These scenarios do not consider the uncertainty inherent in actual operations and therefore tend to underestimate the storage required for flood control or provide less-effective flood control for available storage space. This mode is included because the Entities have traditionally used it to optimize the critical period operation and determine flood control and refill curves for planning studies and AOP.

In forecast mode, analysts use historical water supply forecasts and associated errors to determine the drawdown of the reservoir, which incorporates the runoff volume uncertainty and errors. Both Canadian and US Entities have stated that forecast mode is more appropriate when trying to reflect how Called Upon would actually be implemented. Scenario 5 differs from the other scenarios in that only Canadian local flood control is used at Grand Coulee, a dam along the River in the state of Washington. The use of Canadian local flood control only means that Canadian Entities would no longer share their power draft plans with the US Entities, thus the US Entities would be unable to include incidental flood control benefits from upstream power drafts into their planning process. This scenario is would not occur should the Treaty continue, but is included by the study as a comparison case.

Table 1 shows the five scenarios modeled by the USACE and BC Hydro that are used in this analysis. The first column indicates the scenario number. The column named 'Grand Coulee Flood Control' indicates the aspects taken into consideration by the US Entities when planning flood control operations at the Grand Coulee dam. 'Upstream power draft' indicates that the US Entities assume they would receive information about Canada's power draft operations and thus be able to take into consideration the flood control benefits offered by those operations. 'Canadian local flood control' indicates that the US would have no information about Canadian power draft operations, and can only plan flood control operations at the Grand Coulee based on upstream information about Canadian local flood control. The column 'Flood control objective' indicates the maximum flow allowed at the Dalles, and 'simulation mode', as previously stated, indicates the assumptions about uncertainty under which the scenarios were forecasted.

Table 1. Scenarios Analyzed under Assumption that Treaty Continues

Scenario	Grand Coulee Flood Control	Flood control objective	Simulation mode
1	Upstream power draft	600kcfs	Observed
2	Upstream power draft	450 kcfs	Observed
3	Upstream power draft	600 kcfs	Forecast
4	Upstream power draft	450 kcfs	Forecast
5*	Canadian local flood control only	600 kcfs	Observed

*Included for comparison only

4.3. Benefits to the US

One of the key issues that came to light after the modeling work was that the maximum flood flow objective at the Dalles was the strongest determinant of the frequency of Called Upon flood control operations. It is important for the Canadian Entity to have full information on the amount of benefit that the US receives from the flood control operations of the CRT, as this could inform the negotiation process from the Canadian prospective. While the benefits received by the US may not directly relate to the amount of compensation received by Canada, the knowledge is important for the Canadian Entity to have in order to be in an informed position during the negotiations.

Through modeling work, the Phase 1 report conclude that each scenario where the maximum flow objective was 600 kcfs triggered Called Upon operation at least once in 21 years out of the 70-year period of evaluated. In comparison, scenarios where the flow objective was 450 kcfs triggered CUFC at least once in 52 years out of the 70. That is the say if the flood objective were to be set at 600 kcfs; there would be at least 31 occurrences where flow at the Dalles would exceed 450 kcfs, thus potentially resulting in minor damages. The results were consistent regardless of whether the Treaty continued.

It is important to note that under the current assured primary flood control operations, the flow at the Dalles has not been allowed to exceed 400 kcfs. The US Entity has requested flood control operations to keep the Dalles' peak flow below 350 kcfs in months where the unregulated flow at the Dalles would have reached 500 kcfs (U.S. Army Corps of Engineers; Bonneville Power Administration; B.C. Hydro, 1964-2013).

These results demonstrate that setting a less stringent flood prevention objective (600 kcfs) results in fewer number of Called Upon operations as compared to setting a more stringer flood objective (450 kcfs). A 33% increase in the flood control objective is associated with a 60% increase in the number of Called Upon operations needed. This means that the number of Called Upon operations needed increases dramatically as the flood control objective becomes more stringent but the risk of flooding diminishes (and vice versa). As is implied by the results here, by setting the flood control objective at 600 kcfs instead of 450 kcfs, there are 31 occasions of incurring minor damages due to flooding within the US portion of the CRB. The predicted damages here are still within the range of acceptable risk as outlined currently by the Treaty, however, it is important to take these into account when looking at the tradeoffs of decisions regarding the flood control objective.

Table 2 shows the average Called Upon volume required under each scenario analyzed by the Phase 1 report, as well as the maximum CUFC storage required. The volumes listed in table 2 were analyzed with the consideration of local flood control and power drafts under the planned operations of the Canadian reservoirs. Thus, the storage volume required is the additional storage volume needed by CUFC that has not been met through existing Canadian operations.

Table 2. Called Upon Storage volumes (Maf) Required From Canadian Projects

	Volume of Called Upon storage (Maf)
Average over 21 called upon years (flood objective at 600 kcfs)	1.3
Maximum	2.3
Average over 52 called upon years (flood objective at 450 kcfs)	1.5
Maximum	3.4

Source: (US Army Corps of Engineers Northwestern Division, 2011)

BC Hydro has previously estimated that the flood control benefits offered to the US portion of the CRB between 1964 to 2012 to be valued at 32 billion 2012 Canadian dollars(BC Ministry of Energy and Mines, June 25, 2013). Between the years of 1964 to 2012, flood control was provided to the US through the use of 744 maf of reservoir space from Canada (U.S. Army Corps of Engineers; Bonneville Power Administration; B.C. Hydro, 1964-2013). Using a 3% discount rate, I have estimated the flood control benefit to the US of Canada providing 1 maf to be $79.3 million (2012 CND).[7] Note that this value is an average based on historical years and has not been adjusted to account for economic and population growth. As a result, due to expected population and economic growth in the future within the US portion of the CRB, this value is an under-estimation of the actual economic benefits provided to the US by CUFC. Based on that estimate and the forecast Called Upon storage volume presented by both the Canadian and US Entities, I have estimated the benefit of flood control provided by Called Upon to be within the range of $2.1 billion to $14 billion in the 50 year period between 2024 and 2074, given the average and maximum storage requested as forecasted by both the Canadian and US Entities models.[8]

It is important to note that these figures are based on the estimates published by BC Hydro. That is, the figures are provided by one of the negotiating Entities in Columbia River Treaty. This is to say that the estimate provided by BC Hydro, as well

[7] Detailed calculations in Appendix B

[8] Detailed calculations in Appendix C

as the figures that follow this estimate, have not been vetted by a non-interested party. Therefore, the numbers I have estimated are not meant to be exact representatives of the benefits that the US receives, but is meant to illustrate the potential magnitude of the benefits to the US.

These numbers were used to establish a baseline of what would happen without the incremental impact of climate change. The models from the Phase 1 report do not take into account the potential effects of climate change on the hydrology in the CRB as it is based on historical data and cannot incorporate climate change impacts. However, the models are useful for establishing what the future in the CRB could look like without climate change, which could be considered as a Business-As-Usual (BAU) scenario.

Having established the BAU, the next step is to analyze what would happen with climate change incorporated into the scenarios, or what the incremental effect of climate change would be.

As stated in section 4.1, using hydrological models from PCIC, I have estimated that the impact of climate change would imply a corresponding increase of 3% to 19% of incremental flood risk in the US portion of the CRB. Assuming that the economic damage from increased flood risk is directly proportional and linearly related to changes in flood risk, the increases of flood risk due to climate change would result in a corresponding 3% to 19% increase of benefits to the US from CUFC. As such, the incremental, benefit of preventing floods due to climate change would be roughly $51 million to $2.1 billion in the 50-year period between 2024 and 2074.[9]

It is important to note that these benefits are associated with the avoided loss of economic productivity and avoided loss of life or loss of quality of life within the US portion of the CRB. These may include costs associated with property damages, public infrastructure repair, emergency services, temporary relocations, and foregone employment. However, these values do not take into account the Called Upon benefits of preventing non-market damages such as loss of recreational activities, environmental losses and loss of EG&S, which could be substantial but are largely intangible. Due to

[9] Detailed calculations in Appendix D

limited scope of this study, these benefits were not able to be quantified and monetized in detail.

However, I include here a rough estimation of what these benefits could look like. Lantz et al. (2011) published a survey on the estimated cost of floods in Canada due to climate change. Lantz surveyed community members in the community of Fredericton, NB, Canada, which has just under 22,000 households. The survey included questions eliciting the non-market costs of flood control, mainly the social impacts including pain and suffering from loss of security or trauma from floods. This study finds that non-market costs associated with flooding due to climate change can be substantial. Overall, non-market costs were estimated to represent 23–42% of the total costs of flooding due to climate change, depending on the different climate and population scenarios considered.

There is a growing area of research focused on estimating the benefits of flood risk reduction. However, these studies use the contingent valuation method to estimate the willingness to pay for adaptation projects that would reduce the risk of flooding in the future. Thus the studies are assessing the households' total costs of floods and do not separate the market and non-market components of the costs.

Lantz et al.'s study differs from the rest of the existing literature in that while the study uses contingent valuation, the values are elicited in such a way that the magnitudes of market and non-market costs can be inferred, and the questions are formatted to obtain a household's willingness to accept.

The location used in the Lantz et al.'s study was the Saint John River basin. It is similar to the CRB in that the Saint John River basin can be divided into two parts, the hydroelectricity production is most concentrated on the upper part, and the lower part of the basin is more prone to flood risk. Similarly to the CRB, one of the determining factors of flooding is the volume of water flowing into the lower basin, which is highly dependent on snowmelt and rainfall.

The community of Fredericton located in the Saint John River basin has just under 22,000 households and had suffered a severe flooding in 2005. Lantz el al. divided the area into three zones based on flood damages obtained in the 2005 flood. In total, 2,051 households were surveyed by mail to elicit responses on estimation of both market and non-market costs of a past flood event in 2005, the response rate was on average 35% across the 3 zones.

Lantz et al. then estimated the expected change in flooding frequency and resulting annual average cost of flooding under various climate change scenarios, then adjusted the costs of estimation to account for population growth. These were used in combination with the surveyed results of 2005 costs to obtain the expected annual average cost of flooding due to climate change and population growth.

Lantz el al. found that the non-market costs of flooding can contribute 23% - 42% of the total costs of flooding due to climate change. The variation in the percentage estimate is due to different climate change and population growth scenarios.

Given Lantz et al.'s estimates, and assuming that a flooding event in the CRB would result in similar damages to households, I have extrapolated that non-market benefits of preventing floods due to climate change in the CRB to be between $24 million to $1.5 billion. This is calculated taking into consideration BC Hydro's estimation of market costs of flooding and previous estimations of cost of flooding due to climate change.

The values provided here are not meant as a precise analysis of the costs of flooding due to climate change or the exact values of the benefits provided by Called Upon, but more to illustrate the magnitude of the impact of climate change on flood control as well as what the inclusion of these costs may mean for general planning.

4.4. Costs to Canadians

In order to have an idea of what the benefits represent, it is important to also compare the incremental costs of operating Called Upon flood control due to climate change. The cost of operating Called Upon flood control can be categorized into 2 types. First is the cost of affected economic activities due to Called Upon. These activities can include, for example, power generation, transportation, and fishery management. Second are the environmental and social costs associated with the operation of Called Upon.

The cost to Canada due to impacts on power generation represents only a small portion of the total costs to Canada of operating CUFC. As previously stated, it is expected that most of the Called upon draft from the Canadian reservoirs will be drafted from Arrow reservoir. As such, CUFC is expected to largely impact hydroelectricity at Arrow, as Mica is not expected to be affected drastically and Duncan has no hydroelectricity generation capacity.

In addition to the hydropower generation that may be affected, CUFC is expected to affect the communities living around Arrow as it changes the hydrology and available water supply in the area. In fact, of all the people who live within the Canadian portion of the CRB, 80% live in communities close to the Arrow.[10] If CUFC is used, the change in Arrow's hydrology would affect non-hydro use such as fishery management, recreational use (fishing, hiking, etc.), and transportation uses of the Columbia River.

Table 3 provides a summary of the impacts of Called Upon operations on Canadian generation in the case without any climate change impacts. For the months of January to August, the predicted minimum, average, and maximum amount of electricity generation lost is shown in MWh. The minimum, average, and maximum annual value is shown to the right, as well as the total value between the 70-year study period of The Phase 1 report. This is obtained by multiplying the average price of electricity in BC with the MWh change in power production. The total value is computed by multiplying the annual value by the predicted number of times Called Upon would be incurred (21 times if flood objective is set at 600 kcfs, 52 times if flood objective is set at 600 kcfs). This data is based on the modeling work done by both Canadian and US Entities. The modeling inputs were based on historical data, and therefore do not include climate change considerations.

As shown in the table, the overall impact of Called Upon is relatively small on a yearly basis. However, the variation between the different months is large. The models

[10] Roughly 2 million residents.

confirmed that the higher the maximum flow objective in the US, the less frequently Called Upon operations in Canada would be required, and thus the smaller impact on power generation.

In order to monetize the impact of CUFC on hydroelectricity generation in Canada, the average price of electricity in BC was used as a proxy for the value of the foregone power production. The average price of electricity in BC was multiplied by the quantity of lost power production to obtain the value of foregone electricity.

If the flood control objective is set at the more stringent level of 450 kcfs, then it implies there would be less water flowing through the turbines at Arrow, therefore leading to a greater loss of generation potential for Canada. Conversely, if the flood control objective at the Dalles is set at the more lax level of 600 kcfs, then more water would be allowed to flow through the Arrow, which would lead to a smaller loss of power generation potential for Canada.

Table 3 below shows the foregone generation in the Canadian portion due to the operation of CUFC. Where a negative number in the table below indicates a loss of MWh of electricity generated due to the operation of CUFC, a positive number indicates a gain in generation. A gain in generation is possible when operating CUFC due to the variability of monthly flows and the potential for incidental power benefits for Canada when operating CUFC at certain reservoirs.

As shown, if the flood control objective at the Dalles is set at 450 kcfs, the impact of CUFC to Canada is approximately an average of a loss of $6.15 billion. If the flood control objective at the Dalles is set at 600 kcfs, the impact of operating CUFC to Canada is approximately with an average of a loss of $3.2 billion.[11]

These values present only a rough estimate of what may happen when CUFC is incurred. In reality, the impacts of CUFC to Canadian generation would be highly dependent on market conditions as well as real-time power demands and non-power water needs.

[11] Detailed calculations in Appendix E.

Table 3. Canadian generation difference between called-upon and non-called-upon scenarios

Flood Control Objective		Jan (MWh)	Feb (MWh)	Mar (MWh)	Apr (MWh)	May (MWh)	Jun (MWh)	July (MWh)	Aug (MWh)	Annual Value ($M)	Total Value ($B)
600 kcfs	Max	8,760	560,640	0	96,360	61,320	61,320	0	70,080	66	1.41
	Avg	-122,640	-219,000	-543,120	-280,320	-420,480	-245,280	-87,600	-8,760	-150	-3.16
	Min	-315,360	-998,640	-1,182,600	-674,520	-937,320	-1,033,680	-1,121,280	-131,400	-498	-10.47
450 kcfs	Max	560,640	2,233,800	1,112,520	1,287,720	744,600	166,440	1,191,360	797,160	631	32.83
	Avg	-96,360	17,520	-508,080	-70,080	-359,160	-306,600	-210,240	17,520	-118	-6.15
	Min	-385,440	-1,217,640	-2,426,520	-1,147,560	-1,427,880	-1,366,560	-1,427,880	-534,360	-774	-40.29

Source: Canadian and U.S. Entities, July, 2010

In addition to the direct loss of power generation ability, there could also be indirect losses to power due to additional drafts that would be needed in order to avoid spills. As previously stated, climate change would likely result in a 3% to 19% increase in water flow in the Columbia River, this means that in order for Canada to offer the same level of protection to the U.S., more water would have to be stored in the Canadian reservoirs, given the impacts of climate change.

Given the current capacity and usage of the Canadian reservoirs, the additional volume of water would not challenge the capacity at Mica or at Duncan. However, Arrow has already gone through with increased drafting in the past in order to prevent spills, thus with the additional quantity of water, it would be expected that Arrow would have to increase the volume of water that is drafted, which would lead to additional losses of power generation. For example, Arrow increased drafting in both July and August of 2008 and 2010 while the reservoir was filled at capacity.

It is difficult to predict when and how much of additional drafting would be required at Arrow due to the effects of climate change; as such year to year forecasting has not been undertaken by either of the Entities. However, taking the drafting that occurred in 2010, Arrow outflow was maintained to be around 55 kcfs in the months of July and August (U.S. Army Corps of Engineers; Bonneville Power Administration; B.C. Hydro, 1964-2013). To illustrate the impacts of climate change, if those outflows were to be increased by 3% to 19% as predicted, using an industry rule of thumb, the corresponding loss of hydroelectricity generation would be equivalent to approximately 225 MW to 280 MW. This would be equivalent to $1.5 million to $2 million if valued at current electricity prices.

These values are only to illustrate what the additional impact of climate change could mean for the operation of CUFC. Again, the loss of hydro generation is only a small portion of the total cost. Other costs associated with the increased outflow could be impacts on downstream fisheries, as the downstream management of whitefish and rainbow trout spawning and incubation flows (U.S. Army Corps of Engineers; Bonneville Power Administration; B.C. Hydro, 1964-2013). However, with the additional flow and potential of spillage as a result of climate change, it may become more costly for Arrow to manage its outflows.

Additional to the hydropower losses, Canada is also expected to be impacted by the CUFC in other areas. In particular, recreational values of the Canadian portion of the CRB are expected to be negatively affected due to the operation of CUFC. However, due to the limited scope of this study, the environmental and social costs associated with operation of Called Upon were not quantified or monetized. These costs are expected to be significant, and should be considered by decision makers in order to fully understand the impacts of operating Called Upon to Canadians. As such, the costs described quantitatively in this study represent only a small portion of the total costs to Canada of operating CUFC.

4.5. Summary

. To summarize, the Phase 1 report expect flooding to being in the lower Columbia when flow reaches around 450 kcfs at the Dalles, while major damages begin when flow at the Dalles is around 600 kcfs. Based on the combination of both entities hydrological modeling and climate change scenarios as modeled by PCIC, the US would likely call on CUFC at least 52 times in the 50 year period between 2024 and 2074 if the flood objective is to be set at 450 kcfs at the Dalles, and at least 21 times between the same period if the flood objective is set at 600 kcfs at the Dalles. This translates to the US receiving benefits valued between approximately $2.1 billion to $14 billion in the 50 year period between 2024 and 2074.

With the added effects of climate change, it is expected that the Columbia River would see an increase of water flow between 3% and 19%. As such, the incremental benefits due to avoided market costs with the flood objective set at 600 kcfs would be between $63 million to $0.4 billion between 2024 to 2074; the benefits with flood objective set at 450 kcfs at the Dalles is estimated to be approximately between $0.19 billion to $1.18 billion. This is to say that the damage due to flooding in the US would be greater given climate change impacts, therefore US receives greater benefit from the prevention of floods through actions in Canada.

In addition to the avoided market costs of as a result of avoided flooding, the US would also enjoy benefits in terms of avoided non-market costs. These benefits are estimated to be between $24 million and $0.23 billion if the flood objective is to be set at 600 kcfs and $93 million to $1.5 billion if the flood control objective is set at 450 kcfs. Table 2 below shows the summary of estimated benefits to the US of Called Upon due to climate change from 2024 to 2074. In general, having the flood control objective at the Dalles to be more stringent (450 kcfs) brings about larger benefits to the US, while a more relaxed flood control objective (600 kcfs) brings less benefits. However, in both cases it is obvious that the damage in the US due to flooding as a result of climate change is significant, ranging from between $75 million to $3.6 billion over 50 years.

Table 4. Incremental Benefits to the US of Avoiding Flood due to Climate Change, 2024 - 2074 (millions of Canadian dollars)

		Flood Objective 450 kcfs		**Flood Objective 600 kcfs**	
		Low range	High range	Low Range	High Range
Benefits (2013 $M)	Economic benefits	330	2100	51	320
	Non-market benefits	93	1500	24	230
	Total Benefits	423	3,600	75	550

While the benefits the US receives are much higher if the flood control objective is to be set at 450 kcfs rather than 600 kcfs, the costs to Canada would also be higher should the flood control objective be set at the more stringent level.

The potential loss of power generation represents only a small portion of the total Canadian costs of operating CUFC; it is the only quantifiable cost within the scope of this study. With the flood objective set at 450 kcfs, it would cost Canada on average $118 million in loss of electricity generation in order to operate CUFC annually, while if the flood control objective was to be set at 600 kcfs, it would cost Canada on average $150 million in loss of electricity generation to operate CUFC annually. Additionally, it is possible that Canada would lose $1.5 million to $2 million annually of power generation due to additional drafts that need to be undertaken to avoid spills at the Arrow reservoir solely as a result of adapting to the impacts of climate change.

Chapter 5.

Compensation Methods for Called Upon Flood Control

Another area in need of clarification in the Treaty is the components that should be included in the compensation to Canada for operating Called Upon flood control. According to published documents from US Entities, Canada will be compensated for the operating and economic losses due to Called Upon flood management. Canada's costs will include the operating cost as well as the lost power production. However, documents from the Canadian Entities indicate that the compensation should include a variety of components, including social cost, environmental cost, cost to irrigation, transportation, recreation, as well as power generation. The inclusion or exclusion of certain costs will have significant impacts for financial implications of enlisting Called Upon flood management. As a result, various methods of compensation for Canada were evaluated.

5.1. Choosing a Compensation Method

5.1.1. Compensation for Canada to include operating cost and loss of power generation only, determined at time of Called Upon request.

This is the option that was outlined by the US Entities in their discussions of post-2024 flood control operations. This option takes "economic loss" associated with flood control operations to only be realized in the form of loss of power production. Under this policy option, Canada would need to provide data after the request for Called Upon has been made to determine the incremental costs associated with the loss of power production. This loss can then be compensated to Canada either as an addition to the Canadian Entitlement or as transfers of electricity.

However, given what is currently known about the Canadian position, it is highly unlikely that Canadian Entities would agree to this mode of compensation. As such, this option is deemed unrealistic and not furthered analyzed.

5.1.2. Compensation for Canada to include operating cost, loss of power generation, social and environmental costs, and full impacts to other economic sectors, as determined at the time of the request.

This option broadens the definition of "economic loss", so that sectors that are outside the scope of the Treaty are also considered. A very similar option was discussed in a document released by the Canadian Entity as a reasonable approach to seeking compensation from the US for Called Upon (Government of British Columbia, 2012). The option presented here is slightly modified to give more details for its implementation. This option takes “economic loss” resulting from Called Upon operations to be the incremental loss of power generation in BC, any social and environmental costs, and the impacts to other economic sectors including irrigation, recreation, and transportation.

Here, social costs are those associated with loss of recreational opportunities due to Called Upon operations, such as fishing or boating opportunities that may have taken place if not for Called Upon operations. In addition, social costs may exist if Called Upon operations disturb waters that may have held cultural or spiritual significance for communities with the CRB in Canada. While these costs are often difficult to quantify and monetize, it is important to note that they are real costs that will be borne by Canadians, and should be taken into consideration during the decision-making process.

In addition, there also needs to be consideration for potential environmental costs resulting from Called Upon operations. This would include disturbances to the environment such as impacts on fish and wildlife due to water flow change, as well as potential impacts to the ecosystem services that are being provided.

Many of the ecosystem services are fundamental to human life and wellbeing. The health and wellbeing of human populations heavily depends upon the services provided by ecosystems and their components – organisms, soil, water, and nutrients. As such, it is important to take into account the impact of Called Upon on these aspects, and should there be losses in value, it would be reasonable for Canada to seek compensation.

Under this option, Canada would need to provide data estimates of the incremental economic costs associated with Called Upon flood management at the time of the request. Data would be needed for all sectors in which Canada is claiming a negative impact.

Including the environmental and social impacts into compensation considerations means a higher implementation cost for the Canadian Entity. Because environmental and social costs are often different to quantify and monetize, it is more likely that this option would be implemented via a ex-ante agreement of what the magnitude of the environmental and social cost for each Maf per day of storage that is requested of Canada for Called Upon, similar to the compensation model of the Canadian Entitlement that is currently used. However, this would mean additional negotiation efforts as well as efforts to monetize in some way an acceptable value of environmental and social cost, which may require further consultation with the community. As such, it is expected that the inclusion of environmental and social impacts into the compensation considerations would generate additional implementation costs to the Canadian Entity.

Nevertheless, the inclusion of environmental and social impacts into compensation models allows Canada to be more flexible in terms of evaluating the existing Treaty should new information be made available. This is a particularly important consideration given that the current modeling of climate change impacts within the CRB is not yet at a satisfactory level of detail. Thus, it is important that the Treaty provisions are flexible in the face of new information discovered about climate change effects. The inclusion of these aspects into Canada's and the US's cost considerations means that the environmental costs can be updated to reflect new information on the climate change trajectory or impacts. This allows additional flexibility in evaluation and implementation of Called Upon flood control when new knowledge on climate change is uncovered, which makes this policy more desirable.

The inclusion of environmental and social benefits allows for more sustainable development as these impacts will be factored into the decision-making process. This has the potential to minimize decisions that would have otherwise had significantly negative environmental or social impacts, thus allowing a more sustainable path of development. In addition, this encourages the analysis on areas not directly impacted by the Treaty, such as agriculture, fisheries management, transportation, etc., which would provide addition information that could help the Entities gain better understanding how ecosystem goods and services in the Basin flows. This could give insights to how climate change impacts an ecosystem as a whole.

Finally, in terms of community acceptance, the inclusion of the environmental and social impacts into the cost considerations will better reflect the impacts of Called Upon on the community and offer a complete picture of how community members would be affected. Therefore, this option would have a higher level of community acceptance than the compensation only for economic impacts.

5.2. Considerations for Choosing Compensation Method

5.2.1. US commitment to preservation of fisheries

In the current Treaty operation framework, operations are also bound by non-power use agreements between the two Entities. These include objectives for fishery management through flow augmentation in the Canadian portion in order to meet the flow required by fisheries in the US (Canadian and U.S. Entities, July, 2010). As such, the current operations already take into account parts of the ecosystem goods and services that are provided by the CRB. It would be expected that these operations would need to continue in the future due to US regulations on endangered fish species that exist in the US portion of the Basin. Given that climate change would make the hydrological flows in the Columbia River more volatile, the Canadian Entity would have make larger changes to the flow of the River in order to satisfy the flows required downstream.

5.2.2. Smooth operation of policy operation

There is always the potential for friction among the Treaty Entities involved in the operation of the CRT. However, it is important that policies to be implemented ensure the smoothest possible operation of the CRT. This is reflected in both the time period it takes to implement the policy as well as in the administrative complexity of a given policy.

5.2.3. Incorporate flexibility into options to accommodate potential for discovery of new information or changes to existing models

Given the relative short amount of time climate science has been studied and the amount of uncertainty with the existing data on climate change, any policies aiming to address the effects of climate change will need to be flexible enough to ensure adaptability. To that end, the policy should have built-in adaptation mechanisms that allow changes to be made timely should new information be uncovered on the effects of climate change within the basin.

5.3. Potential Value of Ecosystem Goods and Services in the CRB

The following sub-section details the potential value of the EG&S offered by the CRB, which serves to highlight the trade-off in the choice of inclusion or exclusion of the impacts on EG&S when considering compensation for Canadian operations of CUFC.

While valuating ecosystem goods and services is a relatively new field, there exists a number of studies that attempt to quantify and monetize the EG&S of river basins. However, many of them are derived by using benefit transfer, which makes them difficult to rely on for the purposes of this analysis. In a 1999 study by Loomis et al., the value of EG&S in the Platte river basin was analyzed through contingent valuation, where the willingness to pay (WTP) to preserve the ecosystem surrounding the Basin was elicited through surveys to the households within the Platte basin. The study found that the WTP to preserve the ecosystem surrounding the South Platte basin near Denver Colorado is $252 per household per year (Loomis, Kent, Strange, Fausch, & Covich, 2000). More specifically, the study found that monthly WTP per household was $21 per month with a 95% confidence interval of $20.50 - $21.65 for the increase in ecosystem services along the South Platte River.

Loomis et al. concede that the WTP may be influenced upward by the proximity of interviewed households to the river, however, the authors point out that while the $252 annual payment may be a substantial sum, it is not out of line with other river or lake preservation studies such as Desvousges et al. (1983) study of the Monogehela river ($196 annual WTP in 1997 dollars, Hanemann et al. (1991) study of WTP to increase salmon in the San Joaquin River ($415 using an annual payment vehicle), and Loomis (1987) for Mono Lake ecosystem preservation ($526 using a monthly payment vehicle).

In the Loomis et al. study, ecosystem services that were considered included natural purification of water, erosion control, habitat for fish and wildlife, and recreational values. These benefits are similar to those offered by the ecosystem in the CRB, and are appropriate to be used as proxies for potential WTP to preserve the ecosystem within the CRB. In addition, the economic activities with the South Platte basin are similar to those carried out in the CRB, which makes the benefit transfer more appropriate.

Based on the Loomis et al. study, I have estimated that the WTP to preserve an ecosystem within the CRB is calculated to be between $108 million, with the potential to range from $105 million to $112 million. This WTP indicate a desire to preserve such EG&S as natural purification of water, erosion control, habitat for fish and wildlife, and recreational values. The estimates presented here are an illustration of one method (WTP) of estimating the value of EG&S using a benefit transfer approach[12]. They are not meant to be used to compare and contrast uses of the CRB's water resources for their value, but as a demonstration of the potential values. Some values were not included in these estimates because the data to assess them either are not readily

[12] Benefit transfer is a method often used to estimate the value of an ecosystem good or service. It aims to estimate the benefits for one EG&S by adapting an estimate of benefits from another, often similar, EG&S.

available or do not exist. As a result, the presented estimates for the value of EG&S is likely an underestimation of the true values of the EG&S within the CRB.

These values are only meant to demonstrate the potential impact of Canadian operations of CUFC on EG&S in the Canadian portion of the CRB. That is, if the operation of CUFC causes Canada to lose significant portions of its EG&S within the Canadian portion of the CRB, then the Canadian Entities could potentially be compensated $105 - $112 million per year as a result. These values should be used to show that the potential values of EG&S is significant in the CRB, and the exclusion of EG&S impacts when calculating compensation for Canada could result in significant losses for Canadians. In order to obtain detailed analysis, more research is required on the various ecosystem goods and services within the CRB, as well as the impacts of changes in hydrology on a river basin and its EG&S.

Chapter 6.

Final Recommendations

6.1. Renegotiation of the Columbia River Treaty

The re-negotiation of the Treaty must define in clear terms the operation procedures of the Treaty, including aspects such as what the flood management objective is, when a Called Upon request can be made, and what denotes the start of a Called Upon action in Canada.

The analysis shows that in terms of flood control benefits directly resulting from CUFC, the US receives benefits valued between approximately $2.1 billion to $14 billion in the 50 year period between 2024 and 2074.

With the added effects of climate change, it is expected that the Columbia River would see an increase of water flow between 3% and 19%. As such, the incremental benefits due to avoided market costs with the flood objective set at 600 kcfs would be between $63 million to $0.4 billion between 2024 to 2074; the benefits with flood objective set at 450 kcfs at the Dalles is estimated to be approximately between $0.19 billion to $1.18 billion.

In addition to the avoided market costs of as a result of avoided flooding, the US would also enjoy benefits in terms of avoided non-market costs. These benefits are estimated to be between $24 million and $0.23 billion if the flood objective is to be set at 600 kcfs and $93 million to $1.5 billion if the flood control objective is set at 450 kcfs. Table 2 below shows the summary of estimated benefits to the US of Called Upon due to climate change from 2024 to 2074. In general, having the flood control objective at the Dalles to be more stringent (450 kcfs) brings about larger benefits to the US, while a more relaxed flood control objective (600 kcfs) brings less benefits.

In addition, the Entities must clarify the compensation models to be used for Called Upon management. This includes detailing the components of the compensation as well as how the compensation is to be calculated. The analysis shows that the potential values of EG&S is quite large in the CRB and the exclusion of EG&S impacts when calculating compensation for Canada could result in significant losses for Canadians.

6.2. Climate Change in the Columbia River Basin

The Entities need to better understand climate change and ecosystem services within the Basin. This includes continued facilitation of information access as well as continued support of academic and engineering studies of the implications of climate change in the Basin. In addition, more information is needed on the interconnectedness of EG&S within the Basin in order to fully understand how they are affected by climate change.

The Entities also need to continue to monitor and document the hydrology of the Columbia River, as well as make clear any reasoning behind decisions made on the operation of the Treaty.

Chapter 7.
Study Limitation and Future Research

7.1. Study Limitation

The models used in this study were based on the ones published by the Phase 1 report. The models themselves had limitations due to the assumptions that were made at the time of modeling, which would impact the analysis of the study.

Evaluations of the possible impacts of climate change on the CRB and system operations were not incorporated into the models used by the Army Corps. As such, the implications of climate change were estimated without the benefit of a hydrological simulation model, which decreases the accuracy of the analysis.

The study does not take into account the changing portfolio of energy sources in the face of climate change. Regional and national policy is emphasizing clean and renewable resources, which would have implications for hydropower energy production as a part of the resource mix for the future.

Uncertainties involved in modeling future scenarios and environmental conditions are present in all aspects of the analysis. While the models tried to reduce uncertainty by diversifying the scenarios that were analyzed, there remains in effect a host of scenarios that have not yet been looked at.

7.2. Future Research

Continued research in areas of climate change and its impact on hydrological resources and ecosystem goods and services is desperately needed. While knowledge about climate change has increased, it is not yet at a level of understanding that could contribute to improved accuracy of models.

There is a significant lack of studies on the ecological goods and services within the Columbia River Basin, which could be a significant area that the Treaty is overlooking due to the lack of attention paid. Future studies could use contingent valuation to estimate the actual recreation value provided by the Basin, or estimate the value of transportation services of the Columbia River by estimating the cost to replace such a service.

In addition, continued understanding of the environmental and social implications of climate change impacts would be helpful in illustrating the full cost to Canadians of operating Called Upon flood control, which would help illustrate a more complete picture of what the post 2024 flood control would look like.

References

2004 SCC 38, British Columbia v. Canadian Forest Products Ltd..

BC Ministry of Energy and Mines. (June 25, 2013). U.S. benefits from the Columbia River Treaty - past, present and future: a province of British Columbia perspective. Victoria: BC Ministry of Energy and Mines.

Bloodworth, G., & White, J. (2008). The Columbia Basin Project: Seventy-Five Years Later. Yearbook of the Association of Pacific Coast Geographies 70 , 96-111.

Canadian and U.S. Entities. (July, 2010). Columbia River Treat - 2014/2024 Review - Phase 1 Report.

Cohen, S., Miller, K. A., Hamlet, A. F., & Avis, W. (2000). Climate Change and Resource Management in the Columbia River Basin. Water International , 253-272.

Columbia Basin Trust. (2006). Climate Change in the Canadian Columbia Basin: Starting the Conversation. Columbia Basin Trust.

Desvousges, W., Smith, V., & McGivney, M. (1983). A Comparison of Alternative Approaches to Estimating Recreation and Related Benefits of Water Quality Improvements. Washington, DC: US Environmental Protection Agency.

Dietz, T., Ostrom, E., & Stern, P. (2003). The Struggle to Govern the Commons. Science , 1907-1912.

Giordano, M., & Wolf, A. (2003). Sharing Waters: Post-Rio international water management . Natural Resources Forum , 163-171.

Goodstein, E., & Matson, L. (2004). Climate change in the pacific northwest: valuing snowpack loss for agriculture and salmon. In forthcoming in frontiers in envrionmental valuation and policy.

Government of British Columbia. (2012). BC Decision on Columbia River Treaty. Victoria: Government of British Columiba.

Grzybowski, A., McCaffrey, S., & Paisley, R. (2010). Beyond International Water Law: Successfully negotiating mutual gains agreements for international watercourses. Pacific McGeorge Global Business and Development Law Journal .

Hearns, G. (2010). Analysis of Process Mechanims Promoting Cooperation in Transboundary Waters. Vancouver: University of British Columbia.

Interagency Agricultural Projections Committee. (2012). USDA Agricultural projections to 2021. Washington, D.C.: United States department of agriculture.

IPCC. (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. IPCC.

Lane, O., Cohen, S., Murdock, T., & Eckstrand, H. (2011). Climate Change Impacts and Adaptation in the Canadian Columbia River Basin: A Literature Review. Vancouver, BC: Columbia River Trust.

Loomis, H., Kent, P., Strange, L., Fausch, K., & Covich, A. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics , 103-117.

Osborn, R. (2012). Climate Change and the Columbia River Treaty. Washington Journal of Environmental Law & Policy , 77-123.

Pacific Climate Impacts Consortium (PCIC). (2006). Preliminary Analysis of Climate Variability and Change in the Canadian Columbia River Basin: Focus on Water Resources. Pacific Climate Impacts Consortium (PCIC).

Paisley, R., & Hearns, G. (2006). Some Observations from Recent Experiences with the Goverance of International Drainage Basins. In Precious, Worthless or Immeasurable: the Value and Ethics of Water (pp. 73-103). St, Lubbock: Texas Tech University .

Payne, J. T., Wood, A. W., Hamlet, A. F., Palmer, R. N., & Lettenmaier, D. P. (2004). Mitigating the effects of climate change on the water resources of the Columbia River Basin. Climatic Change , 233-256.

Penfold, G. E. (2012). A review of the range of impacts and benefits of the Columbia River Treaty on Basin communities, the region and the province. Victoria: BC Ministry of Energy, Mines and Natural Gas.

Schneide, S. H. (2002). Climate Change Policy: A Survey. Island Press.

Schnorbus, M., & Rodenhuis, D. (April, 2010). Assessing Hydrologic Impacts on Water Resources in BC. Victoria: Pacific Climate Impacts Consortium (PCIC).

Shrestha, R. R., Berland, A. J., Schnorbus, M. A., & Werner, A. T. (2011). Climate change impacts on hydro-climatic regimes in the peace and Columbia watersheds, British Columbia, Canada. Pacific climate impacts consortium. University of Victoria, Victoria: PCIC.

The Governments of the United States of America and Canada. (1961, January 17). Treaty relating to cooperative development of the water resources of the Columbia River Basin (with Annexes).

U.S. Army Corps of Engineers; Bonneville Power Administration; B.C. Hydro. (1964-2013). Annual Report of the Columbia River Treaty - Canada and United States Entities.

U.S. Entities. (2013, December). U.S. Entity Regional Recommendation for the Future of the Columbia River Treaty after 2024. Retrieved from Columbia River Treaty 2014/2024 Review: http://www.crt2014-2024review.gov/Files/Regional%20Recommendation%20Final,%2013%20DEC%202013.pdf

U.S. Geological Survey. (2013). Nutrient and Suspended-Sediment Transport and Trends in the Columbia River and Puget Sound Basins, 1993–2003. U.S. Department of the Interior.

UNEP. (2005). The Millennium Assessment Framework: Ecosystem and Human Well-Being. Washington, DC: Island Press.

United States Envrionmental Protection Agency. (2013, April 4th). About the Columbia River . Retrieved September 8th, 2013, from Columbia River: http://www2.epa.gov/columbiariver/about-columbia-river

US Army Corps of Engineers Northwestern Division. (2011). White paper on Columbia River post-2024 flood risk management procedure. Portland, Oregon: US Army Corps of Engineers.

Washington State Department of Ecology. (2011). The 2011 Columbia \river Basin Long-Term Water Supply and Demand Forecast . Pullman, WA: Washington State Department of Ecology.

Wolf, A., Stahl, K., & Macomber, M. (2003). Conflict and Cooperation Within International River Basins: The Importance of Institutional Capacity. Corvallis, Oregon: Oregon State University.

Appendix A

Types of US Storage Available for Flood Control

There are seven types of reservoir spaces that may contribute to flood storage requirements in the US:

1. US projects authorized for system flood control
2. Projects authorized for local flood control
3. Canadian power drafts
4. Grand Coulee Operations
5. Effective use storage at US reservoirs
6. Incidental storage (uncertain)
7. Called-upon storage in Canadian reservoirs.

The Phase 1 report has categorized these storage spaces into 3 tiers. Tier 1 storage would be sufficient for years with at water supply forecast at the Dalles of less than 120 Maf. Tier 2 storage will be implemented for those years where water supply forecast is between 120 Maf to 130 Maf, and tier 3 storage will be needed for years with water supply forecast greater than 130 Maf. The Canadian Called-Upon storage falls into the Tier 3 category.

In their Phase-I study; both Canadian and US Entities have predicted that Called Upon flood management will be needed 52 times out of the 70 years of record using recent SRDs. In a second phase study, both Canadian and US Entities have deemed that the frequency of Called Upon over the 70-year study period is between 4 to 6 times. No reason was given for the large discrepancy between the studies, but it has been stated that the Phase-II study is closer to actual operation.

Another option available to the US Entity is to request Canada change reservoir releases to aid in flood risk management. In this situation, the planned refill of the Canadian reservoirs would be modified by a call from the US during the refill period to reshape the refill operations in Canada. This would likely occur in larger water years (between 110 - 130 Maf) when the US has not requested additional drafts, but due to changes in runoff shape or volume, the US requests that Canada modify the planned rate of refill.

Appendix B

Derivation of Annual Flood Control Benefits Offered to the US

Average flood control benefits to the US of 1 maf of Canadian reservoir storage:

$$\mathrm{B} = \sum_{k=0}^{n} \binom{n}{0} (maf \times x) \div (1 + r)^{\mathrm{n}}$$

Where:

B= $32 \times (10)^9$*: the $32 billion in total benefits to the US from Canadian storage between 1964 - 2012*[13]

Maf = 15.5: annual 15.5 maf of Canadian storage offered to the US between 1964 and 2012

x*: Monetized value of average annual benefits offered by Canadian storage between 1964-2012*

r = 3%: discount of 3% used in calculations

n = number of years into the past between 1964-2012

Solving for x, the average annual benefits offered by Canadian storage = $79.3 million.

[13] (BC Ministry of Energy and Mines, June 25, 2013)

Appendix C

Derivation of Total CUFC benefits offered to the US between 2024 and 2074

Based on the estimated value of the annual flood control benefits offered to the US and the forecast Called Upon storage volume presented by both the Canadian and US Entities, the estimated average called-upon volume needed would be 1.3 maf with a maximum of 2.3 maf if the flood control objective is set at 600 kcfs, and CUFC would be used for at least 21 times; whereas the estimated average reservoir volume needed for CUFC would be 1.5 maf, with a maximum of 3.4 maf if the flood objective is to be set at 450 kcfs, where CUFC would be used at least 52 times.

As such the range of flood control benefits to the US is calculated as:

$$b \times maf \times n$$

Where

b=79.3: the present value of monetized average flood control benefit offered by 1 maf of Canadian storage in 2012 dollars,

Maf: volume of Canadian storage needed by CUFC

n: number of times CUFC is needed

Thus, the range of CUFC benefits to the U.S. is between $2.1 billion to $14 billion in the 50 year period between 2024 and 2074.

Appendix D

Derivation of incremental CUFC benefits due to climate change offered to the US between 2024 and 2074

As stated in section 4.1, using hydrological models from PCIC, I have estimated that the impact of climate change would imply a corresponding increase of 3% to 19% of incremental flood risk in the US portion of the CRB. Assuming that the economic damage from increased flood risk is directly proportional and linearly related to changes in flood risk, the increases of flood risk due to climate change would result in a corresponding 3% to 19% increase of benefits to the US from CUFC.

If the flood objective is set at 600 kcfs, then CUFC would be used on at least 21 occasions, with an average reservoir volume needed of 1.3 maf.

As such, the baseline CUFC benefits for having the flood objective set at 600 kcfs is

$$\$79.3\ million \times 1.3maf \times 21 = \$2.1\ billion$$

Given the increase of 3% to 19% due to climate change, the incremental benefits of CUFC (B_{cc}) then becomes

$2.1*3 %< Bcc<$2.1*19%

Thus, B_{cc} is between $63 million to $0.4 billion.

If the flood objective is set at 450 kcfs, then CUFC would be used on at least 52 occasions, with an average reservoir volume needed of 1.5 maf.

As such, the baseline CUFC benefits for having the flood objective set at 450 kcfs is

$$\$79.3\ million \times 1.5maf \times 52 = \$6.2\ billion$$

Given the increase of 3% to 19% due to climate change, the incremental benefits of CUFC (B_{cc}) then becomes

$6.2*3 %< Bcc<$6.2*19%

Thus, B_{cc} is between $0.19 billion to $1.18 billion.

Appendix E

Derivation of incremental CUFC impacts to Canadian hydroelectricity generation

In order to monetize the impact of CUFC on hydroelectricity generation in Canada, the average price of electricity in BC was used as a proxy for the value of the foregone power production. The average price of electricity in BC was multiplied by the quantity of lost power production to obtain the value of foregone electricity.

Average residential rate of electricity in BC in 2024 is forecasted to be $0.078/KWh ($78/MWh), which is used as a proxy for the cost generating one additional unit of electricity.

The annual loss of electricity generated if the flood control objective is set at 600 kcfs is 1,927,200 MWh.

Thus, the annual value of the loss of electricity for BC is $150 million. Given that under the flood control objective of 600 kcfs, CUFC would be used at least on 21 occasions, the total value of average loss of generation is approximately $ 3.2 billion.

The annual loss of electricity generated if the flood control objective is set at 450 kcfs is 1,515,480 MWh.

Thus, the annual value of the loss of electricity for BC is $118 million. Given that under the flood control objective of 600 kcfs, CUFC would be used at least on 52 occasions, the total value of average loss of generation is approximately $6.15 billion.

Appendix F

Derivation of Value of EG&S in the CRB

Loomis et al. found that monthly WTP per household was $21 per month with a 95% confidence interval of $20.50 - $21.65 for the increase in ecosystem services along the South Platte River.

Due to the fact that the Loomis et al. study did not include demographic variables such as income, education, or age in their final model, it is not possible to adjust the WTP estimates according to differing demographics (However, it can be noted that average household income in the Platte river basin is similar to that in the Columbia River Basin (<8% difference).

Within the Canadian portion of the CRB, there are approximately 1 million people, constituting 0.4 million households who may be impacted by changes in the EG&S offered by the CRB. Thus using the unadjusted WTP values from the Loomis et al. study and applying the value to the number of households in the CRB, the WTP to preserve an ecosystem within the CRB is calculated to be approximately $108 million annually, with the potential range of $105 million to $112 million calculated based on the confidence intervals in the Loomis et al. study. The WTP indicate a desire to preserve such EG&S as carbon sequestration and storage, soil retention, water purification by wetlands and riparian habitat, and habitat for wildlife.