Liquid assets: The Value of North Eastern British Columbia's Groundwater Resources in the Face of Climate Change and Competing Uses

by

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Abstract

Northeastern British Columbia will experience future groundwater scarcity as a result of climate change and competing uses of water. The Government of British Columbia (BC) now regulates groundwater for the first time in history through the Water Sustainability Act (WSA). The WSA allocates water based on a first-in-time, first-in-right system which does not promote sustainability or efficiency.

This study uses lessons learned from water management in Australia's Murray-Darling Basin, Alberta's South Saskatchewan River Basin, California's Kern County Subbasin, and Colorado's Denver Basin to formulate policy options for sustainable and efficient groundwater management in BC.

This study recommends that the BC Government begin a water market pilot program, continue to collect data about BC's water, begin a groundwater banking feasibility study, and increase the price of water to capture more rents.

Keywords: Groundwater; Northeastern British Columbia; Public Policy; Drought; Climate change

Dedication

For my loved ones and all who enjoy fresh, clean water.

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List of Acronyms

BC	British Columbia
CEF	Critical environmental flow
DB	Denver Basin
EC	Environment Canada
EFN	Environmental flow needs
FITFIR	“First-in-time, first-in-right”
KCSB	Kern County Subbasin
KCWA	Kern County Water Agency
MDB	Murray-Darling Basin
ML	Megalitre
M^3	Cubic metre
NEBC	North Eastern British Columbia
NEWS	Northeast Water Strategy
OGC	Oil and Gas Commission of British Columbia
RWM	Regional water manager
SSRB	South Saskatchewan River Basin
SWP	State Water Project (California)
WSA	Water Sustainability Act

Glossary

Groundwater	Water found in pores, cracks, and crevices in the earth that feeds wells, springs, rivers, and lakes (BC Gov, 2015a; Nowlan, 2005).
Environmental Flow Needs (EFNs)	"[The] volume and timing of water flow required for the proper functioning of the aquatic ecosystem of the stream" (MOE, 2015, p. 4)
Ecosystem services	Services provided by the environment, such as clean air and fresh water.
Precautionary principle	"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (United Nations Environment Programme (UNEP), 1992: Principle 15).
Resiliency	Resiliency is the "ability of a social-ecological system […] to persist, learn, change, and/or transform in response to a wide range of disturbances without compromising future adaptability" (Krievins et al, 2015, p. 2).
Surface water	Water in rivers, lakes, and streams on Earth's surface
Sustainability	A system's ability to function now and in the future

Executive Summary

Over the coming decades our waterways, lakes, and groundwater aquifers will face increasing pressure from climate change and water extraction. Cumulative impacts of resource development and climate change will impact watersheds in North Eastern British Columbia (NEBC) near Fort St. John, and could jeopardize access for municipal, industrial, and agricultural water uses and water for ecosystems. Although BC's water policies were recently updated, they do not provide mechanisms or incentives to efficiently manage water or adequately account for future scarcity. Thus, the policy problem is that BC's current groundwater management system is inadequate to sustainably manage water when drought or shortages arise that result from climate change and increasing withdrawals of water by competing uses.

BC introduced the Water Sustainability Act (WSA) on 29 February 2016. The WSA regulates groundwater use (other than for domestic purposes) with licencing, and prioritizes water rights using the First-in-time, First-in-right (FITFIR) system. Under FITFIR senior license holders (i.e. users who received a license first) retain full or partial water access rights while junior license holders (i.e. those who received a license later) may have their access rights reduced or revoked if water supply is insufficient to meet cumulative demand in a management area. The WSA does not account for the end-use values of water and does not promote efficiency.

To understand different approaches to water management, I examined four jurisdictions that use have groundwater management strategies: Murray-Darling Basin (MDB) in Southern Australia, the South Saskatchewan River Basin (SSRB) in Southern Alberta, the Kern County Subbasin (KCSB) in California's Central Valley, and the Denver Basin (DB) in Colorado.

Based on case study findings, I present four policy solutions beyond the status quo as represented in the WSA and FITFIR and evaluate them for their ability to sustainably manage water in NEBC. The policy options are: (1) a share-based system where users lose equal access to water during shortage, (2) a use-based system that allocates water based on type of water use, (3) a water market to allow users to trade water licenses, and (4) a groundwater bank to store surface water in.

This study recommends the introduction of a water market pilot program in NEBC to test its ability to allocate water efficiently and equitably. FITFIR is retained due to its dominance as a right, but permit holders who have lower valuations for their water will be able to sell to users who have a higher marginal value. I also recommend more robust data collection and sharing of information to increase our understanding of BC's water stocks and flows. My policy recommendations treat ground and surface water as an integrated resource to facilitate sustainable water management.

Chapter 1. Introduction

Groundwater is a vital but nearly invisible resource. Stored in pores, cracks, rocks, and soil below Earth's surface, it feeds Canada's wells, springs, lakes, and rivers. (Nowlan, 2005; Government of British Columbia (BC Gov), 2015a). Although Canada contains about 20 per cent of the world's freshwater resources, only about 7 per cent is renewable within a human lifespan (Gleeson *et al*, 2015). The remainder is fossil water contained in aquifers, glaciers, and lakes (Environment Canada (EC); 2012 Gleeson et al, 2015). Roughly one-third of Canadians rely on groundwater as their primary source of drinking water, 80 per cent of whom live in rural and remote communities (Nowlan, 2005).

According to the BC Government's Ministry of Environment (MoE) (n.d.), the largest consumers of groundwater in BC are industry (55 per cent), followed by agriculture (20 per cent), municipalities (18 per cent), and rural domestic users (7 per cent). Canadians are large water consumers on average and use about 60 per cent more water than other OECD countries (MoE, n.d.). British Columbians consume an average of 350L per-person, per-day, about a quarter more than the average Canadian (excluding industrial and agricultural uses) (BC Gov, n.d.). Our high water consumption isn't yet a widespread issue but seasonal droughts have caused many Canadians to anticipate future water scarcity.

Over the next century our waterways, lakes, and groundwater aquifers will face increasing pressure from climate change and water extraction (Stoett, 2012). Watersheds in North Eastern British Columbia (NEBC) near Fort St. John will face increasing pressure from the cumulative impacts of resource development and climate change (BC Gov, 2015a). In particular, rapid expansion of hydraulic fracturing (fracking) for shale gas in this region is placing stress on local water resources. Continued exploitation will contribute to a decline in water availability, which will cause competition between different uses of water such as industry, agriculture, municipal/domestic, and environmental uses in ecosystem services (BC Gov, 2015a). For these reasons, NEBC provides a good test case for assessing the existing method of allocating groundwater in BC and where new policies could be considered. Figure 1 illustrates the location of the NEBC region of British Columbia.

Figure 1: Northeast BC

Source: Google Maps, 2016

1.1. Policy Problem and Study Goals

Policy makers in BC currently know very little about groundwater stocks, flows, and uses. This is because groundwater was unregulated until 29 February 2016 when BC's Water Sustainability Act (WSA) was introduced. BC's WSA requires users to be licensed to extract groundwater, mandates monitoring and reporting of water use, and introduces a water rights prioritization system for use during water shortage. However, the WSA does not account for the end-use value of water and does not promote efficient water use.

In light of climate change, resource development, and over extraction, policy makers need to understand the relative values of groundwater for competing uses, and trade-offs between allocating water for different uses. Once the relative values of water are better understood, policy makers can allocate water more efficiently to protect water rights for valuable uses. Given that little is known about the future impacts of climate change and over extraction, sustainable water management that accounts for efficiency is essential.

Thus, the policy problem is that BC's current groundwater management system is inadequate to sustainably manage water when drought or shortages arise that result from climate change and increasing withdrawals of water by competing uses.

The goals of this study are to analyze competing uses of groundwater in NEBC, and then to evaluate alternative groundwater management policies. The goal of good water management policies is to account for the value of water's end uses, promote conservation and efficiency, and prioritize water for environmental and essential household needs.

Although surface and ground water are essentially interconnected and it is difficult to isolate one or the other, this study emphasizes groundwater management because groundwater was only recently regulated in BC whereas surface water has been regulated for many years. Ultimately, sustainable groundwater management policies should also treat ground and surface water as an integrated resource. The goal of this study is to recommend an integrated water management strategy, but special attention is paid to groundwater.

1.2. Study Outline

The outline of the capstone is as follows. Chapters 1 through 4 provide background and context for the policy problem through an outline of the current state of groundwater in BC, including the causes and impacts of scarcity, uses of water, cumulative impacts of resource development, policy context, water valuation methods and challenges, and information about the Water Sustainability Act. Chapter 5 contains case studies of four comparable jurisdictions where groundwater allocation policy exists. Case studies provide valuable information about the effectiveness of different groundwater policies and management approaches. Chapter 6 introduces the policy analysis framework used to analyze the policy options introduced in Chapter 7. Chapter 8 contains a policy analysis and Chapter 9 contains a policy recommendation. Chapter 10 describes study limitations.

Chapter 2. Groundwater in North Eastern BC

BC's water supplies vary seasonally and geographically. Winters can be notoriously rainy while summers are progressively becoming hotter and drier (Wilson, 2014). Groundwater levels have declined in summer months in BC in the past 40 years as measured by a small number of observation wells. Several regions in BC already experience drought, such as the Okanagan Valley, Vancouver Island and the Gulf Islands (Moore, Allen, and Stahl, 2007). The drought in Summer 2015 was an sign to many of the impacts that climate change could have on our water resources and a reminder to policy makers of the importance of sustainable water management (BC Gov, 2015b).

The next sections outline the main causes of water shortage in BC: climate change and over use.

2.1. Climate change: impacts on water

Earth's temperature is rising and climate patterns are changing. This will alter hydrological systems in at least four important ways (Wilson, 2014). First, diminished winter snowpack will result in a decline in spring and summer runoff and subsequently reduce groundwater aquifer recharge, especially during peak drought periods in the summer. Second, earlier snowmelt and earlier peak spring runoff or freshet in May and June will result in more flooding. Third, although stream flow will increase during the rest of the year, lower water flows in August and September will result in dry conditions and more droughts in summer and fall. Fourth, higher average temperatures will result in increased evaporation and evapotranspiration that will accelerate the movement of water out of regional hydrological systems. Overall, summers will be hotter and drier while winters will be warmer and wetter, and extreme weather events will become more commonplace year-round. Two additional outcomes of climate change are increased intensity, frequency, and severity of forest fires, and an increase in annual growing days and frost-free days (Wilson, 2014).

The Intergovernmental Panel on Climate Change (Kundzewicz et al, 2007) and the Council of Canadian Academies (CCA) (2009) predict that warmer temperatures will lead to less groundwater recharge during key times of the year. They predict that surface water will become less available, because it is more susceptible over extraction and to the effects of rising temperatures from climate change, so groundwater will be used as a substitute. However, groundwater is slow tor recharge so over extraction could jeopardize futures supplies.

In addition, sea level rise in other areas of BC could impact the Peace Region indirectly by increasing demand for agricultural land in the region, consequently increasing water requirements for irrigation (Wilson, 2014). Unfortunately, there is limited data on groundwater stocks in BC because users were not required to report levels of extraction until the WSA was implemented in February 2016. According to Rivera (2005, p. 12), "the limited current knowledge is the main obstacle to improving groundwater regulation". Further, there is limited information on the exact future impacts of climate change and cumulative impacts of resource development in NEBC (CCA, 2014).

2.2. Water extraction: main uses and impacts

Table 1 reports license allocation quantities for the main consumptive uses[1] of water in NEBC in 2014 in declining order of quantity. In the next section, I will evaluate the use of water in industry, municipal/domestic, and agricultural uses, as well as in ecosystem services, an important non-consumptive uses. It is important to remember, as previously noted, that limited data exists on groundwater usage because users were not required to obtain licenses, monitor, or report use until February 2016. Therefore, most information in the next sections if from surface water licensees.

[1] Some license-holders, like BC Hydro, have non-consumptive uses of water. These license-holders are not considered in this study because they have a smaller impact on water resources.

Table 1: Consumptive water licenses in NEBC, 2014

Consumptive use	Amount (million m^3)[2]	Proportion
Industry (oil and gas, mining, forestry)	43	69%
Municipal/domestic	15	25%
Agriculture (including range)	3.6	6%
TOTAL	61.6	100%

Sources: BC Gov (2015a)

2.2.1. Industry

Industry holds 69% of BC's consumptive water licenses (BC Gov, 2015a). Table 2 displays the amount of water allocated to different industrial uses in NEBC in 2014. Oil and gas, coal mining, and forestry use the most water in BC. Water use for resource development is expected to increase in the next 20 years in NEBC (BC Gov, 2015a); As stocks of surface water are depleted in the future, water users will need to extract more groundwater as a substitute which will consequently increase competition between users and impact groundwater stocks (CCA, 2009).

Table 2: Industrial water licenses in NEBC, 2014

Consumptive use:	Amount (million m^3)
Oil and gas	20
Mining	12.6
Forestry	9.8
Road maintenance	0.6
TOTAL:	43

Source: BC Gov (2015a)

Oil and gas operations account for 20 million m^3 of water license allocations within the industrial sector, mostly from hydraulic fracturing (fracking) operations (Boyd, 2014). The recent rapid expansion of fracking has drawn public attention to both the quantity of water used in the process and potential surface and ground water contamination (Gage,

[2] One cubic metre (m3) is equal to 1000 L of water.

14 November 2013; McDiarmid, 30 April 2014). According to the Oil and Gas Commission's 2014 report by Jonathan Boyd, the total amount of water used in NEBC for 643 fracking wells was approximately 8.3 million m^3. The amount of groundwater used from 31 source wells was 785 thousand m^3, and the average amount of water used for fracking in 2014 was 12.8 thousand m^3 per well. Most water used in fracking is from surface water licenses and short-term approvals (11.3 million m^3 in 2014) and eight per cent was sourced from service wells or groundwater sources (BC Gov, 2015a).

There is limited information about the impacts of fracking in NEBC, and to date, "[t]here has never been a confirmed case of groundwater contamination in B.C. as a result of hydraulic fracturing" (BC Gov, 2013). However, there are public concerns over potential groundwater contamination. The process of fracking is unpredictable and involves high pressure injection of fracking or 'frac' fluid[3] into shale rock, causing the rocks to fracture. Research by many agencies into the impacts of fracking is ongoing. The US Congress commissioned the Environmental Protection Agency (EPA) to research fracking; the EPA study is currently available in draft form. The Canadian Council of Academies (CCA) reports that "impacts on water raise the greatest environmental concern by shale gas development" (CCA, 2014: 2); and these impacts "are the most uncertain and controversial" (CCA, 2014: 62).

The CCA report (2014) and EPA report (2015) report that the greatest threats to groundwater from the fracking industry are:

1. Contamination of groundwater aquifers from:

    a) spills of fracture fluid (CCA, 2014; EPA, 2015),
    b) produced water,
    c) fracturing directly into groundwater aquifers,
    d) underground migration of liquids and gases, and
    e) inadequate fracturing fluid and produced water treatment (EPA, 2015);

2. Water extraction in areas with low availability (EPA, 2015), and during the driest times of the year when demand from agriculture is also high (Becklumb, Chong, and Williams, 2015); and

[3] Industry reports the contents of frac fluid to Fracfocus.ca, a chemical disclosure registry.

3. The impact of industrial expansion on the future stock of groundwater, given the predicted decline in availability of surface water (CCA, 2009).

The EPA report found a small number of specific cases of groundwater contamination compared to the total number of fracking wells, and did not find widespread, systemic groundwater contamination. However,

> This finding could reflect a rarity of effects on drinking water resources, but may also be due to other limiting factors. These factors include: insufficient pre- and post-fracturing data on the quality of drinking water resources; the paucity of long-term systematic studies; the presence of other sources of contamination precluding a definitive link between hydraulic fracturing activities and an impact; and the inaccessibility of some information on hydraulic fracturing activities and potential impacts (EPA, 2015, p. ES-6).

This statement reiterates that one of the major challenges facing examination of the impacts of fracking on water supplies is limited information and uncertainty.

2.2.2. Agriculture

Agriculture consumes a large proportion of water through evaporation from storage, evapotranspiration, and irrigation (CCA, 2013). Additionally, agricultural practices can compromise water quality through leeching of pesticides, fertilizers, and waste into surface and groundwater systems (CCA, 2013). Water use for agriculture is seasonally variable: higher in the summer and lower during periods of high precipitation (CCA, 2013). Crop irrigation and drinking water for livestock comprise most water use (CCA, 2013). Agriculture is a key part of the economy in NEBC. The Peace Region produces up to 90 per cent of BC's grain, 95 per cent of its canola, almost 23 per cent of BC's beef cattle, and three-quarters of BC’s bison (Crawford and MacNair, 2012). Overall, the amount of water allocated through licenses for agriculture in NEBC in 2014 was 3.6 million m^3 (or about 6 per cent of total water allocation) (BC Gov, 2015a). This number does not represent groundwater used in agriculture in NEBC because users did not have licenses. The amount of groundwater used for agriculture will become clear within the next year when all agricultural groundwater users obtain groundwater licenses.

Peak irrigation demand for agricultural water users comes in late summer when surface water stocks are lowest (Statistics Canada, 2013), and this demand will increase in the future as climate change reduces summer rainfall (CCA, 2013). The increased demand for water at a time of low surface water supply will likely increase the amount of groundwater used as a substitute for surface water.

2.2.3. Municipal and domestic

The population of Fort St. John is 18,609 (Stats Can, 2016). NEBC's population is growing at an annual rate of 1.3 per cent, which is faster than all regions outside of the Lower Mainland (BC Stats, 2013). Water for the town of Fort St. John is accessed through five shallow wells beside the Peace River with an average daily flow of 9000 m^3 per day for a yearly flow of 3.285 million m^3 (Fort St. John (FSJ), 2013a). The city also has two reservoirs which are used during peak demand periods; The reservoirs hold 6800 m^3 and 36400 m^3 of water and have an average turnover of 18 hours and four days, respectively (FSJ, 2013a). Although there are wells for rural and domestic water users in the region, it is again impossible to determine the amount of water consumed as reporting is not required.

The City of Fort St. John's average per-capita daily water consumption was 550 L in 2008 (FSJ, 2013b), over 1.5 per cent higher than Canada's average. The City reports that since the installation of water meters in 2006 (Saxe, 24 May 2011) as a conservation measure, average water consumption has decreased by 20-25 per cent[4] (FSJ, 2013b). Climate change may reduce water availability for municipal and domestic water users in the City of Fort St. John, especially during summer months. Conservation measures by the municipality are a step in the right direction, and more should be encouraged. However, due to the low aggregate consumption of municipal and domestic users relative

[4] No recent information exists to confirm this number

to that of industry and agriculture, this research focuses on policies targeting the other sectors.

2.2.4. Ecosystem services

Ecosystem services represent an important non-consumptive use of water in NEBC. According to a report by Wilson (2014), the Peace River watershed in NEBC provides at least 12 of the 22 ecosystem services identified by the Economics of Ecosystems and Biodiversity (TEEB), an initiative of the G8+5 countries to measure ecosystem services and incorporate their values into decision-making[5]. Ecosystem services provided by ground and surface water include water supply, wetland soil carbon storage, flood control, nutrient recycling, water filtration, waste treatment, habitat, recreation, and cultural values. These ecosystem services are directly related to water quantity and quality in an ecosystem. Wilson (2014) placed a value of $204.6 billion[6] on ecosystem services of the Peace River watershed over a 50-year period.

2.2.5 Summary

Resource development – particularly oil and gas extraction – has expanded quickly in NEBC with impacts on local ecology, hydrology, and communities. Resource development will increase demand for water in NEBC. Surface and ground water will face pressure from climate change and over extraction. Cumulative impacts from resource extraction will cause environmental degradation and weaken ecosystem resilience (Wilson, 2014).

2.3. Groundwater valuation

Water is highly mobile, both across landscapes and between physical states. It is difficult to lay claim to and manage specific quantities of water as they are likely to flow to another region or evaporate. Groundwater is difficult to value for a multitude of factors; the

[5] For more information, see TEEB, 2012, and www.teebweb.org
[6] Using a 3 per cent discount rate

most problematic are the lack of knowledge about where it flows, its recharge rate and stock at any point in time. Groundwater is an open access resource where most of the time it is either not possible or cost-effective to exclude others from using the resource (Young and Loomis, 2014). Industry's prevalent use of water has resulted in numerous environmental and social externalities and equity issues. Finally, moral issues about rights to access water further complicate water pricing.

Externalities

In addition to being a requirement for life, water is a nearly universal solvent, meaning it can be used to clean, process, transport, and dilute, and is thus in high demand because it is extremely valuable to many human uses. The actions of any one user will have many impacts on nearby users, whether these are recognized and acknowledged or not. This is true for commercial, industrial, municipal/domestic, and environmental uses (Young and Loomis, 2014). These consequences, typically not accounted for in market prices of goods and service, are referred to as externalities. They are negative (or occasionally positive) consequences of market activities that are not included in market prices. For example, a negative externality from agricultural processes is contaminated water leaching into local streams or seeping into groundwater, leading to excessive levels of nitrates that can damage human health.

Equity

Equity issues exist in the distribution of costs and benefits of water extraction. Water used for industrial purposes represents a concentrated benefit but diffuse cost. A small number of industrial operators benefit from their (nearly) free access to water and the costs (i.e., reduced quantity of available water) are spread diffusely across society. Industry can easily recognize the value of water for their operations whereas the public may not be acutely aware of the diffuse costs. Thus, a small number of industrial operators benefit from exploiting this open access resource and have a vested interest in maintaining their access, while the public experiences small but cumulative costs.

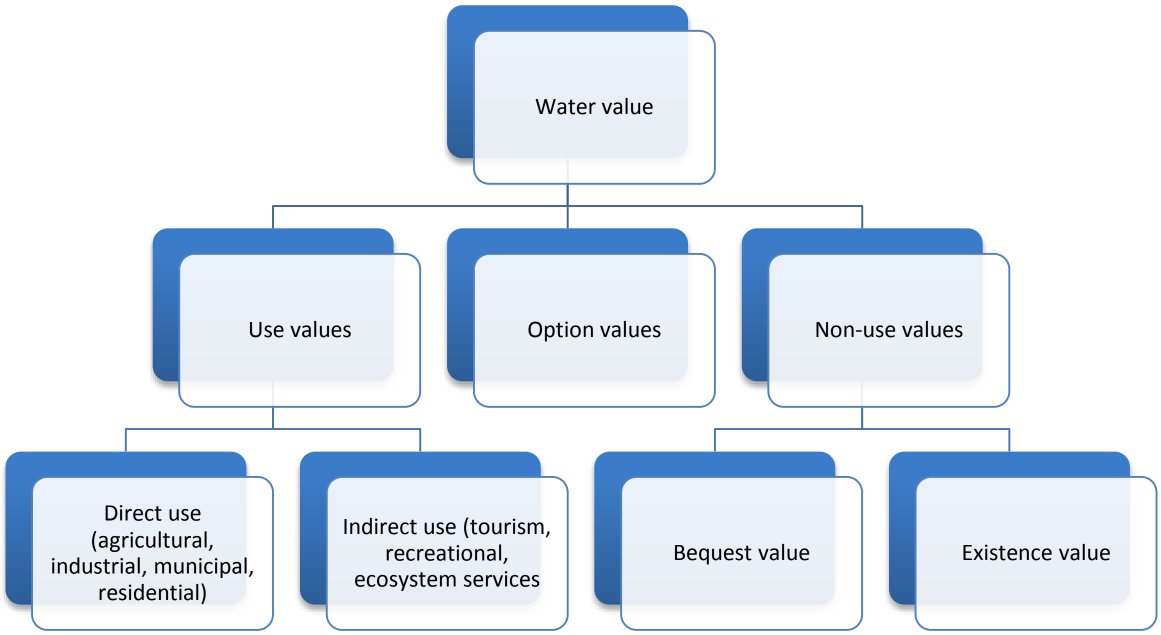
Moral and ethical considerations

There are moral and ethical considerations associated with placing a monetary value on groundwater. Some argue that monetizing water degrades its value, and some cultures and religions consider water to be sacred (Young and Loomis, 2014). Some people are concerned that placing a monetary value on water will result in inequity because the price of water will become prohibitively high and restrict access for some people (Stoett, 2012; Young and Loomis, 2014). Indeed, because water is essential to life there is a strong argument for free or low-cost universal access. I recognize this and think that water for essential household needs and ecosystem services should be protected, but that doesn't mean it should be free. Placing an economic value on water can help policy makers make decisions that account for the value of water resources, so water valuation is actually an important step in sustainable water management. It is important to recognize water's value for non-market uses, such as ecosystem services, in order to ensure the sustained existence of fresh, clean water (Young and Loomis, 2014).

2.3.1. Economic valuation: approaches and challenges

Economists measure water's value though the change in people's welfare that results from a policy change that changes user's water access (Young and Loomis, 2014). Change in welfare is measured through individuals' willingness to pay (WTP) to maintain their current level of welfare, or individual's willingness to accept compensation (WTA) to accept a lower level of welfare. Figure 2 shows categories of water value that can be measured using different methodologies.

Figure 2: Water value categories



Source: Kulshreshtha (1994), Qureshi et al (2012), Young and Loomis (2014).

Economic value of water is easiest to measure when water contributes to the value of a good that is traded in the market. This is referred to as a direct use value. For example, water contributes to the total value of soft drinks, car manufacturing, and canola harvest. It is possible to isolate the portion contributed by water from the total output value of each of these goods (Young and Loomis, 2014).

Many indirect use values of water are difficult to measure, such as an ecosystem's use of water for flora and fauna, or the recreation value of a lake. For example, groundwater contributes to the value of ecosystem services in many ways but it can be difficult to determine these values and at times the services themselves are unknown (Qureshi *et al*, 2012). Valuation of ecosystem services and natural capital is an increasingly accepted practice and there are a number of organizations[7] that have developed specific methodology and criteria for valuation (TEEB, 2012).

[7] Such as The Economics of Ecosystems and Biodiversity (TEEB), Artificial Intelligence for Ecosystem Services (ARIES), and Wealth Accounting and the Valuation of Ecosystem Services (WAVES).

While some ecosystem services involve direct or indirect uses that can be valued through market prices or proxies, others, such as option, bequest, and existence benefits are more challenging to monetize (Qureshi *et al*, 2012; Wilson and Carpenter, 1999; Shaffer, 2010). Option value refers to peoples' willingness to pay for preserving the option to use a resource in the future. Bequest value refers to willingness to pay for the preservation of a resource for the benefit of future generations. Existence value is willingness to pay for the mere existence of a resource, like a beautiful lake or a river. Generally, these values are obtained through some form of willingness to pay estimate such as contingent valuation. Techniques to measure these values are fraught with challenges due to their hypothetical nature, and thus estimates can vary substantially among research studies for the same ecosystem service (Shaffer, 2010; Qureshi *et al*, 2012).

Placing a value on groundwater will not solve all of the issues we face in managing this open access resource but it is an important first step in promoting sustainable management of Canada's wealth of water. Given the expected decline in groundwater stocks in the future it is essential to place a value on groundwater so that its use reflects its actual value. According to Rivera (2005, p. 12), "we should take advantage of the pre-development conditions that seem to prevail in Canada to assess our aquifers before it is too late".

Chapter 3. Methodology

The purpose of this study is to formulate and analyze policy options that promote the best use of water, especially groundwater. This study uses qualitative analysis to analyze effective management policies. The methodology for the study uses two qualitative components:

1. A literature review of BC's water management policies.
2. A cross-case analysis of policy, management, and regulation in comparable jurisdictions

3.1. Case studies

The case study examines four jurisdictions that have implemented groundwater management policies. The four jurisdictions use different strategies to manage their groundwater resources and have achieved varying levels of success. Investigating the creation and outcomes of these policies helps to shed light on factors that lead to success or failure and generate lessons about effective groundwater management.

3.1.1. Case study selection criteria

Case studies were chosen based on the following criteria:

1. The region has implemented groundwater management policies or practices
2. The main uses of water include at least one of the following: agricultural, municipal and domestic, industrial, or ecosystem services

Chapter 4. BC's Water Sustainability Act

The Province of BC owns all water in BC and manages it on behalf of the public (BC Gov, 2016). The Water Sustainability Branch of the BC Government's Ministry of Environment (MoE) regulates water in BC[8] under Bill 18, the Water Sustainability Act (WSA). The WSA came into force on 29 February 2016 and the century-old Water Act was repealed. Prior to the WSA, surface water was regulated under the Water Act and groundwater rights was unregulated. Rights to groundwater aquifers were assumed to be held by landowners (Brandes, Nowlan, and Paris, 2008).

Public consultation informed the WSA and the act addresses issues of climate change and impending water scarcity. The WSA regulates ground and surface water as an integrated resource. The WSA introduces groundwater monitoring to increase knowledge about the state of BC's groundwater, mandatory groundwater licensing for users, and a water access priority system to be applied during periods of water scarcity.

The WSA's policies regarding groundwater licenses and access priority, environment and stream health, and climate change are pertinent to this study. The following sections discuss strengths and weaknesses of the WSA in these three areas.

4.1.1. Groundwater licenses and access priority

The WSA requires authorization of groundwater extraction for anything other than domestic use (BC Gov, 2016a). The BC Government grants groundwater access in the form of licenses or use approvals. Licenses grant groundwater users (eg: municipal, industrial, agricultural, utilities) permanent water access for one or more use purpose, whereas use approvals authorize water diversion for a timespan of less than 24 months (Bill 18, 2014, 10). Water users are required to pay a nominal fee for groundwater. The fee does not reflect an actual value of the resource but instead is set to cover the

[8] BC has jurisdiction over water that does not cross provincial or international boundaries. BC's Oil and Gas Commission (OGC) is in charge of granting water licenses for oil and gas extraction (Parfitt, 2011).

administrative costs of the Water Sustainability Branch (BC Gov, 2015c). The WSA also requires groundwater users to report the quantity of water that they use, which allows the Government of BC to monitor groundwater use for the first time in history (BC Gov, 2015c)[9].

The WSA's water rights priority system is referred to as First-in-time, First-in-right (FITFIR) and is used to control water use priority during drought or scarcity (BC Gov, 2015c). Under FITFIR senior license holders (i.e. users who received a license first) retain full or partial water access rights while junior license holders (ie: those who received a license later) may have their access rights reduced or revoked if water supply is insufficient to meet cumulative demand in a management area (BC Gov, 2015c). BC's surface water rights were managed through FITFIR under the Water Act and will continue to be under the WSA. In the case that two licensees hold the same priority date, priority is then based on water use purpose, and water use purpose priorities are ranked in Section 22:7 of Bill 18 (2014) as follows:

- Domestic
- Waterworks
- Irrigation
- Mineralized water
- Mining
- Industrial
- Oil and gas
- Power
- Storage
- Conservation
- Land improvement

Water for essential household needs (up to 250 litres per day of water for each private dwelling for human and animal needs) and for critical environmental needs take top priority over the above water use priorities during drought or scarcity (Bill 18, 2014).

[9] Water licensees from the oil and gas industry have been required to report water use quantities since 2014 to the Oil and Gas Commission (Boyd, 2014).

The FITFIR system has three main benefits: it is easy to understand and administer, new licensees enter the system knowing that they will hold lower priority and therefore can base decisions on this certainty, and it is the way surface water rights were managed under BC's Water Act (BC Gov, 2013). The key shortcoming of FITFIR is that it does not consider type of water use or the relative value put on the water by different users, and hence, will most likely lead to inefficient use of water. By establishing water rights at a point in time and not operating any sort of market to exchange water rights, reallocation from low value users who happened to have the senior rights to new, high value users is not possible and the system is likely to be allocatively inefficient.

There is no plan at present to regulate deep saline aquifers under the WSA. Salinity is believed to indicate disconnection to freshwater sources, and this water is considered unfit for domestic use due to its salinity and because it often contains hydrocarbons. Water from deep saline aquifers is a viable substitute for freshwater for use in industries like fracking and other oil and gas extraction (BC Gov, 2013). Although more research into the impacts of fracking on groundwater sources is needed, it is possible that water from deep saline aquifers could be extracted and used in fracking in NEBC. This would reduce demand for freshwater in the region.

4.1.2. Environment and stream health

The BC Government defines stream health as a measure of a stream's ecological integrity and function, ability to provide environmental services, and resilience to disturbance (BC Gov, 2013). The Regional Water Manager will be required to consider Environmental Flow Needs (EFNs) for surface and groundwater license applications under the WSA. The WSA defines EFNs as "the quantity and timing of flows in a stream that are required to sustain freshwater ecosystems, including fish and other aquatic life" (BC Gov, 2013, p. 18).

Nearly all new water license applications will be required to complete at least a simplified EFN Assessment in the application process, and some will be required to provide additional information in a more detailed assessment (BC Gov, 2013). License applications that are exceptionally low-use and low-risk and do not pose any threat to fish or fish habitat may be exempt from EFN assessment (BC Gov, 2013). Existing license holders will not be required to undergo an EFN assessment unless they are required to undergo a license assessment. Decision-makers will retain the right to limit water allocations by reducing junior license holder allocations to protect the environment during times of water shortage (BC Gov, 2013).

The MOE's EFN Policy, effective 15 June 2015, establishes a risk management framework for EFNs that has three risk management levels plus a special considerations level (Table 3).

Table 3: EFN policy risk management levels

Risk:	Aquatic environment details:	Actions:
Level 1	Sufficient water available, cumulative water withdrawals below threshold of concern	• May require additional information from applicant or licensee if sensitive species or habitats are present
Level 2	Flow-limited, or cumulative water withdrawals are above threshold of concern	• Possibly require additional information from applicant or licensee • Applicant or licensee may be required to minimize impacts on EFNs through license terms and conditions
Level 3	Very flow-limited, or cumulative water withdrawals are above a threshold of concern	• Additional information likely required • More rigorous review of potential risk • License terms and conditions likely
Special consideration	Sensitive species or habitats	• Require site-specific information to determine risk management level

Source: MOE, 2015

The policy states that:

> In situations where a water allocation decision will significantly impact on environmental flow needs, the comptroller or regional water manager may refuse the application or specify conditions for water use. […]
>
> This policy can be used where there is limited site-specific hydrological or biological data; however, the trade off for its simplicity is a conservative estimate of cumulative

> withdrawal thresholds that would have minimal impact on EFNs (MOE, 2015, p. 3).

Thus, the WSA aims to set conservative limits on groundwater extraction that take into account EFNs and sensitive species and habitats. Adaptive management is identified as “particularly important with climate change projections for shifts in streamflow hydrographs and increasing variability” (MOE, 2015, p. 8) and will be used through monitoring to update policies.

4.1.3. Climate change

The WSA offers several improvements over the Water Act to address the impacts of climate change on water systems. First, the WSA includes adaptive management to facilitate integration of new information into water management. This addresses changing conditions from climate change (BC Gov, 2013) and increases flexibility in water allocation to enable adaptability in future approval decisions in light of changing conditions (BC Gov, 2013). Second, the WSA uses FITFIR and the policy risk management levels to limit negative environmental and economic impacts during periods of water shortage. Third, the WSA regulates groundwater for the first time, meaning decision-makers may limit abstraction during periods of drought and scarcity and collect valuable water demand information.

The WSA will introduce critical environmental flow (CEF) thresholds for ground and surface water to supplement EFNs. EFNs are intended to protect environment and stream health in the long term, while CEF thresholds protect environment and streams in short-term situations when low flows could result in severe damage to ecosystems (BC Gov, 2013). The WSA regulates ground and surface water short-term use approval and license holders in an integrated way to protect CEF thresholds.

4.2. Northeast Water Strategy

BC created the Northeast Water Strategy (NEWS) in March 2015 as a policy outline and context for integrating the WSA into NEBC. The strategy’s goal is "the responsible use and care of water resources through conservation and sustainable practices to ensure human and ecosystem needs are met now and into the future" (BC Gov, 2015a, p. 4). The goal will be met through the following five action areas, specifically designed to integrate the WSA to meet the needs of NEBC:

1. Improve information resources and address knowledge gaps. This is achieved by improving water quality and quantity data, implementing a NEBC water research strategy, creating a protocol to gather and integrate traditional knowledge into the strategy, and determining current and future water needs for different water uses, particularly First Nations, agriculture, and oil and gas.
2. Create new regulations and implement existing regulations to strengthen the regulatory regime. This is achieved through the WSA in 2016 which improves environmental objectives by introducing the following regulations: making consideration of Environmental Flow Needs (EFNs) of streams necessary, including water objectives in land use planning, regulating and protecting groundwater, auditing to achieve security, efficiency, and conservation of water, monitoring and reporting for large users, and encouraging local involvement. Current regulations will be fortified through stakeholder (including First Nations) engagement during regulation development, improving oil and gas monitoring and reporting, and bolstering environmental protection by encouraging use of alternatives to fresh water where possible (eg. deep saline aquifers).
3. Coordinate and streamline decision-making processes. This is achieved by coordinating overlapping water management activities, sharing knowledge and data, and by working collaboratively with First Nations and other partners to periodically revise and update the strategy. This also includes implementing cumulative impacts frameworks, promoting conservation in decision-making, supporting development of Water Sustainability Plans in priority watersheds, and building capacity within First Nations for participation in enforcement, oversight, and reporting.
4. Support adaptive management by enhanced monitoring and reporting by industry and government. This is achieved through producing regular "state of" reports that report water quantity, quality, aquatic ecosystem health, cumulative impacts assessment, monitoring and reporting on impacts of climate change. Web-based reporting of surface water quality and quantity data through the North East Water Tool (NEWT), a GIS-based tool built by the Oil and Gas Commission (OGC) and Ministry of Forests, Lands,

and Natural Resource Operations (FLNRO), provides information about surface water quantity in NEBC to support decision-makers (BC OGC, 2015). Additionally, this objective improves compliance and enforcement of water activities and involving First Nations in monitoring, enforcement, and reporting.

5. Build a water stewardship ethic in NEBC. This is achieved by making water quality and quantity data publicly available, improving collaboration and communication, and promoting stewardship, conservation, and efficiency. A multi-party Water Working Group will be established, including First Nations, provincial, federal, local governments, regulators, industry, and academia.

4.3. Discussion: Strengths and shortcomings

The full impact of the WSA will not be clear until after it is fully implemented in 2017 but it is possible to draw some conclusions about its strengths and weaknesses by analyzing the WSA and the NEWS.

Strengths:

- Introduces groundwater regulation
- Requires monitoring and reporting of groundwater use
- Improves water quality and quantity data
- Uses adaptive management to respond to changing conditions
- Sets conservative EFNs to protect ecosystems
- Plans for First Nations involvement
- Streamlines decision-making and regulatory processes (eg. CEFs)
- Manages surface and ground water as an integrated resource

Shortcomings:

- Does not account for water's end use value
- Does not require or incentivize efficient water use or water conservation
- No security of water rights for new high value water users
- Price of water does not encourage efficiency

- Does not call for research directly into the impact of fracking on groundwater
- Price of water does not reflect economic value or social value
- Junior license holders may lose some or all water access during shortage

The WSA is an important step for BC towards sustainable water management. The case studies in Chapter 5 provide a number of different water management strategies that are used in other jurisdictions. Some aspects of these approaches address the WSA's shortcomings.

Chapter 5. Case Studies

This chapter contains results from case studies of four jurisdictions with groundwater management policies. The chosen jurisdictions have experienced groundwater scarcity, exacerbated by climate change and over extraction. They have implemented groundwater management policies and can be used as a testing ground for water management policy. This chapter examines the relative successes and failures of management policies in different jurisdictions and provides a basis for policy options for groundwater management in NEBC.

5.1. Locations

The case studies jurisdictions are the Murray-Darling Basin (MDB) in Southern Australia, the South Saskatchewan River Basin (SSRB) in Southern Alberta, the Kern County Subbasin (KCSB) in California’s Central Valley, and the Denver Basin (DB) in Colorado. Each case study jurisdiction serves as an example of a solution to the problems facing NEBC. The MDB addresses the problem of inefficient water allocation and water scarcity through a water market (MDBA, n.d. d). The SSRB is the only Canadian example of a water market (AWP, 2013). The KCSB is a major fracking centre in California and provides an example of a water banking system (WAKC, 2016). The DB takes a prior appropriation approach to groundwater licensing, similar to BC, but attempts to improve equity and efficiency of water use by junior and senior holders through augmentation plans (CDGR, 2012).

5.2. Results from case studies

This section sets the policy context of each case study jurisdiction by outlining water rights are allocated and reassigned, and the history of water management. Table 4 outlines the regulatory context of each case study jurisdiction and the first section of each case study explains each case in more detail.

Table 4: Case study characteristics

Name:	Murray-Darling	South Saskatchewan	Kern County	Denver
Location:	**Australia**	**Canada**	**USA**	**USA**
Water rights allocation:	Share-based	Seniority-based (FITFIR)	Seniority-based (riparian rights and prior-appropriation)	Seniority-based (Riparian rights and prior-appropriation)
Water rights reassignment method:	Tradable (water market)	Tradable (water market)	Increased supply (groundwater banking)	Increased supply (augmentation plans0
Governing bodies:	6 Government bodies, 36 water resource plan areas	Alberta Government	Kern County Water Agency, an agency of the State Water Project which is overseen by the California Department of Water Resources	Colorado Division of Water Resources
Main uses of water:	Agricultural	Agricultural, municipal, industrial	Agricultural, industrial, municipal	Municipal

5.2.1. Murray-Darling Basin, Victoria, New South Wales, Queensland, and South Australia, Australia

Australia's Murray-Darling Basin (MDB) is over 1 million square kilometres. It spans the states of Queensland, New South Wales, Victoria, and South Australia. Water Resource Plans are required by the 36 water resource plan areas in the MDB to manage water resources (MDBA, n.d. e). In 1997, the Australian Government placed a cap on further extraction of water in the MDB, relaxed water license transfer regulations, and reduced water transaction costs to create water market (Wheeler *et al*, 2014).

Overview of water rights

State governments in the MDB assign water rights via water licenses through entitlements or allocations (MDBA, n.d. d). Entitlement holders have permanent rights to access a share of the MDB's water based on the total amount of water available in the basin each year. In the MDB water market, entitlement holders may sell their entire entitlement permanently through an entitlement trade that transfers water rights from one user to another. Access can also be traded permanently via allocation trades that transfer a set quantity of water from seller to buyer for one-time use (MDBA, n.d., d). Allocations can be transferred between water license holders (ie: users who have a water entitlement) on a day-to-day or short-term basis (MDBA, n.d., d).

The MDB's National Water Market System is an information management system intended to make water trading information available in real time (Grafton and Horne, 2014). The system facilitates license trading by allowing prospective license buyers to identify license holders who wish to sell their license or allocation.

Outcomes of water markets in the MDB

The MDB's water markets have resulted more efficient water use, more efficient water allocation, local economic benefits, and increased environmental flows (Wheeler *et al*, 2014). Most water allocations and entitlements have been purchased by horticultural and dairy farmers, who typically have higher value crops, from large-scale crop operations, or 'broadacre' farmers, who typically produce lower value crops (Wheeler *et al*, 2014). This reflects efficiency gains and a transfer of water rights from low to high value uses: dairy and horticultural farmers gain more economic benefits from water use, and broadacre farmers can adapt farming habits to conserve water.

Water trading in the MDB has positive impacts on local economies and ecosystems. According to Grafton and Horne (2014), water trading in the MDB has increased the gross regional product by $370 million, reduced the social and environmental impacts of drought, and reduced drought-related risk for towns, cities, and industry. Grafton and Horne (2014) also report that water markets have resulted in increased volume of end-of-system flows in Murrumbidgee, Goulburn, and Lodden Rivers, even during drought.

The price of water in the MDB water market is responsive to changes in supply and demand and reflects the value of different types of entitlements (for example, more reliable water entitlements are worth more than less reliable entitlements) (Grafton and Horne 2014). The price of water licenses fell sharply at the end of the Millennium Drought. "Australia's experience with water markets in its MDB illustrate that markets, in conjunction with an effective regulatory and compliance framework, can contribute towards achieving a sustainable balance between the environment and agriculture" (Grafton and Horne, 2014, p. 67).

5.2.2. South Saskatchewan River Basin, Alberta, Canada

The South Saskatchewan River Basin (SSRB) in Alberta has been closed to new water license applications since 2006 as a response to high demand and uncertainty of water supply (AWP, 2013). License trading was permitted after the cap was implemented, and Canada's first water market was created.

Water rights in the SSRB

Similar to BC, water access rights in the SSRB are based on seniority, meaning older licenses have priority over newer licenses (Weber and Cutlac, 2014). License holders with seniority have priority over junior licensees during periods of water shortage, and junior licensees access may be reduced or suspended (Weber and Cutlac, 2014).

Sellers in the SSRB's water market can trade a portion of their license allocation or the full allocation on a temporary or permanent basis (AWP, 2013). A set amount of water is transferred in the case of a partial transfer, whereas an entire license amount is traded in a full transfer. Much like allocation transfers in the MDB, a temporary transfer in the SSRB reallocates water from the license holder to the transferee for a predetermined, temporary period of time. A permanent transfer in the SSRB functions like the MDB's entitlement transfer and permanently transfers the allocation from seller to buyer. License priority is attached to the water license and therefore is transferred to the buyer in both temporary and permanent transfers (Weber and Cutlac, 2014).

All permanent transfers undergo a public review to assess potential third-party effects and hydrological consequences. Licenses are subject to a 10 per cent holdback (ie: a 10 per cent reduction in the quantity of water allocated to the licensee) of water in the allocation for water conservation objectives (WCO) (ie: water that is left in the stream) (AWP, 2013; Weber and Cutlac, 2014).

Senior irrigation licensees hold 75 per cent of water licenses and municipalities hold 14 per cent (Weber and Cutlac, 2014). Some municipal allocations are at risk during scarcity because some irrigation licensees hold higher priority than municipalities (Weber and Cutlac, 2014). Irrigated water use is expected to increase by 50 per cent by 2030 (Weber and Cutlac, 2014). Sixty-eight per cent per cent of median flows are allocated in the SSRB (Weber and Cutlac, 2014).

Outcome of water markets in the SSRB

Very few temporary or permanent transfers have taken place in Alberta's water market (Cutlac and Horbulyk, 2011). According to Cutlac and Horbulyk (2011) this is because "procedural restrictions coupled with monetary and nonmonetary transaction costs tend to limit the actual use of these transfer provisions in practice" (p. 93). Using the Aquarius model, Cutlac and Horbulyk (2011) assess optimal annual uses of water between agricultural irrigation and urban/industrial uses (environmental uses of water are not considered to be a user in the model, but instead are a constraint on water flows in the basin). The authors conclude that the current economic benefit of water use in the SSRB, $930 million per year, is well below what it could be under optimal allocative conditions, $1,123 million (Cutlac and Horbulyk, 2011).

Weber and Cutlac (2014) find that Alberta's current water market system is inefficient. First, there is uncertainty surrounding the review process and holdback rules that discourages trade. Second, there is no formal institution to match sellers and buyers or track market prices resulting in high search and negotiation costs.

The environmental impacts of the SSRB's water market are unclear. Some of the SSRB's ecosystems are already degraded and there are concerns that because not all licenses are being fully used – only about 39 percent of allocations are consumed – full use of allocations that may result from license trading could cause more damage to already jeopardized ecosystems or impact currently healthy ones (Bjornlund, Xu, and Wheeler, 2014). For example, if a license that was previously only partially used is traded and the new user consumes 100% of the license's allocated water, there may not be enough water left for other users or EFNs.

Local perceptions of water markets have important implications on water use in the SSRB because there is "an increasing fear that if they (licensees) do not start using more of their licensed water, the government might force them to share it" (Bjornlund, Xu, and Wheeler, 2014, p. 175). Therefore, it is possible that some licensees will begin to extract more water than they currently are to secure their access, which will further degrade sensitive river areas.

Although a cap was placed on extraction in the SSRB in an effort to protect ecosystems, the SSRB's water market may result in increased water use if licensees extract more water in fear of losing their allocations or because when licenses are purchased, new licensees will more fully use water licenses (Bjornlund, Xu, and Wheeler, 2014).

5.2.3. Kern County Subbasin, California, USA

Kern County (KC) is located in California's Central Valley. The city of Bakersfield in KC receives an average annual 6.45 inches of precipitation (US Climate Data, 2016). The region relies heavily on water to irrigate 800,000 acres of farmland (Christian-Smith, 2013) for energy production, including oil, natural gas, and hydroelectric power, and for resource and mineral exploration (Kern Economic Development Corporation, 2015).

Landowners in KC have the right to extract underlying groundwater and put it to 'beneficial' use without approval by a court or water board (California Water Boards (CWB), 2015). This is known as a riparian or overlying right (Moran and Cravens, 2015). A user must obtain approval through the courts to put groundwater to use outside the basin, which is known as an appropriative right. Appropriative groundwater rights are seniority-based like BC's FITFIR system (Moran and Cravens, 2015).

Groundwater banking

KC began groundwater banking in the 1970s to increase water supply during the dry season (Christian-Smith, 2013). KC's groundwater banks collect surface water during periods of precipitation (seasonally or during wet years) and pump it underground into aquifers for use during dry periods.

According to KC's Groundwater Agency there is about 12.3 billion m^3 of storage capacity available in KC (Christian-Smith, 2013). KC is well suited to groundwater banking because its water-permeable silt and sand geology allows for underground water storage (Water Association of Kern County, 2016). The KC Water Association (KWCA) (2011) estimates that 4.2 billion m^3 of water have been recovered for use since 1987 and over $300 million has been spent to build groundwater banking infrastructure (KWCA, 2011). Banks can be owned publicly, privately, or through a public-private partnership.

The Semitrophic Groundwater Storage Program is a groundwater bank in KC. Six partners deliver a proportion of their water license allocations to the bank each year and then the water is extracted during dry seasons (Clifford, Laundry, and Larsen-Hayden, 2004). Groundwater banking costs include initial capital costs and ongoing administrative costs like water input and withdrawal fees, annual operation and maintenance (Clifford, Laundry, and Larsen-Hayden, 2004).

Outcomes of groundwater banking

KW's groundwater banks have been a success overall. Groundwater banking treats ground and surface water as an integrated resource and ensures responsible management and stability of water supply. It allows for flexibility in water storage in use storing excess water for use during dry summer months. Groundwater banking is especially well suited to climate change because climate change will increase precipitation and runoff during all times of the year except summer, when water access is most crucial. Additionally, groundwater stored underground in aquifers is not susceptible to evaporation, an important consideration because climate change will increase evaporation of water during the hotter, drier summer months (Christian-Smith, 2013).

Groundwater banking can have positive environmental outcomes by increasing water availability to meet local environmental objectives. For example, KC's Rosedale-Rio Bravo Water Storage District's plan ensures adequate water for ecosystem needs by mandating that for every two units of water banked, only one unit may be withdrawn and one unit must remain in the aquifer (Christian-Smith, 2013).

There are some drawbacks to groundwater banking. It is limited to areas where aquifers are accessible, easy to fill and pump from, and are not vulnerable to subsidence, liquefaction, or water quality issues (Christian-Smith, 2013). Another drawback to groundwater banking in California is uncertainty over water rights resulting from California's litigious groundwater regulation system. For example, landowners could theoretically claim water from water banks or extract water without permission if water banks have not secured rights through courts. Therefore, any groundwater management plan "is in jeopardy of being undermined by users claiming that the scheme violates their property rights" until rights are determined by courts (Moran and Cravens, 2015, p. 16). Additionally, water transfer rights issues are raised as water is transported in and out of regions (Christian-Smith, 2013).

5.2.4. Denver Basin, Colorado, USA

Colorado's Denver Basin (DB) provides groundwater for domestic, industrial, agricultural, and municipal uses (CGS, 2003). The basin's four aquifers have experienced continual decline of water levels over the past 20 years (CGS, 2003).

Water rights in Colorado

The Colorado State Water Court grants ground and surface water licenses (NCSL, 2013). Water rights can be granted on conditional or absolute terms. Conditional terms last until the given project is complete, at which time the licensee may apply for an absolute right (NCSL, 2013). Water rights granted on an absolute basis are permanent, and considered "decreed water rights" (NCSL, 2013).

The DB's water regulations evolved as a result of a series of water conflicts throughout the twentieth century (Cech, 2010). Colorado's water rights were based on riparian rights which give surface water access rights to adjacent landowners and groundwater access rights to above land owners, provided water is put to beneficial use (Cech, 2010). Colorado adopted the Doctrine of Prior Appropriation in 1876 to ensure water access for senior license holders. However, conflict arose because surface and ground water were regulated separately (the former being regulated according to Prior Appropriation, the latter mostly lacking regulation), but groundwater extraction was impacting surface water volumes and limiting surface water license holders access to their water allocations (Cech, 2010). Surface water license holders lobbied and the State responded in 1969 with the Water Rights Determination and Administration Act. This Act "stated that all tributary irrigation wells had to follow the same priority system of water allocation described in the Colorado Constitution" (Cech, 2010, p. 309). As a result, groundwater license holders now held lower priority water licenses than most surface water licensees.

The Denver Basin introduced augmentation plans in an attempt to make water access more equitable between groundwater license holders (who now mostly held lower priority licenses) and surface water license holders (mostly senior license holders) (Cech, 2010). Augmentation plans allowed junior license holders to use water as long as they returned enough water to the stream to meet senior licensees' allocations[10] (CDGR, 2012). Augmentation plans come into effect when water is scarce. A senior water right holder may place a "call" for water in the case of water shortage which revokes some or all of junior water rights access to water, and augmentation plans allow junior licensees to continue to use water during a call. Augmentation plans must be supported by an engineering analysis and are usually prepared by a water resources engineer. They must show how the water needs of the new project will not jeopardize senior licensees (CDGR, 2012).

Water for augmentation plans could be sourced reusable municipal effluent, water rights to a ditch or reservoir, and groundwater recharge, which includes diversion of water during rainy season to a dry streambed or lined gravel pit (Cech, 2010). The last method is similar to groundwater banking in that water can be collected and stored during rainy periods and released into the stream during dry periods.

Outcomes of augmentation plans

Augmentation plans were effective during wet periods but problems arose during the 2002 and 2006 droughts. Low flows reduced water availability and compromised senior license holders water access. The State responded in 2005 with a court decree

[10] Augmentation plans are made possible because many water uses are not consumptive, so water can be used and returned to the watershed (sometimes after it has been treated).

mandating more stringent water accounting and prohibiting pumping unless there was sufficient water to replace all of the previous year's pumping. Many junior licensees were unable to find water to fit their augmentation plans and lost water access. The situation worsened for many groundwater licensees during the 2006 drought when 400 wells were not allowed to pump water for crops that had already been planted (Cech, 2010). This resulted in lost cropland, jobs, tax revenue, and agricultural business, especially in small agricultural communities (Cech, 2010).

5.3. Discussion

Each case study jurisdiction's experience provides important lessons about water rights allocation and reallocation during scarcity. The case studies exemplify five broad solutions to water rights allocation and water scarcity: seniority-based allocation, share-based allocation, water markets, use-based allocation, and increasing supply. They provide two additional lessons about managing water during scarcity: monitoring and reporting of water, and treating ground and surface water as an integrated resource. The following sections further discuss these six lessons.

5.3.1. Seniority-based allocation

Seniority-based allocation encompasses priority-based allocation (prior appropriation) and FITFIR. The seniority-based allocation system is most common throughout the case studies: the DB and KC allocate water rights based on prior appropriation, the SSRB uses FITFIR, and BC's WSA uses FITFIR.

Denver Basin's experience illustrates the inequity and economic losses that can result from seniority-based water allocation systems. The junior licensees in the DB had their water access suspended during drought years, resulting economic losses, while senior licensees retained full or partial access rights. This occurred despite the DB's efforts to mitigate the shortcomings of seniority-based allocation through augmentation plans.

As previously discussed in section 4.1.1, seniority-based systems allow junior licensees to plan for reduction or revocation of water rights, and this certainty can be seen as a benefit.

5.3.2. Share-based allocation

The MDB allocates water rights each year as a share based on the total amount of water available in the basin, constrained by environmental flow needs. Share systems are more equitable than seniority-based license allocation systems. In a share system, *all* users face a proportional reduction of water rights subject based on water availability whereas in a seniority-based system only junior licensees face reduction or revocation of rights. Thus, the impact of water shortage in a share system is spread more equally over license holders (Weber and Cutlac, 2014). Share systems can result in a more efficient allocation of water when they provide more water to junior licensees if those users have higher marginal values for water (Weber and Cutlac, 2014).

Share systems can allocate water rights ex-ante or ex-post. Australia's MDB uses an ex-ante share system to determine water entitlements each year. An ex-post share system would use real-time water quantity information to adjust allocation quantities. Such a system would reduce all allocation quantities by a set proportion in the case of shortage.

There are several drawbacks of share systems. Adopting a share system in BC presents a political challenge because it would require a significant change to the current system. Senior license holders would experience a reduction in their access rights while junior license holders would gain access. A share system may not result in allocative efficiency, depending on junior and senior license holders' marginal values for water. For example, if junior licensees have factored risk into their choices, or if they have more elastic demands or lower willingness to pay for water, then a share system would not result in allocative efficiency (Weber and Cutlac, 2014).

5.3.3. Water markets

The MDB experience shows that well managed water markets increase allocative efficiency of water uses, provide local economic benefits, and allow for environmental needs to be met (Wheeler *et al*, 2014). For example, license holders in the MDB with low value crops tended to sell their licenses to farmers with higher value crops. The MDB system has also resulted in entitlement trades to the Australian Government for environmental uses (Wheeler *et al,* 2014).

In contrast, the SSRB experience has yielded little success[11] (Weber and Cutlac, 2014). According to Weber and Cutlac (2014), the difference between the MDB and SSRB may be explained by the absence of a centralized water market information platform in the

[11] The SSRB has not experienced the same magnitude of water scarcity as the MDB. The most trading in the MDB occurred during drought years, and the SSRB has not experienced a drought to the same extent as Australia. It is possible that a severe drought could prompt more trading in the SSRB.

SSRB. The SSRB does not have a centralized trading information system to help buyers and sellers trade licenses like in the MDB, the SSRB's trading procedures are opaque, and there is uncertainty about cost. Thus, a lesson drawn from comparison between the MDB and SSRB experiences is that well functioning water markets make available information about license buyers and sellers, cost of license transfers, and details of trading procedures.

5.3.4. Use-based allocation

Use-based allocation refers to allocating water rights based on the end-use value of water. No case studies allocated water rights based on end use, but in essence this approach uses regulation to achieve the same distribution of rights as a water market, such as in the MDB. Higher value water users in a water market may purchase more water, meaning allocations end up reflecting water's end-use value. While water markets *reallocate* water rights based on end-use value, use-based allocation *initially* distributes rights based on end-use value at the time of licensing. Markets encourage licensees to adopt more efficient technology and water use practices so that they can sell excess water allocations for a profit. This achieves desirable environmental and social outcomes because it increases the total amount of water available for EFNs and for all water users. To achieve this outcome through regulation, regulators must allocate water based on a user's ability to use water efficiently by adopting efficient technology and water use practices.

Using a use-based allocation system would require a large amount of government resources. Government agencies and regulators would need to determine end-use value of water between different uses and up-to-date information about licensee's ability to adopt efficient technology and water use practices. This information would need to be reflected in water allocations and updated regularly. This is a major drawback.

5.3.5. Increasing supply

Kern County solves their water shortage problem by using groundwater banks to increase water supply. This is one of the only feasible options available to Kern County because it has such a low supply of water. Groundwater banking has several benefits. It can be low-cost and mitigate the impacts of water scarcity if the aquifer's geology allows for pumping and storage. It is particularly well suited to climate change because it provides flexible access to water, takes advantage of high winter precipitation, and safeguards against evaporation. Groundwater banking in California has facilitated economic prosperity in a drought-stricken region.

California's experience provides several lessons. First, water for environmental needs must be explicitly incorporated into water banking systems. Both the SSRB and MDB placed caps on water extraction (at least in part) to protect environmental needs so these water markets by default promoted environmental sustainability. In contrast, groundwater banking does not necessarily protect ecosystems. Groundwater banks must therefore explicitly allocate water for environmental needs where demand for water exceeds supply available for ecosystem services. The Rosedale-Rio Bravo Water Storage District's water extraction limits allocate water for environmental needs and is a good example of water banking that protects ecosystem services. Finally, groundwater bank managers must carefully monitor input and output of water to ensure equity and environmental sustainability.

The DB also attempted to solve water scarcity by increasing supply. Theoretically, the augmentation model presents opportunities to increase water availability by offsetting water supply through substitution of water sources. The DB's augmentation plans allowed junior licensees to access full water rights provided they returned equivalent quantities of water into the watershed to fulfill senior license-holders' allocations. Unfortunately, the approach was not successful in the DB during drought. However, a variation of this model could be adopted in NEBC, where water license holders could make arrangements with municipalities or other licensed water users to use treated waste water in industrial operations. Although alternative technologies exist that would reduce or eliminate the use of freshwater in fracking, none are yet widely used (Boyd, 2014) because the cost of surface water licenses is very low and the cost of groundwater is also low, based on the cost of drilling. One example is the partnership between the Town of Edson in Alberta and Shell. Edson sells municipal wastewater to Shell for use in fracking operations (AWP, 2013). Another option, which was discussed in Chapter 4, is using saline water from deep saline aquifers for industrial operations like fracking.

5.3.6. Improving information: monitoring, reporting, and research

Monitoring and reporting of water quantity and quality is important for adaptive management. Policy makers must know how much water is available, how much is being used, recharge rates, and in the case of groundwater, potential contaminants in order to effectively manage resources. Water monitoring is important in jurisdictions that frequently experience drought and would be beneficial to all jurisdictions because it improves information about water stocks and flows. The WSA introduces mandatory water monitoring and reporting for ground and surface water users, as discussed in section 4.

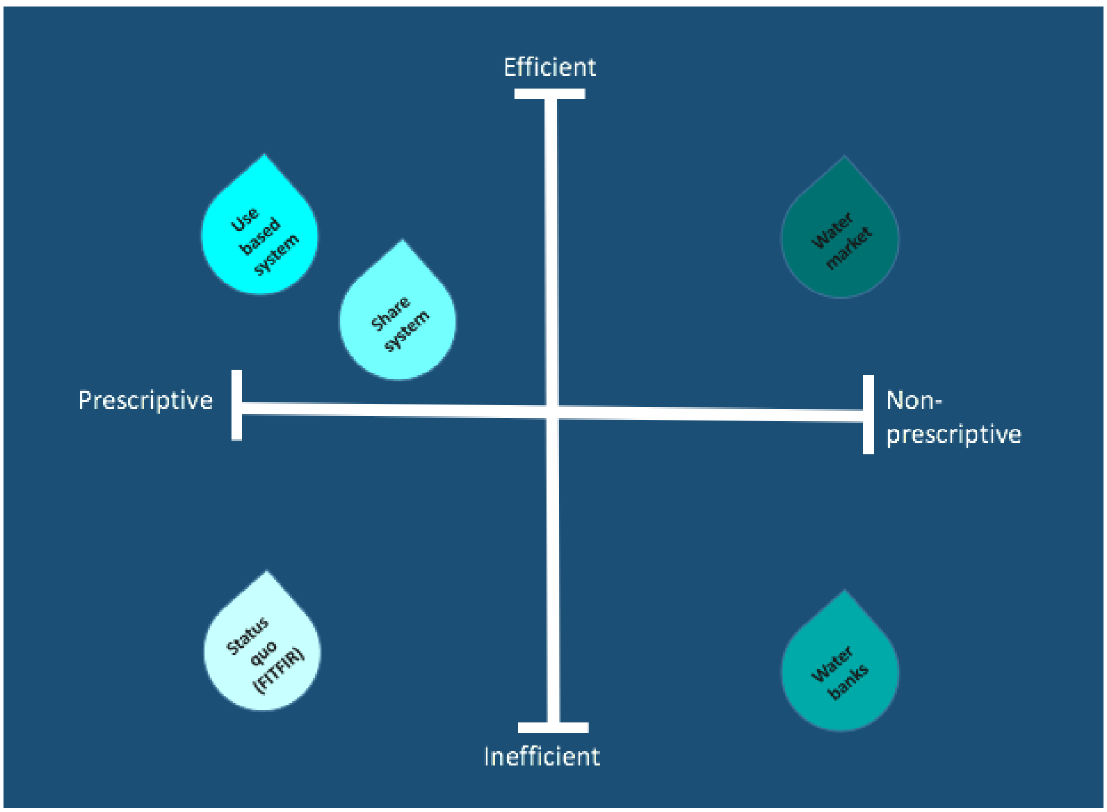
5.3.7. Treating ground and surface water as an integrated resource

Treating ground and surface water as an integrated resource encourages responsible management because the two types of water are necessarily interconnected. The DB experience illustrated problems associated with separately managing the two because unregulated groundwater extraction began to impact surface water supplies. Treating ground and surface water as an integrated resource facilitates a holistic understanding of the resource that results in better understanding of supply and demand and ecosystem needs. Data collection and analysis is a necessary first step in treating water as an integrated resource. More information about surface and ground water supply (stocks and flows) and demand (including environmental needs) facilitates understanding of the interconnection between ground and surface water.

Chapter 6. Key Considerations for Policy Options

Conceptualization of groundwater management policies as a 2 x 2 matrix in Figure 3 sets out the policy options. On one side are market-based mechanisms such as water markets and water banking that are non-prescriptive, and on the other end are prescriptive regulations. Each policy option presented in Chapter 7 incorporates a combination of management policies and can be placed somewhere on the 2 x 2 matrix, between efficient and inefficient, prescriptive and non-prescriptive.

Figure 3: Conceptualization of policy options



Source: Author

Because groundwater is an open access resource, water markets require government oversight rather than being totally ‘free’ in the economic sense. Water markets can take a number of different forms. The level of efficiency promoted by different policies varies, making some policies efficient and others inefficient as I explain below.

The ultimate goal of sustainable groundwater management policies is to ensure that societal and governmental objectives are met. Societal objectives are equity, efficiency, and sustainability, and governmental objectives are stakeholder acceptability and administrative ease. Two additional considerations are First Nations involvement and cost. Table 5 below provides details about the social and governmental objectives used to evaluate the policy options. The following sections explain societal and governmental objectives and two additional considerations.

Table 5: Societal and governmental objectives and evaluation criteria

Societal Objectives		
Objective:	**Definition:**	**Evaluation Criteria:**
Equity	• The impact that the policy has on groundwater users *relative to each other* in terms of access to groundwater during water shortage.	• Do any water users lose more access than others during shortage?
Efficiency	• The degree that the policy promotes economic efficiency by providing opportunities for high value groundwater users to access licenses	• Can high value users access water rights?
	• The degree that the policy encourages efficiency by promoting adoption of efficient practices and/or technologies.	• Are technically efficient practices promoted?
Sustainability	• The policy's ability to adapt to changing water supply and demand which result from climate change	• Is the policy flexible to changing climate conditions?
	• The policy's ability to ensure adequate water supply in the future	• Is the precautionary principle used to ensure enough water for ecosystems in the future?
Governmental Objectives		
Objective:	**Definition:**	**Evaluation Criteria:**
Stakeholder acceptability	• The impact that the policy has on groundwater users *relative to their previous level of access.*	• Do any license holders lose access relative to their previous level of access?
	• The degree of public support for the policy.	• Does the public support the policy?
Administrative ease	• The level of simplicity of policy formulation, implementation, and regulation.	• Does the policy require regulatory changes or formation of new agencies for implementation or regulation?

6.1. Equity

Equity refers to the impact that a policy has on individuals or groups who are affected by the policy relative to each other. An equitable policy is one that does not disproportionately negatively impact some groundwater users relative to others. For example, during drought an equitable policy would not fully revoke water access rights of one group while allowing full access to another, because this disproportionately negatively impacts one group.

The criterion to evaluate the equity objective:

- Do any water users lose more access than others during shortage?

6.2. Efficiency

This objective refers to economic efficiency and water use efficiency. The first is met by allowing opportunities for high value users (those whose end-use value of water is high, assumed to be the same users who place a high marginal value on water) to access adequate groundwater supplies through licenses. The second, water use efficiency, includes adoption of efficient practices and technology that reduce water waste. For example, an efficient industrial user may use a substitute in place of water or reuse waste water; an efficient agricultural user may use more efficient irrigation techniques or technology.

Two criteria define the efficiency objective:

- Are there opportunities for high value water users to access groundwater?
- Is adoption of efficient groundwater use practices and technologies encouraged?

I assess the allocation of groundwater for environmental needs under sustainability, so it is not included in the efficiency objective to avoid double counting. Groundwater for municipal and domestic use is a priority use under the WSA and it is beyond the scope of this research to assess the efficiency of these water uses. For example, municipalities typically have some form of management plan for droughts, but assessing these plans is a major research topic in itself.

6.3. Sustainability

Sustainability is defined as an ecosystem's ability to function now and in the future. The sustainability objective is reached through resilient water management. Resiliency is the "ability of a social-ecological system […] to persist, learn, change, and/or transform in response to a wide range of disturbances without compromising future adaptability" (Krievins et al, 2015, p. 2). It refers to a system's ability to undergo change without changing state.

Ecosystems provide environmental goods and services such as water supply, water filtration, and fish habitat, which are referred to as ecosystem functions. A minimum level of groundwater stocks and flows must remain in the ecosystem to ensure ecosystem functions. The WSA sets environmental flow needs (EFNs) to reflect the minimum amount of water necessary to ensure ecosystem functions. This is discussed in Chapter 4. The amount of water necessary to ensure ecosystem sustainability is different depending on the characteristics of the ecosystem. Water management policy that promotes sustainability ensures that adequate water is allocated to environmental needs. By necessity, this requires continuous monitoring and reporting on water quantity and quality as well as research into EFNs for local ecosystem functions.

Resiliency in water management refers to managing for change instead of against change (Krievins et al, 2015). A policy must be flexible in the long term as climate systems and ecosystems change. The WSA addresses resiliency through mandatory groundwater monitoring, reporting, and adaptive management. However, the sustainability objective also measures the policy's ability to adapt to short-term as seasonal variations in precipitation require different quantities of groundwater allocation. One criterion for the sustainability objective is that the policy is flexible to short-term changes in groundwater supply and demand.

The precautionary principle is an important component of sustainability. The Rio Declaration on Environment and Development defines the precautionary principle as follows:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (United Nations Environment Programme (UNEP), 1992: Principle 15).

The precautionary principle must be incorporated into planning for NEBC's water systems because relatively little is known about the region's hydrology. The precautionary principle should be considered when setting EFNs, setting groundwater license allocations, and in accepting new and existing groundwater licenses. This is especially important in the case of industrial uses of water such as fracking in NEBC. As noted by the EPA (2015), fracking has been linked to groundwater contamination in the USA. Not enough is known about the stocks and flows of groundwater in NEBC, therefore sustainable groundwater policies must use the precautionary principle when information about the impacts of groundwater extraction is unavailable or uncertain.

Two criteria evaluate the sustainability objective:

- Is the policy flexible to changing climate conditions?
- Is the precuationary principle used to ensure enough water is left in the ecosystem to support ecosystem functions in the future?

6.4. Stakeholder Acceptability

Stakeholder acceptability measures a policy's appeal to stakeholders. Table 6 summarizes the broad concerns of each stakeholder group.

Table 6: Stakeholders

Stakeholders in NEBC		
Broad group:	**Members:**	**Concerns:**
Current groundwater users	• Junior license holders • Senior license holders	• Access to groundwater • Cost of access
Public	• Residents of NEBC • British Columbians • Canadians	• Sustainable groundwater management • Water as a commodity • Economic impacts of groundwater management
NGOs (local, national, international), NEBC organizations	• Environmental • Local Economic Development Organizations • Agricultural organizations	• Conservation and preservation • Ecosystems • Sustainable groundwater management • Economic impacts of groundwater use and management
Potential groundwater users	• Agriculture • Industry • Municipal	• Access to groundwater • Cost of access
Local First Nations	• Treaty 8 • Other First Nations	• Access to groundwater • Sustainable groundwater management • Economic impacts of groundwater use and management

Current groundwater users are highly impacted by groundwater allocation policies. They are an important stakeholder group and their potential reactions to policies is an important consideration. Groundwater users' support for policies is largely determined by the changes in groundwater access that they will experience as a result of the policy. A policy that drastically reduces one group's access to groundwater will likely be highly unpopular to this group, and a policy that increases or secures access will probably be well regarded. While the equity objective measures users access to water relative to each other, stakeholder acceptability reflects changes in users' access to water relative to their prior level of access.

The public are another important group of stakeholders because they are owners of groundwater. Some issues that sparked public support and opposition are water pricing and use of water in fracking. NGOs and organizations that represent citizens and stakeholders in NEBC have varying interests and concerns for groundwater management. Environmental groups are more concerned with conservation and sustainable management, while local economic development organizations are more concerned with the economic impacts of groundwater management. Both of these groups need water now and in the future, therefore sustainable groundwater management is in their best interest.

The interests of environmental NGOs are aligned with the criteria in the sustainability objective, therefore their acceptance of policies is not assessed in the stakeholder acceptability objective. Similarly, the interests of economic development organizations are accounted for both in efficiency in the case that water use is economically beneficial, and in equity in the case that the organization represents a group of water users. Finally, the interests of potential groundwater users, while not represented today, should be incorporated so that rigidities in allocation are minimized.

Local First Nations groups are also a very important stakeholder and are considered separately, as outlined in section 6.7.

Two criteria evaluate stakeholder acceptability:

- Does the public support the policy?
- Do either junior or senior licenseholders lose access relative to their previous level of access?

6.5. Administrative Ease

Administrative ease refers to the level of ease or complexity associated with formulation, implementation, and regulation of the new policies. The administrative ease criterion accounts for the amount of regulatory changes that result from the policies and any new agencies that must be created for implementation and regulation. This objective considers resources required to undertake a policy.

The criterion to evaluate administrative ease:

- Does the policy require regulatory changes or formation of new agencies for implementation or regulation?

6.6. Weights and Measures

Criteria are assessed qualitatively using a binary (yes or no), a scale from low, to medium, to high, and description. Qualitative analysis facilitates investigation of trade-offs between policy options without creating a false sense of precision, as some information is limited in this analysis. All societal and governmental objectives are weighted equally. Table 7 outlines criteria and measures used to assess the societal and governmental objectives.

Table 7: Criteria and measures

Societal Objectives		
Objective:	**Evaluation Criteria:**	**Measure:**
Equity	Do any water users lose more access than others during shortage?	No
		Some
		Yes
Efficiency	Can high value users access water rights?	Yes
		Some barriers to access
		No
	Are technically efficient practices promoted?	Efficiency compulsory or incentivized
		Efficiency not addressed
		Efficiency discouraged
Sustainability	Is the policy flexible to changing climate conditions?	Yes
		Somewhat
		No
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Yes
		Somewhat
		No
Governmental Objectives		
Objective:	**Evaluation Criteria:**	**Measure:**
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	Yes
		Some
		No
	Does the public support the policy?	Yes
		Somewhat
		No
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	None or few
		Some
		Many

There are two important considerations in addition to the social and governmental objectives above: First Nations involvement and cost.

6.7. First Nations Involvement

The Treaty 8 First Nations and other local First Nations must be involved in any successful groundwater management policy. The WSA and the NEWS address this through collaborative management, monitoring, reporting, enforcement, and strategy. First Nations involvement is outside of the scope of this research, but First Nations involvement, as outlined in the WSA and NEWS, must be incorporated into the policy recommendation.

6.8. Cost

Cost was not assessed as a criterion because there is a risk of double counting: the cost of a policy may be reflected in the stakeholder acceptability, administrative ease, or efficiency objectives and criteria. High cost policies may be unacceptable to stakeholders who see spending as excessive. Creation of additional governmental branches and agencies incurs costs. Use efficiency incorporate cost because more efficient uses of water will ultimately lower cost. Cost is also not assessed because it is difficult to accurately estimate cost of the policy options as some of them have never been implemented in Canada, and this may lead to analysis based on inaccurate numbers.

Chapter 7. Groundwater Management Options

This section discusses policy options for water management in NEBC based on lessons learned from the case studies. The policy options presented in the following sections were analyzed separately to facilitate identification and discussion of trade-offs, but they are not mutually exclusive and in many instances are complimentary. Common to all policy options are the following:

Improving knowledge of water:

The WSA's groundwater monitoring and reporting and EFN regulation are an important component of successful groundwater management policies. Data gathered through monitoring and reporting is essential to our understanding of groundwater supply and demand. This facilitates adaptive management and flexibility.

Capturing more water rents:

The WSA has imposed a nominal fee on water extraction for licensees. This reflects government administrative costs, not any market-based price or economic value. Government is advised to increase the price of ground and surface water to enable the capture of more water rents. As shown in the MDB case study, a higher price of water discourages excessive or wasteful use, and encourages water conservation and substitution where possible through increased efficiency and adoption of new technologies. Rents collected can be used to cover operating costs of the Water Sustainability Branch, and additional revenue can be placed in a fund which may be used to supplement water research initiatives with the goal to advance information about water supply, demand, and quality. Increasing the price of water and capturing more water rents is *not* included in the status quo option.

Stakeholder engagement:

Stakeholder engagement is necessary in every policy option to some degree. Government benefits from stakeholder engagement because they gain access to local knowledge. This allows government to identify problems before they arise, allows policy makers to tailor policies specifically to local needs, and increases the likelihood of stakeholder and public buy-in for policies. The WSA was informed by extensive stakeholder engagement and this approach should continue to inform policy making.

7.1. Status quo

This policy option proposes no changes to the status quo. The WSA will be implemented as planned throughout 2016 and 2017; water will be allocated based on the FITFIR system, EFNs will remain as planned in the WSA. Water licenses are non-transferrable. Water prices will not increase and more water rents will not be captured. This option does not require stakeholder engagement beyond what is planned in the WSA.

7.2. Share system

This policy adopts a share system instead of the FITFIR system to equitably distribute water access rights. This limits the impacts of water scarcity on junior licensees. This is accomplished by equally distributing extraction limits. Under this option the burden of drought is spread equally over all water users. Municipal users of water and EFNs are exempted, but it is expected that municipalities will impiose drought restrictions on local residents and commercial water users during drought. All other licensees will be required to limit their water extraction either by the same percentage of their total license, or by a set volume of water.

As explained in section 5.3.2, this may be accomplished ex-ante or ex-post. The BC government would need to amend the WSA to change FITFIR to share system and reallocate water accordingly.

This option treats ground and surface water as an integrated resource to ensure sustainable and accurate management. Therefore, surface water must also be managed under a share system.

7.3. Use-based system

This policy is a regulated version of an efficient market that allocates water rights based on end-use of water instead of seniority. The logic behind this option is that licensees will increase water efficiency through adoption of technology and available substitutes, and that major economic losses will be avoided by identifying sectors which absolutely require water during drought. Exceptions are municipalities (who again will be expected to implement drought strategies) and EFNs.

Water users receive allocations based on the value of water use, amount of water required by the user, and opportunities for efficiency gains through technology adoption or substitutes. Water allocations reflect the amount of water users would need if they adopted technically efficient practices. Users who don’t have technical efficiency are therefore required to become more efficient because their allocation is limited to the quantity of water they would need if they were efficient.

To allocate water, the licensing authority requires information from each licensee about water use amounts, any efficiency measures taken, and amount of water absolutely required for each licensee to avoid detrimental economic losses. The licensing authority also requires updated information about available efficiency and substitute technologies in each sector. Based on this information, the licensing authority assigns water allocations each year adjusted for projected stocks and flows (ex-ante), or requires licensees to reduce their water consumption by a percentage of total use or a set measurement of water during drought (ex-post).

Similar to the share system policy option, the BC Government would need to adopt use-based management for both ground and surface water to ensure that they are treated as an integrated resource. This would require the BC Government to amend the WSA and change the way licenses are granted and change existing license allocations based on water’s end-use value. To allocate water for environmental needs, regulators could either set EFNs as a constraint on a basin’s available allocations, or allocate water for ecosystem services based on the economic values associated with water’s contribution to the ecosystem good or service. If the latter approach is taken, Government would need to lead or commission investigation into the economic value of water for ecosystem services.

7.4. Groundwater banking feasibility study

This option recommends feasibility studies to explore opportunities for groundwater banking in NEBC. The feasibility study assesses availability of aquifers, viability and cost of pumping surface water underground, rainfall patterns in the region, and seasonal variability in demand for water. Groundwater banks can be owned and operated publicly by provincial or municipal agencies, privately by a non-profit organization or for-profit corporation, or through a public-private partnership (Clifford, Laundry, and Larsen-Hayden, 2004). Privately owned water banks would be regulated by the BC government. This option treats ground and surface water as an integrated resource.

This option does not address allocation of water rights. Instead, it increases overall supply of water to reduce water scarcity, encourage use of water from banks as a substitute for groundwater abstraction, and avoid conflict over water access.

To implement this option, BC Government would need to decide on a management model (private, public, or public-private partnership), develop regulations and rules, and engage and consult stakeholders.

7.5. Water market pilot program

This option recommends that the BC government start a small-scale water market pilot program in NEBC to test the feasibility of water markets in the region. Surface and ground water are treated as an integrated resource in the water market. Water markets can be used in conjunction with FITFIR, share systems, or use-based allocation. Extensive stakeholder engagement and consultation should take place prior to the water market pilot program. This is essential to understand local challenges, including stakeholders' concerns and perceptions of water markets, to collect local knowledge about water, and to educate stakeholders about water markets.

The pilot program study area should be a well-defined aquifer or watershed where both junior and senior licensees hold allocations, and where water shortages exist. After stakeholder engagement and consultation, the government must place a cap on new water licenses, and then create a water market website.

The water market website must include, a license transfer mechanism, clear information about the water license transfer process and timelines, associated costs, a history of transactions, water use quantities, and hydrological data.

Chapter 8. Evaluation of Management Options

This section contains an analysis of the groundwater management policy options presented in Chapter 7. The policies are evaluated qualitatively using the criteria, introduced in section 6, based on the objectives – equity, efficiency, sustainability, stakeholder acceptability, administrative ease – which reflect broad societal and governmental goals that are embodied in good policies.

8.1. Status quo

Table 8: Status quo

Objective:	Evaluation Criteria:	Assessment:
Equity	Do any water users lose more access than others during shortage?	Yes (junior licensees)
Efficiency	Can high value users access water rights?	Some barriers to access
	Are technically efficient practices promoted?	Efficiency not addressed
Sustainability	Is the policy flexible to changing climate conditions?	Yes / Somewhat
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Yes / Some
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	No
	Does the public support the policy?	Somewhat
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	None or few

Equity: Status quo is not equitable because it uses the FITFIR system. The FITFIR system creates inequity between junior and senior license holders because junior licensees have less secure water rights and are subject to partial or full revocation of water rights during drought.

Efficiency: The FITFIR system is allocatively inefficient because it does not account for water use and marginal willingness to pay for water.

Sustainability: Status quo protects water for future needs by prioritizing EFNs during scarcity. However, the precautionary principle does not inform license approval or water allocation. The policy protects sustainability because it is flexible to changing short-term climate conditions: during scarcity the policy restricts junior licensee's access to protect EFNs and uses CEFs in short-term extreme drought situations. The sustainability objectives are not fully met because of the shortcomings of EFNs and CEFs. First, they rely on incomplete information to determine the critical threshold of water required by a water source. The water needs of ecosystems and the relationships and interactions within ecosystems are uncertain. Not enough is known about water to accurately determine EFNs and CEFs, so these estimates must use the precautionary principle and be very conservative. Second, it is not clear how often EFNs will be reviewed and updated for licenses under the WSA. EFNs would need to be reviewed and updated regularly to meet ecosystem needs and ensure flexible and sustainable water management.

Stakeholder acceptability: No licensees lose access relative to their prior level of access. There is an application fee for new ground and surface water license applications (as of 29 February 2016, but this fee is waived for groundwater applications until 2017). The low price of groundwater has garnered negative public attention in the past from stakeholders who wish to see water priced at a higher value to protect it and acknowledge its social value.

Administrative ease: The status quo option requires no administrative changes because it is already in place.

8.2. Share system

Table 9: Share system

Objective:	Evaluation Criteria:	Assessment:
Equity	Do any water users lose more access than others during shortage?	No
Efficiency	Can high value users access water rights?	Yes / Some
	Are technically efficient practices promoted?	Yes (incentivized)
Sustainability	Is the policy flexible to changing climate conditions?	Yes
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Somewhat
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	Yes (senior)
	Does the public support the policy?	Yes
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	Many

Equity: The share system improves equity by giving junior licensees equal water access to senior licensees during shortage.

Efficiency: The share system improves economic efficiency somewhat by allowing high value junior users to access a share of total water available during scarcity. However, all users are allocated a share based on available water and water need, not on end-use value of water or value for water. Junior, and especially senior licensees use efficiency would improve because they would have to adapt their water use practices and technologies in response to lower water allocations.

Sustainability: The precautionary principle criterion is not met because this option does not consider end-use of water. However, allocations are constrained by EFNs to protect future supply. This option is flexible to short-term changing climate conditions if it allows for ex-post water allocation restrictions to protect the ecosystem.

Stakeholder acceptability: By improving equity, the share system reduces senior licensees access to groundwater relative to their prior access level. It is therefore likely to be popular with junior licensees but not with senior licensees.

Administrative ease: The policy requires large scale regulatory changes because it is very different from the FITFIR system. Surface water regulations would also need to be changed in order to treat all water as an integrated resource.

8.3. Use-based system

Table 10: Use-based system

Objective:	Evaluation Criteria:	Assessment:
Equity	Do any water users lose more access than others during shortage?	Yes
Efficiency	Can high value users access water rights?	Yes
	Are technically efficient practices promoted?	Yes
Sustainability	Is the policy flexible to changing climate conditions?	Yes
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Yes
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	Some (senior)
	Does the public support the policy?	Yes
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	Many

Equity: A use-based system disproportionately impacts some users by providing them with less water if their end-use value is lower or if they can improve efficiency. Therefore, this option is inequitable relative to the status quo for water users with a low value for water or users who can improve efficiency.

Efficiency: Use-based systems are economically efficient because high-value users can access water. The system mandates efficiency by requiring users to take available efficiency measures.

Sustainability: The licensing authority uses the precautionary principle to grant water allocations because allocations are based on the end-use of water and the amount of water available in the ecosystem. EFNs can be set as allocation constraints or water can be allocated to environmental needs based on the economic value of ecosystem services. The policy is flexible to changing climate conditions if allocations are updated ex-post.

Stakeholder acceptability: Senior licensees may lose some access relative to their previous level of access if they are low-value water users or can improve their efficiency. Because water is allocated based on ability to adopt efficient technology there is potentially less negative impact than in the share system.

Administrative ease: Government would need to make many regulatory changes to adopt this option. Determining the end-use value of water requires significant ongoing government resources.

8.4. Groundwater banking

Table 11: Groundwater banking feasibility study

Objective:	Evaluation Criteria:	Assessment:
Equity	Do any water users lose more access than others during shortage?	Depends on allocation system
Efficiency	Can high value users access water rights?	Yes
	Are technically efficient practices promoted?	No
Sustainability	Is the policy flexible to changing climate conditions?	Yes
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Somewhat
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	No
	Does the public support the policy?	Yes / Somewhat
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	Some / Many

Equity: In the case of groundwater banking, equity is determined by the allocation system used in conjunction with groundwater banking. For example, groundwater banking in a share system has high equity, while groundwater banking in a use-based or FITFIR system has low equity. Groundwater banking on its own does not disproportionately impact any groups during drought. No change is made to access, and any group can theoretically have increased access to water via groundwater banks.

Efficiency: This policy allows high value users to access water by increasing the overall availability of water during scarcity. However, it does not promote efficient water use or technically efficient practices.

Sustainability: This policy does not use the precautionary principle because it simply increases the stock of available water for any use. However, increased water stocks protect groundwater supplies for future ecosystem functions and improve flexibility to changing climate conditions and this option could be combined with any of the other options that employ the precautionary principle.

Stakeholder acceptability: Overall, this option has relatively small impacts on stakeholders and can potentially increase groundwater access for all users. Some stakeholders may dislike the idea of groundwater banking because it brings up the idea of water as a commodity. An educational outreach campaign would help to alleviate any negative associations that stakeholders and the public may have about groundwater banking.

Administrative ease: Government operated banks would require formation of some new agencies. Privately run banks would require some government oversight and regulation. Public-private partnerships would require government resources.

8.5. Water market pilot program

Table 12: Water market pilot program

Objective:	Evaluation Criteria:	Assessment:
Equity	Do any water users lose more access than others during shortage?	No
Efficiency	Can high value users access water rights?	Yes
	Are technically efficient practices promoted?	Yes (incentivized)
Sustainability	Is the policy flexible to changing climate conditions?	Yes
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Yes
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	No
	Does the public support the policy?	Yes / Somewhat
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	Many

Equity: Similar to groundwater banking, the water market pilot program has no disproportionate impacts on any groups during water shortage because it does not prescribe allocations.

Efficiency: Water markets allow high-value users to access water through the purchase of allocations or licenses. Water markets incentivize adoption of efficient practices and technologies because users who save water can sell excess allocations for a profit. Fluctuation of market value of water is an additional efficiency incentive: as shown in the MDB case study, the price of water increases during scarcity to reflect the quantity available. High prices discourage low value water uses and encourage efficiency and conservation.

Sustainability: Water markets can be set up to ensure environmental protection by allowing users to purchase licenses for conservation and environmental needs. The precautionary principle would be used when new applications to the market and license transfers are being approved, as in the MDB and SSRB, because the regulator can withhold approval for environmentally damaging uses. This policy is very flexible to changing conditions because licenses may be bought and sold at any time on a temporary or permanent basis.

Stakeholder acceptability: Water markets will not cause any licensees to lose access relative to their prior level of access unless they choose to sell their licenses for profit. Water markets may be unpopular with some stakeholders, such as some public who believe that a water market is a step towards treating water as a commodity.

Administrative ease: This option requires many regulatory changes, a large stakeholder engagement and consultation process, the creation of a new website and license trading mechanism, and potentially the formation of a new regulatory agency.

8.6. Comparison

I analyze the five discrete policy options above to identify trade-offs associated with different approaches. However, each option can be modified to reflect the relative strengths and weaknesses shown in the analysis, and complimentary options can be combined. Table 13 compares trade-offs between policy options.

Table 13: Comparison of policy options

Objective:	Evaluation Criteria:	Status Quo	Share	Use-based	Banks	Market
Equity	Do any water users lose more access than others during shortage?	Yes	No	Yes	Depends on allocation system	No
Efficiency	Can high value users access water rights?	Neutral	Yes / Some	Yes	Yes	Yes
	Are technically efficient practices promoted?	No	Yes	Yes	No	Yes
Sustainability	Is the policy flexible to changing climate conditions?	Yes / Somewhat	Yes	Yes	Yes	Yes
	Is the precautionary principle used to ensure enough water for ecosystems in the future?	Yes / Somewhat	Somewhat	Yes	Somewhat	Yes
Stakeholder acceptability	Do any license holders lose access relative to their previous level of access?	No	Yes	Some	No	No
	Does the public support the policy?	Some	Yes	Yes	Yes / Somewhat	Yes / Somewhat
Administrative ease	Does the policy require regulatory changes or formation of new agencies for implementation or regulation?	None or few	Many	Many	Some / Many	Many

Chapter 9. Recommendation and implementation

9.1. Recommendation

I recommend that the BC Government continue with the status quo, retaining FITFIR and implementing the WSA. In addition, I recommend that they prepare a water market pilot program, increase the price of water and capture more rents, continue to collect data about BC's water, continue to involve First Nations, and begin a groundwater banking feasibility study. These recommendations are discussed in detail below.

1. Water market pilot program

This recommendation acknowledges that the WSA was implemented very recently and therefore changing to a use-based or share system would be politically unpopular and require many resources. The water market pilot program compliments the status quo. Water markets improve economic efficiency by allowing users with a high value of water to purchase water from sellers with a lower value for water, or users who are better able to conserve water. They also incentivize technically efficient water use where possible because license-holders may sell unused water for a profit. Water markets use the precautionary principle in license transfer approval because EFNs must be reassessed with each transfer.

The price of water within a water market responds to short term changes in supply and demand, further incentivizing efficient use because it encourages conservation and efficiency when prices are high. Stakeholders are likely to support a water market, especially as a pilot. If the market does not work as intended, the users have some assurance it will either be rectified or not made permanent. The major drawback is the set-up cost, so I recommend a pilot program to test-run the policy before making major investments.

Policy makers should incorporate the following components into the water market pilot program:

Water market website:

The water market website should contain a water license transfer mechanism, information about the water market, and publicly available information about license transaction histories and water supply. A license transfer mechanism is a very important part of a water market because it enables existing license holders and potential buyers to identify each other and carry out transactions. Clear information about water transfer procedures encourages use of the water market because both buyers and sellers understand the transfer process, costs, resource, and time requirements. Transaction information, water use quantities, and hydrological data should be reported and publicly available to provide licensees with information about the availability of water in the area. Information about transactions can alleviate public concern over buying and selling water as a commodity. Transparency is very important in adaptive management and to gain public acceptance.

EFNs and water for conservation:

Each temporary or permanent license transfer must undergo an EFN review to assess EFNs and impacts of water use. In addition to groundwater withdrawal constraints for environmental needs, water rights for conservation and environmental purposes should be available for purchase, publicly or privately, to ensure short- and long-term flexibility in supply of water to environmental needs and to support conservation projects.

Transfer costs:

The cost of a groundwater license in the water market is determined by supply and demand. Beyond the cost of the license, additional license transfer fees should cover administrative costs but should be relatively low so that buyers are not discouraged from participating in the water market.

Temporary and permanent transfers:

Licenses may be traded on a temporary or permanent basis between license-holders. In a FITFIR system, licenses retain original priority date after they are traded, so the new license-holder will have the same access priority that the seller had. In the case that the seller only trades a portion of the water license, they also retain original access priority date. In the event of drought, these two users who have the same access date would be granted access priority per the WSA's water use priority hierarchy in section 4.1.1.

New users who wish to temporarily or permanently purchase water licenses would go through an application process to gain the right to purchase water licenses.

2. Additional recommendations

Increase the price of water and capture more water rents

The market value of water may not fully reflect the true value of water but it is a more representative value than the current price of $2.25 per 1000 m^3. Increasing the price of water incentivizes licensees to use water more efficiently and can potentially reduce water demand for low-value users. Government can also collect revenue by capturing a larger share of water rents. Revenue can cover operations of the Water Sustainability Branch, and can be directed towards beneficial programs such as water research, saved for future water initiatives, or used to incentivize water licensees to adopt efficient technology. Government can gradually increase the price of water to reduce disproportionate impacts on users.

Forecasting demand for water need by industry, agriculture, municipalities.

This will help government to understand future water needs and compare demand forecasts to supply forecasts. This will facilitate sustainable water management strategies. Government should forecast for individual basins and for NEBC overall.

Continual ground and surface water monitoring and reporting for adaptive management.

Ground and surface water users should monitor and report their use to government. Government should undertake monitoring to supplement user's data and to improve our understanding of water stocks and flows.

Research on future water supply and water quality in NEBC.

Government should continue research into groundwater supply in BC to understand current levels and the magnitude of future scarcity. Understanding ground and surface water quality in BC is essential because it is a determinant of supply.

Continued First Nations involvement.

First Nations involvement can range from planning to monitoring and reporting, to managing.

Groundwater banking feasibility study.

Groundwater banking may not be required in the near future but could be a low-impact and effective way to increase water supply if the need arises in the future and the geology is conducive to underground storage. Groundwater banks can be a good safeguard for extreme drought or emergencies.

9.2. Implementation

I recommend that the pilot program take place in a basin that is experiencing some water shortage. The first step in the program is to stop accepting new license applications, thereby placing a cap on ground and surface water extraction in the basin. Existing license holders may trade temporary and permanent water rights that are linked to a set quantity of water. All trades must undergo an EFN review process. Prospective water users who do not already have a license for the basin may apply for a license if they wish to purchase temporary or permanent water rights from a seller. New applications will undergo BC's regular review process which collects information about type and volume of water usage, and reviews EFNs. If an applicant is approved, then they may purchase water rights from sellers. Basin-wide EFNs should be reviewed and updated regularly, as determined by BC Government scientists.

The water market will likely be more successful if government begins to collect some information immediately. I recommend that the government collect the following information to assist in the water market pilot program:

1. Basin selection

Government must first select an appropriate basin for the water market pilot program. This requires the following information:

- What are ground and surface water stocks, flows, and recharge rates, and are there seasonal variations?
- What is the nature of the connection between ground and surface water?
- How many ground and surface water licenses exist in the basin, what are the priority dates, how much water is allocated, how much is used, and what are the broad categories of water users?

Answering these questions will help policy makers to choose a good candidate basin for the water market pilot program. The ideal basin is one that is experiencing some scarcity, so policy makers need to know the estimated quantity of ground and surface water stocks within the basin, the recharge rates, and any seasonal variations that affect water supply.

Policy makers must also know how many water licenses are in the basin, the total amount of water allocated within the basin, and within that total, the proportion of water actually used by license holders. This information helps government to set a cap on allowable water extraction within the basin. This is important if, for example, the amount of water used was far less than the amount allocated, because license reallocation through the water market could result in more total water being used within the basin, impacting local ecosystems and other water users.

Policy makers must understand who is using water in the basin, and what they are using it for, and the range of priority dates. A basin with a variety of different water uses and priority dates is ideal for a water market so that water rights can be traded between different types of users. Licenses with older priority dates will probably have a higher value than licenses with less secure, newer priority licenses. It is important to ensure that the pilot program basin contains a variety of priority dates to give buyers and sellers different options.

Information about local hydrology allows regulators to set appropriate water market regulations. Policy makers must have an idea of ground and surface water stocks and flows and seasonal variations to set the basin's extraction limit, to set EFNs, and to update EFNs. Similarly, policy makers must know if EFNs vary according to climate conditions so that they can understand seasonal variation in supply, and limit water allocations accordingly. Information about the connection between ground and surface water facilitates better management of ground and surface water licenses so that surface water users won't be impacted by groundwater extraction, and vice-versa.

2. Planning water market regulations

Government should seek the following information to plan appropriate water market regulations:

- What are demand forecasts for different categories of water use?
- What are the ecological impacts of different water users, are there water quality concerns?
- What constitutes efficient water use for different uses within the basin, and how can efficient water use be promoted?

Supply and demand forecasting helps policy makers understand how much water and what type of demand will exist in the future and therefore which type of water users may be seeking licenses in the future. This is useful information for sustainable water management, particularly because it allows for demand-side management, but also may inform some aspects of the water market. Information about the local impacts of different water uses allows policy makers to better understand the impacts of water users on the basin's ecology. Understanding any water quality impacts is important because poor water quality essentially reduces supply.

In the case of scarcity, government would be equipped to help license holders adopt technically efficient behaviours if they understand what constitutes efficient water use for different water users. Additionally, if policy makers understand what incentivizes efficient use, they can use appropriate tools to improve efficiency during drought.

Chapter 10. Study Limitations, Future Research, and Conclusion

In this section I identify limitations to my research, recommend future research, and conclude.

10.1. Limitations

1. The WSA was implemented 29 February 2016 so its impacts are unclear.
2. Very little information exists about groundwater stocks and flows in NEBC.
3. Very little information exists about groundwater uses in NEBC because groundwater was not regulated until 2016.
4. Uncertainty over who exactly are the high versus low value users currently or who will be in future.
5. Uncertainty over the administrative ease objective in analysis. I do not know exactly show many staff are required to change regulations from status quo.

10.2. Future research

This study leaves many doors open for future research.

1. Investigating the impacts of the WSA:

A study on the impacts of the WSA would be helpful to policy makers and regulators who seek to change behaviour of water users. Policy makers and regulators must understand any impacts that the WSA had on water use efficiency or end value of water use to assess the policy's ability to promote efficient behaviour. Additionally, research can investigate the policy's impacts on ecosystem wellbeing to evaluate the effectiveness of EFNs in protecting ecosystems.

2. Understanding the impacts of climate change:

Further research into the impacts of climate change is essential. This research can help decision makers prepare for future changes to water systems.

3. Understanding the impacts of surface and ground water extraction:

Research into the impacts of surface and ground water extraction in NEBC is essential so that authorities can manage water allocations.

4. Forecasting demand:

Demand forecasting is an important aspect of water management. It helps to indicate future pressure on water systems and allows authorities to plan accordingly.

5. Evaluating the value of different water uses:

A study evaluating the value of different water uses relative to each other would be valuable for policy makers wanting to understand allocative efficiency.

10.3. Conclusion

BC has a wealth of water resources that must be managed sustainably to ensure supply of clean, fresh water in the future. The WSA is an important step in the right direction for BC and the BC government must continue to take action. The BC government can learn important sustainable water management lessons from jurisdictions worldwide that have taken steps to conserve their water resources. BC should continue to adaptively manage water and incorporate best practices into water policy.

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