

Reducing Produced Water Leaks and Spills by Improving Industry Compliance in British Columbia's Natural Gas Sector

by

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Abstract

The International Energy Association asserts that natural gas is poised to enter a golden age. This is particularly true for British Columbia, which possesses world-class shale gas reserves. Produced water – the water emanating from fracturing shale - is the largest waste stream associated with oil and gas activities. Wastewater associated with natural gas extraction is highly toxic and has serious implications for environmental and human health if spilled or leaked. Because of the corrosive nature of produced water pipeline leaks are more than twice as common as other product types. This paper identifies and assesses different policy options designed to improve the compliance of industry operators with regulations to reduce the frequency and severity of spills. Cross-jurisdictional and cross-industrial case studies are used in the methodology and supported by gap analysis. The viability of policy instruments is assessed according to effectiveness, community and stakeholder support, administrative complexity and cost, and the overall robustness and flexibility it adds to the regulatory framework.

Keywords: Produced Water; Wastewater; Pipelines; Oil and Gas Regulation; Compliance; Hydraulic Fracturing

As iron sharpens iron, so a man sharpens the mind of his friend.

(Proverbs 27:17, WYC)

For my friends and colleagues in the Masters of Public Policy program.

I could not have done this without you.

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List of Acronyms

AER	Alberta Energy Regulator
Bbl.	Oil barrel (Refer to Glossary for additional information)
CAPP	Canadian Association of Petroleum Producers
CBI	Canadian Boreal Initiative
CEAA	Canadian Environmental Assessment Act
CEPA	Canadian Energy Pipeline Association
EA	Environmental Assessment
EAO	Environmental Assessment Office
EGS	Ecosystem Goods and Services
EIP	Ex-Post Insurance Policy
EPA	Environmental Protection Agency
IEA	International Energy Agency
IMP	Pipeline Integrity Management Program
IFRBP	Industry Funded Risk-Based Premium
LMR	Liability Management Rating Program
LNG	Liquefied natural gas
M-KMA	Muskwa-Kechika Management Area
Mm btu	One million British Thermal Units
MMcf.	One million cubic feet
MEM	Ministry of Energy and Mines
MNGD	Ministry of Natural Gas Development
MOE	Ministry of the Environment
NEB	National Energy Board
OGC	Oil and Gas Commission
PCCA	Prepaid Collateral Closure Agreement
PLNGFR	Pipeline and Liquefied Natural Gas Facility Regulation
Tcf.	One trillion cubic feet
TEV	Total Economic Value
WGR	Produced water to natural gas production ratio
WSA	Water Sustainability Act
ZOI	Zone of Influence

Glossary

Basin	A geological area defined by its sedimentary, stratigraphic, or permeability characteristics. A basin may include multiple plays.
Bbl (oil barrels)	One oil barrel is a standard measure used in Canada and the United States for volume. One bbl is equivalent to 42 American gallons, or 159 liters.
Breaker	An additive to fracturing fluid that breaks down the viscosity of the fluid.
British Thermal Units (Btu)	A unit of measure to define energy. It is equal to 1055 joules, and is the amount of energy required to heat or cool one pound, or roughly half a kilogram, by one degree Fahrenheit.
Crosslinker	An additive to fracturing fluid, that when interacting with other ingredients such as gels, increases the viscosity of the fracturing fluid.
Deepwell Disposal	The technology of placing fluids deep underground, in porous formations of rocks, through wells or other similar conveyance systems. The fluids may be water, wastewater or water mixed with chemicals. Also referred to as “injection.”
Directional Drilling	The technology used for drilling non-horizontal wells, and is used in conjunction with hydraulic fracturing to stimulate unconventional resource reservoirs. Horizontal or slanted well shafts are used effectively to exploit greater quantities of fossil fuels trapped in bedrock, or to access reservoirs that may be situated below developed lands. Directional drilling permits reservoirs to be accessed at many points from a single well pad and many horizontal fractures can be completed from one wellpad going in different directions, and at different depths.
Flowback Water	The fluids returning to the surface of a well after hydraulic fracturing is complete. Also see Produced water.
Hydraulic Fracturing	A technology used to stimulate hydrocarbon reservoirs that pumps liquids at high pressure down a well to fracture and shatter the formation rock. Chemicals and propping agents are used to keep the fissures open and facilitate hydrocarbon flow to the surface.
Leak	A pipeline failure where a pipeline is losing product, but might continue to operate until the leak is detected.
Million Cubic Feet (MMcf)	A unit used to estimate gas and coalbed methane production volumes. According to the US Department of Energy 1 MMcf is the approximate volume of gas used by twelve American households in one year.

Play	A group of identified or suspected oil and/or gas reservoirs sharing similar geologic and geographic properties such as source rock, migration pathways, and hydrocarbon type. “Play” refers to regions that are commercially viable, whereas “basins” are defined according to geological characteristics.
Produced Water	The term used by oil, gas, and coalbed methane industry operators to refer to water produced in conjunction with hydrocarbon extraction activities, and may include water pumped down a well shaft to stimulate a reservoir, or formation water released at the same time as the resource, or a mixture of both. Produced water is typically very salty, or briny, and contains chemicals, trace and aromatic hydrocarbons, and naturally occurring radioactive materials.
Proppant	Sand, ceramic, or other particles suspended in fracture fluid that are deposited into rock fissures to keep them open after the pressure from fracturing activities has abated.
Release	The loss of any kind of product from a pipeline including, but not limited to produced water, oil, gas, and their derivatives.
Rupture	A pipeline failure where the pipeline cannot continue to operate.
Trillion Cubic Feet (Tcf).	A unit used to estimate gas and coalbed methane production volumes. According to the US Department of Energy 1 Tcf is the approximate volume of gas used by twelve million American households in one year

Executive Summary

Geophysical assessments within British Columbia estimate that the shale gas resource base held in the Northeastern corner of the province is as much as 645 tcf. of marketable natural gas, while other sources estimate more than 1,000 tcf. (MNGD, 2013; NEB, 2013; Parry, 2013). The Montney Play Trend alone is one of the largest unconventional shale resources in the world and holds the resource equivalent to fuel all of Canada's consumptive needs for 145 years (NEB, 2013). Because of this and improvements made to the dual technologies of hydraulic fracturing and directional drilling, BC is on the verge of unprecedented development in its natural gas industry.

Along with economic benefits, shale gas extraction also poses risk. In particular, the wastewater (produced water) emanating from hydraulic fracturing activities is saline, radioactive, and contains water-soluble chemicals and additives that are toxic and bio accumulative. As many as 750 synthetic and natural properties may also be present in fracturing wastewater, making produced water generated from natural gas extraction as much as ten times more toxic than oil or coalbed methane (FracFocus, 2013; Spellman, 2013; Veil et al., 2004). Because of the corrosive properties of produced water, up to 57% of pipelines will experience scale and internal corrosion that may produce failure (AER, 2013); furthermore, the toxicity of produced water can mean that even small releases (<100m³) can be harmful.

Other jurisdictions that have benefitted from developing oil and gas reserves have not concurrently made similar improvements to the regulatory frameworks that protect human health and the environment (Ernst Environmental Services, 2013). Lack of robust regulations has produced negative effects elsewhere in North America. Now is the time to strengthen monitoring and enforcement in BC as a mechanism to prevent produced water accidents by improving industry compliance in the natural gas sector. The benefits of accident prevention include avoidance of the economic and social costs incurred by remediation, preservation of ecosystem goods and services, and maintaining the integrity of subsistence and cultural activities practiced by First Nations and residents of Northeastern BC. Spills and leaks can compromise the vitality of these aforementioned benefits.

The research provides an overview of the existing regulatory regime and six case studies to identify cautionary principles and best practices from other shale gas producing jurisdictions and industries. The case studies and regulatory context provide the basis for assessing the weaknesses and opportunities within the existing framework and identifying policy options that better balance development and environmental objectives while also implementing effective barriers to accidents. Using multi-criteria decision-making analysis, the study adjudicates the performance of the status quo, increasing inspections on pipeline infrastructure, implementing bonding instruments, and implementing an Industry Funded Risk-Based Premium according to four criteria. The criteria use well-defined metrics to measure the performance of each policy option according to its overall effectiveness, robustness and flexibility, administrative complexity and cost, and community and stakeholder support. Community and stakeholder support includes a separate sub-criterion that acknowledges the position of First Nations in Northeastern BC.

The recommendation of this study is to implement two complementary policy options together: the Industry Funded Risk-Based Premium (IFRBP) together with increased inspections on pipeline infrastructure. In particular, the revenues from the IFRBP support an industry-funded framework to support enforcement and monitoring. Additionally, the increases in capacity required to effectively implement and sustain the policy option will be covered by the premiums collected through IFRBP. Because the premiums are assessed on the basis of risk, the industry is funding its own inspections in order to reduce the risk from natural gas extractive activities and make them as sustainable as possible. Increasing the number of inspections increases the capacity of the regulator to monitor and enforce compliance. Critical next steps for produced water management in BC will emphasize performance measures and outcomes for industry that will improve environmental protections, but concurrently facilitate development. Implementing IFRBP with inspections achieves these goals.

Chapter 1. Introduction

The International Energy Agency asserts that: “natural gas is poised to enter a golden age” (IEA, 2012). This may be particularly true for British Columbia. Geophysical assessment done by the National Energy Board (NEB) have determined that BC holds a resource base of 645 trillion cubic feet of natural gas (NEB, 2013), and the Canadian Society for Unconventional Resources has estimated that the volume likely exceeds 1,000 trillion cubic feet (Parry, 2013). Assuming low range estimates, there is enough natural gas in Northeastern BC to provide all of the energy needs of New York City and Los Angeles combined for more than 600 years.¹ In order to capitalize on the potential benefits of natural gas, the Province has implemented a natural gas strategy and liquefied natural gas (LNG) strategy to begin developing its newest resource industry. To date more than \$7 billion has been invested in resource acquisition, planning, and development (MEM, 2013). Many major LNG projects have been proposed and subsequently approved by the National Energy Board and the Province. Because global LNG demand is expected to increase by 50% by 2020, the Province is responding quickly in order to realize its potential as an energy exporter (MEM, 2013).

In many respects, natural gas in BC may be a double-edged sword. BC’s vast reserves promise as much as \$3 trillion to be added to BC’s gross domestic product over the next three decades and more than 100 thousand jobs (Jang, 2014). However, the risks may be significant. Prior to 2008, natural gas in BC was considered an infant industry. Because the scale of development is happening rapidly it is critically important to ensure that the regulatory capacity and institutional frameworks are concurrently expanded so as to address new challenges and manage risk. Experiences within BC and other jurisdictions tell us that regulating shale gas extraction can be problematic. The Ministry of Natural Gas Development was only created in 2013 and the Oil and Gas Commission is already experiencing an increase in the size of the industry and infrastructure it is responsible for regulating. Because BC is embarking on a major

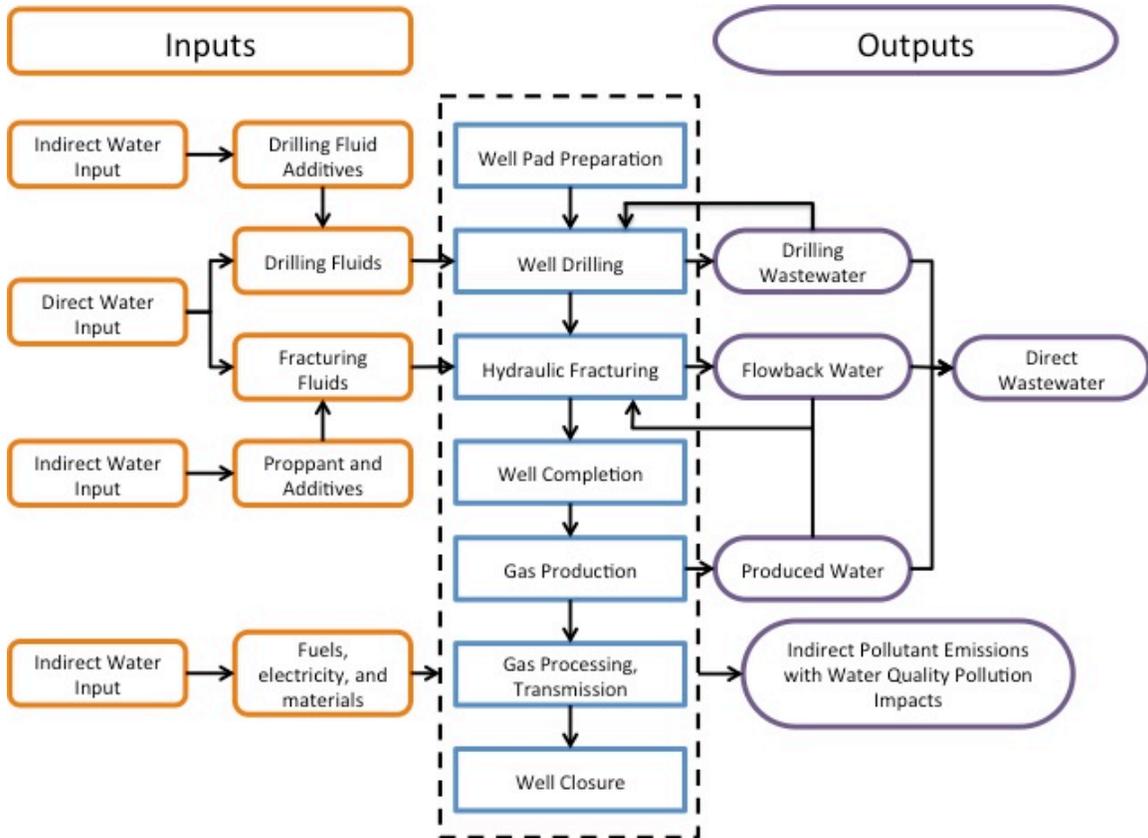
development, it is paramount that the Province considers weaknesses and opportunities for improvement in its shale gas regulations before problems arise.

The process of extracting unconventional natural gas is water intensive and produces significant volumes of wastewater. Global production volume of produced water for a single year may be more than 77 billion oil barrels (bbl) worldwide, with at least 14 billion bbl arising from onshore production in the United States. 14 billion bbl is equivalent to 3.2 trillion liters, or the yearly domestic water use of 26.7 million Canadians by Environment Canada calculations. Furthermore, produced water associated with natural gas production may be as much as ten times more toxic to environmental and human health than produced water associated with other hydrocarbon types such as oil or coalbed methane (Veil et al., 2004: 17, 22). The costs and risk associated with managing produced water are substantial. In particular, moving produced water between locations exponentially increases the chance of a spill or leak (Siler, 2012). Because of this, produced water transport has a greater than average risk profile when compared to all product types moved by pipeline and other upstream natural gas activities when measured by consequence and probability.

Indeed, “produced”, “flowback”, or “spent” water is the largest waste stream associated with oil and gas activities worldwide (Lee & Neff, 2011; Spellman, 2013). One gas well alone can require between 20,000 and 60,000 cubic metres of water per fracture, dependent upon geology, (Al, et. al., 2012). A recent study conducted across thirty counties in the United States noted that during the tenure of its study period those jurisdictions required over 3.8 billion liters of water for fracturing activities, and subsequent transport and treatment (Freyman, 2014). Moreover, unconventional gas wells in Northeastern BC are considered to be “deeper and more complex” than the global norm and require greater volumes of fracturing fluid to effectively stimulate the reservoir while also incurring greater capital costs for all active phases of extraction (NEB, 2010). Figure 1.1 (next page) illustrates the flow of water during natural gas extraction. The central column shows the sequential phases of initiating gas production at a wellsite, stimulation of the reservoir, production of natural gas, and finally site reclamation. Water inputs, are on the left in orange, and purple ovals on the right illustrate outputs (or the waste stream) of the hydraulic fracturing process. Most

importantly, Figure 1.1 provides a basis to understand how wastewater volumes are generated, the chemical properties of produced water as a result of exposure, and how this contributes to the consequence and probability of accidents during transport.

Figure 1.1: Generation of Wastewater from Natural Gas Extraction



Adapted from: Jiang, Hendrickson, & VanBriesen (2014, p. 1912).

Once a well has been fractured, gas flows into the well and is pumped to the surface where it is captured. Approximately 10 to 50% of produced water returns to the wellbore site with the gas, where it is sequestered, and shipped off-site for treatment and/or disposal, or to be reused in another fracturing operation (Abdalla et. al, 2012; Rahm et al, 2013). The remaining 50-90% of fluids is recovered after the well shaft is flushed out post-fracturing (BC Fracfocus, 2013). Studies done in the United States estimate that the produced water to natural gas production ratio (WGR) is roughly 260 barrels (bbl) per million cubic feet (MMcf) for onshore production sites (Clark & Veil, 2009: 48). As reservoirs are depleted over time, the WGR becomes less favourable and

wastewater constitutes a growing percentage of volume returning to the surface until the reservoir is deemed to be non-profitable (Veil et al, 2004).

Geophysical surveys estimate that British Columbia possesses world-class unconventional shale reserves (MNGD, 2013; NEB, 2013). Development will not happen overnight and its scale is dependent on market demand; however, a recent analysis of the implications of BC approving 7 of the proposed LNG export licenses estimates that their combined daily output could be as much as 14.6 billion cubic feet per day of natural gas (Hughes, 2014). Achieving these targets will require as many as 50,000 gas wells over the next 27 years, averaging 3,000 per year, and each will require up to 3.7 million of liters of water for fracturing in order to fulfill the objectives set by the Province and the NEB (Hughes, 2014). Assuming the 260 bbl/Mmcf ratio is applicable to BC's deposits, if BC is capable of extracting only twenty percent of its ultimate potential gas estimate of 376 tcf. from the Western Sedimentary Basin, the province could generate approximately 20 billion bbl, or just over 3 trillion liters of produced water. 3 trillion liters is the liquid volume required to fill 1.2 million Olympic sized swimming pools. Averaged over 27 years, this estimate will produce just under 33 thousand Olympic sized pools of produced water per year. Managing and transporting such large volumes of produced water will exert wear on pipeline infrastructure. This scale of growth creates challenges to the regulatory environment particularly with regard to assessing and mitigating the risk of pipeline accidents.

1.1 Policy Problem and Research Goals

Produced water is either reused on the same site, transported and reused at another site, or transported to a certified deep injection well for disposal. Some jurisdictions treat produced water in municipal treatment centers. At some point in its life, all produced water must be transported, and pipelines are the most common and cost effective means. Unlike transmission lines used to move oil or natural gas long-distances, produced water lines are smaller and shorter, averaging 1.2 kilometres in length (AER, 2013). Effective accident prevention relies on using a series of risk controls upstream of the incident to reduce the frequency and severity of pipeline spills and

leaks¹. The more barriers, or accident prevention actions utilized, the lower the consequence and probability of the event.

Currently, BC does not have sufficient mechanisms to prevent produced water incidents occurring during transport. The BC Oil and Gas Commission (OGC) reports that the overall incident rate in 2010 was 1.38 incidents per 1000 kilometres of pipeline, and dropped to 0.87 incidents per 1000 kilometres in 2011 for all product types (OGC, 2011), whereas water lines have a far higher incident frequency rate (4.96 incidents per 1000 kilometres in 2010), and in most cases failure is attributed to internal corrosion (OGC, 2011). Internal corrosion is responsible for 30-57% of all pipeline failures in Western Canada, the vast majority of which are pipelines carrying produced water or multiphase pipelines that have a mix of product types including produced water (Alberta Energy Regulator, 2013; OGC, 2011). The risk of pipeline failure on any individual segment or pipeline is low; however, the cumulative probability of the province experiencing many small leaks and spills, and at least one medium to major spill is high. Alberta's oil and gas industry is significantly more developed than that of BC, and between 1990 and 2012, the Alberta oil and gas sector experienced 9730 produced water leaks. 55 of them released more than 1000 cubic metres of water (Alberta Energy Regulator, 2013)². Because of the characteristics of produced water, even small spills can have serious effects on ecosystems and human health. Hence, my policy problem is identified as:

BC's lack of accident prevention mechanisms specific to produced water transport in the natural gas sector expose the province to increased environmental and economic risk caused by increases in the frequency and severity of produced water spills and leaks.

¹ By "upstream of the incident" I mean the factors and mechanisms contributing to an eventual produced water pipeline failure. This use of "upstream" is not to be confused with the "upstream" or "midstream" sectors of natural gas production and processing, where "upstream" would encompass exploration and production, and "midstream" activities include transporting hydrocarbon products and by-products, but not their waste stream.

² Since the 2013 Alberta Energy Regulator report was issued at least two more serious spills have occurred, one releasing more than 10000 m³ of produced water, and the second released between 1000 and 10,000 m³ of produced water into a tributary connected to the Athabaska River system. The first spill occurred in Zama City, AB in June, 2013 and the second was recorded in January, 2014 close to Whitecourt, AB.

My research identifies effective accident prevention mechanisms to include industry compliance rates, inspections done on pipeline infrastructure, robust regulation and legislation, comprehensive risk assessment instruments, strong enforcement including fines, monitoring and data sharing, and industry operator performance and internal risk mitigation. Given the apparent absence of many of these mechanisms in BC's existing regulatory framework, the research questions this study attempts to address are: *How might each of these mechanisms be introduced and/or strengthened to reduce the consequence and probability of produced water leaks and spills during transport? What best practices and accident prevention mechanisms can be identified from other jurisdictions and industries that BC might find useful as shale gas extraction activities intensify?*

1.2 Study Outline

The following chapter will briefly describe the processes of hydraulic fracturing and directional drilling, and will provide a more comprehensive overview of the chemical and physical properties of produced water, and its effects on human health and the environment. Chapter 3 will describe the current state of BC's natural gas industry including its potential, jurisdictional oversight, and other regional considerations including economic and social costs of produced water spills. Within this section I identify the presence or absence of existing accident prevention mechanisms, and determine their impact on mitigating the risk of produced water spills and leaks during transport. In particular, I build a case for my claim that BC lacks an effective accident prevention regime and illustrate how industry growth will exacerbate existing deficiencies leading to measurable increases in frequency and severity of spills and leaks. In Chapter 4 I describe my methodology, which includes a gap analysis of the existing regime (contained in chapter 3), and case studies (contained in chapter 5). The case studies examine other jurisdictions currently exploiting shale gas reserves, and other industries to identify best and worst practices for risk mitigation useful to BC's context. The latter part of chapter 5 analyzes the case study findings. In chapter 6 I provide the criteria and metrics by which I will assess the four policy options introduced in chapter 7. The options are selected through the gap analysis and case studies. Chapter 8 provides an analysis

for each option according to their performance against the criteria, and I will make immediate and long-term recommendations in chapter 9. Additionally, chapter 9 contains next steps, broader implications for the natural gas industry, research opportunities, and my conclusion.

Chapter 2. Hydraulic Fracturing: Process and Products

2.1 Hydraulic Fracturing and Directional Drilling

The first documented case of hydraulic fracturing took place in Grant County, Kansas in 1947. It utilized more than 3700 liters of naphthenic acid and palm oil (napalm), mixed with gasoline to blast apart a limestone formation in order to induce gas flow and capture (Severtson, 2013). The process was patented by Halliburton Oil Well Cementing Company two years later, and has since seen many iterations and improvements in technology to improve the overall production of oil and gas wells, including its most recent innovation in directional drilling. These combined technologies make the current estimated production ratio for a horizontal well 3.2 to 1 (sometimes more) when compared to a vertical well, whereas the cost ratio is only 2 to 1 (IOGA, undated). In other words, hydraulic fracturing and directional drilling make it possible to produce greater volumes of natural gas at lower costs per cubic meter than previous drilling technologies used alone.³

Hydraulic fracturing activities in British Columbia vary between companies and geographic regions. Each play in question has its own unique geology and chemical characteristics within the formation and reservoir itself. Because of these conditions, it is not possible to establish precise measurements of well depth, water use, or a consistent formula for fracturing fluid that would be effective in another jurisdiction or even another well pad in the same jurisdiction.

Modern hydraulic fracturing (sometimes referred to as “fracking” or “hydrofracking”) uses directional drilling techniques to access natural gas trapped in

³ Production ratio refers to the amount of natural gas produced at a given site vis-à-vis another site. Horizontally drilled wells are able to capture roughly 3.2 times more product than a vertical well, while investing only double the cost.

shale deposits roughly three thousand metres below the Earth's surface, and has a lifecycle of four stages: exploration; development, or construction of the site itself; production; and abandonment (Al et. al, 2009). Vertical wells are drilled down until the drill-bit reaches shale, and then is turned 90 degrees, and drilled horizontally for a kilometre or more to maximize surface area for capture of reserves. The fracturing process always begins after the well is drilled, but before well completion and gas production.

Once the well is drilled, a mix of many thousands of cubic metres of water, sand, and chemicals is pumped under high pressure into the shale causing it to crack and create numerous fractures that facilitate the escape of natural gas; proppant is used to brace fissures open to ensure resilient pathways for gas to migrate, and fracturing fluid may contain up to one million tons of sand, ceramic beads, walnut shells, or other cost effective materials strong enough to prevent collapse of cracks formed in shale beds after water pressure abates (Abdalla et. al., 2012; NEB, 2009; Spellman, 2013). Specific to British Columbian shale, the BC Ministry of Energy and Mines together with the Oil and Gas Titles Branch state that: "after each well is drilled it is treated over about 6 intervals with about 4000 cubic metres of water and 100 tonnes of sand per interval. Therefore, the amount of water, sand and completion tracking units used is very large at the beginning of production. Production is then anticipated to decline for 2 to 3 years, and then stabilize for several decades allowing for a longer than conventional production cycle" (*Dene Tha' First Nation v. British Columbia* [2013]: Para. 27). This production profile may have the effect of requiring more fracturing events than what is typical of other North American shale plays.

2.2 Produced Water Characteristics

Achieving maximum performance from hydraulic fracturing cannot be done using water alone. Although water comprises 95-99% of fracturing fluids by volume, produced water is high in dissolved salts (briny), acids, diesel and other fuels, gelling agents, and other chemicals required to perform specific functions during fracturing and gas production; however, flowback water will also contain heavy metals and naturally occurring radioactive elements washed up from the shale bed, and sand and proppant

remaining from the fracturing process (Ahmadun et. al., 2009: 533-535; Lee & Neff, 2011; Smith et al., 2011). Sand and proppants are abrasive, and contribute to internal wear on pipeline infrastructure by accelerating the effects of other interacting chemicals (Smith et al., 2011). As many as 750 synthetic and natural properties may also be present in flowback water, making produced water generated from natural gas extraction as much as ten times more toxic than oil or coalbed methane (CBM) particularly given the concentrations of polycyclic aromatic hydrocarbons (PAHs) (FracFocus, 2013; Spellman, 2013; Veil et al., 2004). Because of the corrosive properties of produced water, up to 57% of pipelines will experience scale and internal corrosion that may produce failure (AER, 2013); furthermore, the toxicity of produced water can mean that even small releases (<100m³) can be harmful. Many of the chemicals used in hydraulic fracturing are water-soluble, and small volumes may adversely affect soil and water quality, and bioaccumulate in local species producing birth defects and population decline (Ernst Environmental Services, 2013).

For a more fulsome overview of fracturing fluid additives and their potential effects please refer to Appendix C.

Chapter 3. Policy Context

3.1 Northeast British Columbia: Shale Reserves

The International Energy Agency asserts that: “natural gas is poised to enter a golden age” (IEA, 2012), and this may be particularly true for British Columbia. Northeastern BC is already a significant contributor to natural gas supply in North America, and generates 20% of the Canadian share of production (NEB, 2011). The National Energy Board (NEB) estimated in 2006 that Northeastern BC holds a resource base with a total ultimate potential of 52 trillion cubic feet (tcf) of recoverable natural gas embedded in shale beds (NEB, 2006). Most recently, the NEB predicted that the marketable resource base for the Horn River Basin alone is in fact closer to 78 tcf, and possibly as much as 109 tcf., notwithstanding other sites containing recoverable natural gas elsewhere in the province (NEB, 2011). In all, the NEB estimates that Northeastern BC holds a minimum of 55% of the recoverable natural gas in the Western Canadian Sedimentary Basin (NEB, 2011: 18), and the most recent assessment of the resource base within BC is estimated be as much as 645 tcf. of marketable natural gas, while other sources estimate more than 1,000 tcf. (MNGD, 2013; NEB, 2013; Parry, 2013). The Montney Trend alone is one of the largest unconventional shale resources in the world and holds the resource equivalent to fuel all of Canada’s consumptive needs for 145 years (NEB, 2013).

There are four shale plays in BC that are considered to have commercially viable gas resources, the Horn River Basin, the Montney Trend, the Cordova Embayment, and the Liard Basin. Almost all development to date has occurred in the Horn River and Montney shale plays, however exploration is well underway in the Cordova Embayment and Liard Basin. To date, the Ministry of Natural Gas Development states that more than 18,000 wells have been drilled since the 1950’s, although some of those are now decommissioned or abandoned.

Reports published by the OGC state that a total of 7,054,704 m³ was used in hydraulic fracturing activities in 2012 (OGC, 2013). Assuming a 50-90% recovery rate of water at the wellhead once a well is flushed upon completion, the gas industry is currently generating between 3.3 million m³ and 6 million m³ of recovered produced water that exists in various stages of recycling, transport, treatment, reuse, and disposal. Increasing the number of wells drilled and hydraulically fractured in Northeastern BC will require the volumes of fracturing fluids required for reservoir stimulation. Even if recycling and reuse decreases the volumes of fresh water required for fracturing activities, the volumes of produced water generated and transported will increase as a function of industry growth.

3.2 Natural Gas Regulation and Policy in British Columbia

Natural gas activities in BC are under the jurisdiction of the Ministry of Natural Gas Development (MNGD, created in 2013). The MNGD is tasked with developing tenure, royalty, and regulatory policy, approving investment applications, and communicating with industry, other involved ministries, major stakeholders, and First Nations. The MNGD also has jurisdiction over its Crown Corporation the BC Oil and Gas Commission (OGC) serving as the single-window regulator in oversight of all permitting, regulation, and compliance within oil and gas exploration and production in the province as per the *Oil and Gas Activities Act* [SBC 2008] Chapter 36 (MNGD, 2013). The OGC also has jurisdiction over special water permits for short-term use (Section 8 Water Permit), which are *ultra vires* the scope of the Ministry of Environment (MOE). Because the OGC acts as the single window regulator for all oil and gas activities, and is also responsible for balancing development objectives with environmental sustainability objectives it been subject to criticism regarding its ability to effectively regulate the industry it is mandated to promote. As the scale of the natural gas industry rapidly expands, there may be an increase in cases where the Commission's goals appear to be in conflict. To a lesser extent, the Ministry of Energy and Mines (MEM) and the MOE provide jurisdiction over other environmental or industry matters that fall under the *Water*

*Act*⁴, *Environmental Management Act*, *Land Act*, *Heritage Conservation Act*, and *Forest Act*; furthermore, a significant portion of oil and gas activities are carried out on Crown land, and regulated by the *Forest Act* and *Forest and Range Practices Act* (FRPA). Under the FRPA, the Forest Practices Board conducts audits of the industry and its operators. Federally, produced water is subject to the *Canadian Environmental Protection Act* (1999), and many environmental advocates argue that produced water should be subject to the regulations outlined in the National Pollutant Release Inventory and tracked accordingly (WCEL, 2013).

Produced water is only weakly regulated in BC. The OGC supports “FracFocus” an online chemical disclosure registry; however, fracturing fluids are subject to copyright laws and a Material Safety Data Sheet filled out by an industry operator, and logged on the website may not specify all of the chemicals utilized in a given fracturing job. Those components deemed proprietary are redacted in accordance with protection of trade secrets legislation in Canada (FracFocus, 2014). Pipelines transporting produced water are also weakly regulated in BC. The Canadian Association of Petroleum Producers (CAPP), The Canadian Standards Association (CSA), and the Canadian Energy Pipeline Association (CEPA) have specific provisions regarding safety, risk, and engineering thresholds that pipeline infrastructure must conform to; however, in BC, section 4 of the *Reviewable Projects Regulation* [B.C. Reg. 370/2002] determines that pipelines not exceeding specified diameters and lengths are not subject to Environmental Assessment (EA). Limiting assessment to major projects has the benefit of reducing lag-time for initiation of eligible projects, focusing resources on the most economically beneficial projects, and reducing the workload of the Environmental Assessment Office (EAO); however, incidents are more frequent for pipelines with a smaller outer diameter – as much as two times more frequent with each reduction of 100 mm (OGC, 2010). Produced water pipelines are built to these minimum thresholds in all jurisdictions because they do not incur as invasive right-of-ways, scope of operations, or performance factors as a long-distance transmission line for example (BCCGA, 2011). Additionally, produced water lines tend not to be metered given that meters can be expensive and are predominantly used for assessing royalties (OGC, 2014).

⁴ On April 11, 2014 the “*Water Sustainability Act*” was introduced as Bill 3 to the BC provincial legislature. The *Act* calls for regulation of large groundwater users.

The cornerstone of pipeline regulatory function is the Pipeline Integrity Management Program (or IMP), which has been a regulatory requirement in British Columbia since they were introduced in 1999 (OGC, 2014). The OGC stipulates that:

“under section 7 of the Pipeline and Liquefied Natural Gas Facility Regulation (PLNGFR), every permit holder designing, constructing, operating, maintaining or abandoning pipeline infrastructure within the province of British Columbia must have fully developed and implemented IMPs.” (OGC, 2014).

An IMP requires that a self-assessment must be done every five years to guarantee the safety and integrity of equipment and practices held by each operator. The IMP is mandatory. It describes how an operator’s program meets OGC specified requirements and expectations, and provides a summary of any known defects as well as a comprehensive timeline for remediation (OGC, 2014). While IMP’s enable the regulator to conserve resources associated with direct monitoring and enforcement, there is evidence to suggest that self-reporting mechanisms may not always reduce risk, and are not easily verifiable without other strong enforcement protocols in place (OECD, 2009). For NEB regulated pipelines, implementation of IMPs has not seen a parallel reduction in pipeline spills and ruptures. Between 1984 and 2003, 61% of ruptures occurred on pipelines that had been subjected to an IMP utilizing electronic monitoring tools. Further review of NEB regulated infrastructure indicated that 22% of cases were missed because the electronic instruments failed to detect the pipeline defect, and another 30% of defects and 26% of corrosion discovered were ignored because they were determined to be “non-critical” (Jelic, 2004). Similarly in BC, IMP’s are underperforming. All pipelines in BC are subject to IMP, yet audits have not found that they are resulting in stronger accident prevention mechanisms, better initial compliance rates, or risk assessment modeling that can accurately identify risk in real time (Forest Practices Board, 2011).

At first, BC appears to have a high compliance rate among oil and gas industry operators. OGC reports in conjunction with IMP submissions indicate that compliance levels are as high as 98%; however, the Auditor General of British Columbia notes that these rates are reflective of compliance only after inspections, complaints made by the public, or accident reports that warranted remediation and corrective action (Auditor

General, 2010). The actual compliance rate is 60% according to the most recent industry audit (Forest Practices Board, 2011). Furthermore, the audit discovered that details were not provided in reporting documents related to industry risks, and that there was no record of initial rates before orders to comply were issued. To date, the OGC has not improved transparency by publishing rates of initial non-compliance, or contamination cases of any severity level.

Compliance in BC is adjudicated according to a computer model that generates a risk profile based on the history of operator compliance, the site sensitivity, and the inherent risk calculated by considering the likelihood of an incident occurring and the probable consequences associated with the incident if it were to occur (OGC, 2010). This model is called “OSI” and provides the primary mechanism by which site inspections are prioritized. Public complaints and requests, or incidents may also trigger inspection (OGC, 2010). Because site investigations are not bound by due process or a formalized investigation protocol, initial cases of non-compliance are not recorded as such. Deficiencies discovered during site inspections are given the following rankings and timeframes for rectification:

Table 3.3: BC Oil and Gas Commission Pre Non-Compliance Deficiency Rankings

Ranking	Definition	Correction Time Period
Minor	Non-compliance with regulations or requirements that poses little or no risk to public and/or the environment and does not adversely affect oil and gas operations.	30-day action timeline to rectify the situation. A site with a minor deficiency outstanding at the conclusion of the 30-day period is deemed to be in non-compliance.
Major	Non-compliance with regulations or requirements that has the potential to impact public safety and/or the environment.	There is a 2-week action timeline to rectify the situation. A site with a major deficiency outstanding at the conclusion of this 2-week period is deemed to be in non-compliance.
Serious	Non-compliance with regulations or requirements that poses major risk to public safety and/or the environment.	There is a 24-hour action timeline to rectify the situation. A site with a serious deficiency outstanding at the conclusion of this 24-hour period is deemed to be in non-compliance.

Information source: BC OGC, 2009/10 Field Inspection Annual Report

If deficiencies are not remedied within the timeframe prescribed by Table 3.3, the OGC may impose penalties under the authority of the *Environmental Management Act* or the *Water Act*. Most cases of non-compliance receive a remediation order stipulating a deadline for compliance, although fines and convictions may also be issued. Unlike other jurisdictions, the OGC has not levied large fines for non-compliance. Whereas fines in the United States for non-compliance under the *Clean Water Act* averaged more than \$89,000 for a single infraction between 1975 and 1985 (Magat & Viscusi, 1990), all fines for all operators levied in quarters 1-3 in BC totalled \$6555, and charges have been laid for negligence only 3 times since 2007 (OGC, 2010).⁵

Every year, the OGC conducts site inspections on oil and gas infrastructure. Well sites under construction, producing wells, geophysical assessments, pipelines, facilities, roads, or any other operation affiliated with oil and gas activities may be inspected. In 2008/09, pipeline inspections constituted 174 of 4359 inspections; In 2009/10, pipeline inspections constituted 478 of 4337 inspections; and to November 2010, pipeline inspections have constituted 305 of 4102 inspections (Forest Practices Board, 2011). As a percentage of all inspections, pipelines constitute 4-11%, despite the fact that pipeline infrastructure is highly susceptible to failure, corrosion, and weather stress (OGC, 2010; Forest Practices Board, 2011). Additionally, the Forest Practices Board (2011) found that inspections were likely to be clustered around easily accessible geographic landmarks such as Fort Nelson or Dawson Creek. The Forest Practices Board Audit (2011) identified the OGC's objective to conduct inspections for all infrastructure every 5 years. Given that the typical commercial production lifespan of a horizontal well in BC is approximately three years with a maximum lifespan of five years (Hughes, 2014; NEB, 2000), some wells will not be inspected during the 5-year cycle.

The final mechanisms used by the BC OGC to mitigate risk are the Liability Management Rating (LMR) Program and Security Letters of Credit in the amount of \$50,000 per kilometer of pipeline. The pipeline letters of credit are used to protect landowners along pipeline right of ways from damage incurred by infrastructure malfunction. The LMR assigns risk rates to individual gas companies based on the ratio

⁵ Appendix G provides a list of all fines levied in quarters 1-3 by the OGC and distinguished the operator receiving the fine, it's amount, and the legislation violated.

between their assessed assets and liabilities. The difference is to be paid in the form of a security deposit. In principle, the LMR provides a safety net for the regulator if an operator is unable to satisfactorily reclaim a site or remediate damages arising from upstream operations. A permit holder with a rating less than 1.0 is classified “high risk” (OGC, 2013). Liabilities are calculated by adding costs of site abandonment and reclamation, or “*ex post costs*” – spills occurring during the lifetime of the project are not captured in the LMR. This enables operators to maintain a favourable LMR separate from their incident rate provided they hold substantial assets. Apache Canada Ltd., for example has a Security Adjusted LMR of 18.75, yet between 1975 and 2013 Apache has reported 949 spills in Alberta alone, and 575 of them consisted of produced water (Thorkelson, 2013). Currently, security deposits in BC are \$7500 per operator and an additional \$50,000 per kilometer of pipeline, yet the costs associated with remediation may be in the tens or hundreds of thousands of dollars. I provide a more fulsome description of the economic costs of remediation in section 3.3. In response to this apparent discrepancy, the Auditor General of British Columbia recommended that \$100,000 would be a more realistic amount for a security deposit (Doyle, 2010).

3.3 Costs of Produced Water Leaks and Spills

Costs of accidents tend to be thought of in terms of economic loss, or their direct effect on human health and safety. This may be calculated in terms of dollars, fatalities or injuries for a given timeframe. The NEB places special focus on ruptures and leaks that have implications for human health, hence pipeline incidents where there is ignition or visible amounts of heavy crude are given special attention (Jeglic, 2004); however, most produced water spills do not produce dramatic consequences like combustion. Produced water lines tend to be shorter than commercial product lines, and transect areas that are very sparsely populated; therefore, damages are primarily felt by local ecosystems and First Nations groups that live on the affected lands. In addition to pure economics, there are other ways to conceptualize the costs and consequence of produced water spills. The following sections discuss economic costs, social costs, and non-use values that are affected by leaks and spills.

3.3.1 Economic Costs

Remediation costs are variable and difficult to predict, particularly when they occur in forested areas or watersheds. The process of remediation depends on the scope of the spill or leak, but always includes soil and water remediation to remove chemicals and toxins from immediately affected features; restoring the site to its pre-accident state. Remediation may require contouring and re-vegetating the land; and disposal of the contaminated water, soil, and vegetation at an approved disposal site (AG, 2010). Remediation costs include wages, equipment, purchases or rentals, and materials. If a contractor is hired to do the work there will also be mark-ups for overhead and other costs which may be higher if a spill is geographically remote (USACE & EPA, 2000). Extraction, containment, disposal, and ongoing monitoring must also be considered in the cost of remediation, as well as the geology and hydrogeology of the affected land. Even very light precipitation can disperse small amounts of produced water. For example, in January 2014, Alberta's Environment Support and Emergency Response team discovered that despite effective application of industry best practices for site remediation, a significant amount of produced water had leached underneath snowpack and into a local tributary, affecting water quality for two kilometers downstream (Alberta Environment and Sustainable Resource Development, 2014).

Estimates for the cost of cleanup vary according to factors associated with the size and nature of the spill or leak. Typically the average cost of cleaning up a spill involving hydrocarbons is \$120,000 in Canada, although insurers will reserve \$30,000 to \$900,000 to cover costs of a spill depending on its severity (Canadian Underwriter, 2010). Costs of effective site remediation in the United States post well closure may cost between \$100,000 and \$700,000 thousand in American dollars dependent upon the extent of contamination and the zone of influence (ZOI) impacted (Mitchell & Casman, 2011). Produced water spills have more serious environmental implications than oil because of their greater rates of dispersion and high salt content (AAPL, undated). I could not determine precise costs for a produced water spill to compare it to other hydrocarbons; however, studies suggest that the costs may be higher because terrain affected by salt water and radioactive debris requires more expensive treatment (AAPL, undated; BTNEP, 2002). Additionally, because produced water does not always have a

visible “sheen” like other hydrocarbon products and is not visible to the eye, detection relies solely on testing for the presence or absence of chemicals and may not capture contamination that has travelled far from its source. Costs for cleanup of hydrocarbons spilled in estuaries and wetlands have ranged from \$268 US per litre of product spilled to more than \$18,500 US per litre (BTNEP, 2002)⁶.

3.3.2 Social Costs

In addition to the costs directly applied to remediation efforts, there are also numerous negative externalities felt as social and environmental costs that are not directly captured by industry expenditures. Because the market does not price social goods and values, accounting for the full range of damages felt by an accident involving produced water is both complex and problematic. Produced water spills and their cumulative effects over time can alter the effectiveness and flow of ecosystem goods and services (EGS); moreover, effects once thought of as being purely local, now have global implications in relation to their net contribution toward loss of biodiversity and climate change. Although the direct benefits of EGS experienced by humans is not as easily observed in Northeastern BC, Pearce et al. (2006) offer a useful way to think about this kind of natural capital flow:

“All ecosystems generate services which are extensive and pervasive. Those services essentially maintain life on Earth so, in one sense, all ecosystem services are economic services – they have an economic value based on the benefits that human beings receive from those ecosystems” (Pearce et al., 2006: 170).

BC’s ecosystems are an enormous source of market and non-market values; moreover, as much as 70% of BC’s Boreal region is intact and free from industrial activity (CBI, 2013), although this is rapidly changing. Intact ecosystems are able to provide very high levels of EGS, for example Northeastern BC’s Boreal forests, wetlands, muskeg, and soils store 5 billion tonnes of carbon or the equivalent of 27 years of Canadian greenhouse gas emissions (CBI, 2013). Providing a comprehensive

⁶ Costs included labour measured in time spent by the company’s own personnel and private contractors hired, and equipment required for cleanup.

analysis of accounting for EGS is beyond the scope of this paper⁷; however, noting that there are considerable monetized and non-monetized components within natural systems provides the baseline for understanding the complexity of determining social costs experienced by the environment after a produced water spill. The Pembina Institute together with the Canadian Boreal Initiative (CBI) conducted an exhaustive literature review of how natural capital assets held as benefits in Boreal forest ecosystems are understood and economically valued. When considering the total economic value (TEV) of non-market EGS in BC's Boreal forest, the non-market value exceeds the net market value by nearly fourteen times, totalling an estimated \$1204 per hectare in 2002 dollars (Anielski & Wilson, 2009: 42). This figure is derived from averaging regional specific data for EGS and the estimated worth of individual goods or services as they function within ecozones. Hence, the location of a spill within an ecosystem, and how dispersed nonpoint source pollution becomes from its origin will significantly impact the social cost of the spill. The CBI has calculated approximate value estimates for individual ecosystems and their features:

Table 4.3: Estimated Values for Ecosystem Goods and Services

Ecozone	EGS	Non-market/Market Valuation	Methodology
Wetlands, Peatlands, and Muskeg	Carbon storage; flood control; water filtration; biodiversity storage and habitat provision	\$4809/Ha. /year	
Forests: Boreal and Taiga	Carbon storage	\$788/Ha. /year	
Outdoor Recreation	Aesthetics; activities	6.1 million outdoor enthusiasts per year nationwide (roughly 350,000+ for BC)	Based on calculating the percentage held by BC stocks (or 5%), and using CBI figures for all of Canada.

⁷ A more fulsome description of ecosystem goods and services can be found in Appendix H.

Ecozone	EGS	Non-market/Market Valuation	Methodology
	Nature related expenditures	\$4.5 billion generated through business revenues, tourism, government revenues and admissions to provincial parks, and personal revenues captured through wages. (\$225 million for BC)	Input/ Output modeling

Information source: Anielski & Wilson (2009).

Peatlands and muskeg, the primary locations affected by produced water spills, are significant contributors to carbon storage, nutrient cycling, and waste cycling, yet their ability to store and cycle water also makes them the most difficult to remediate. Spills of all kinds are absorbed into layers of peat, and may affect soil many metres below the topsoil. In order to ensure complete removal of contaminants, all affected water and soil must be removed from the site. This kind of site remediation eliminates the ability of the affected area to supply EGS for a given period of time and extends the ZOI by increasing habitat disruption and chemical exposure (*Dene Tha' First Nation v. British Columbia* [2013]; Fraser Basin Counsel, 2012).

In addition to understanding resource accounting from a non-human perspective, First Nations are also beneficiaries of the many use and non-use values derived from BC's Northeastern ecosystems. They use their local lands for subsistence and ceremonial purposes, or passive-uses, and have constitutionally protected rights. The courts have interpreted these rights to include cultural, social, political, and economic rights including the right to land, as well as to fish, to hunt, to practice one's own culture, and to establish treaties (*R. v. Calder* [1996]; *R. v. Sparrow* [1990]). A recent court case between the Dene Tha' First Nation and the BC Minister of Energy and Mines not only contested whether or not the government's obligation to consult had been met, but also enumerated some of the specific values placed on the land by the First Nation. The Dene Tha' are not opposed to development per se but noted that they have concerns for how industrial activities will affect their traditional "berry and medicinal plant gathering areas, trapping areas, sacred sites, fishing areas, camps and settlements, trails and

migration routes, traditional ecological knowledge areas, and hunting areas” within their 31,908 km³ range that is overlapped by oil and gas activities; moreover, assessments of the area note that the ZOI for gas activities is growing at a constant rate of 260 km³ per year, and by 2095 land disturbance will reach 100% (*Dene Tha’ First Nation v. British Columbia* [2013]; paragraphs 46-52). Other residents of Northeastern BC have expressed concerns regarding the possibility of biomagnified contamination in wild game and declining populations of hunting stock (Fraser Basin Counsel, 2012).

3.4 Gaps in Data

Produced water is a relatively new field of study across jurisdictions, and many researchers find that federal, state, and provincial data suffers from significant gaps and uncertainties (Ernst Environmental Services, 2013; Veil et al., 2004). Even where data exist they are often imprecise or accessible only through freedom of information requests. Many state and federal reports are not broken down by oil or gas product type, or whether or not produced water is generated on or off-shore (Veil et al. 2004); moreover, existing statistics and volume reports may be under reported, or not reported at all for some jurisdictions and data must be extrapolated according to most-similar case scenarios and subjective estimates. Clark & Veil state in their methodology that despite their study being based on the best available data, “the best available data is far from complete” (Clark & Veil, 2009: 8). Because produced water generation and properties vary according to local geology, formation characteristics, legislative requirements, and industry operator decision-making it is very difficult to determine what the costs of produced water management actually are. Industry operators do not publicize expenditures made on disaster and spill mitigation, thus it is difficult to measure what percentage of production costs are consumed by accidents. Furthermore, lack of data makes it difficult to determine what percentage of volumes may be missing due to spills or improper management.

BC, like many jurisdictions, lacks the kind of comprehensive hydrogeological data that would facilitate a complete risk assessment. Since groundwater is not currently regulated, and aquifers are not mapped it is difficult to express the extent of their susceptibility to contamination. Pipeline right-of-ways are generally constructed along

routes designed to impose the least harm to the surrounding environment. In particular, decision-makers attempt to avoid wetlands and other sensitive ecological areas; however, dependent upon the slope and permeability of local terrain, factors such as precipitation can very easily carry toxins into aquifers or groundwater located in shallow bedrock (Simpson et.al, 2013). Lack of data concerning the location and characteristics of groundwater in Northeastern BC presents a logistical challenge for oil and gas companies attempting to build permanent or temporary infrastructure and places them at a significant disadvantage for conducting risk identification and analysis.

An additional complication is the lack of coordination and communication between government agencies, ministries, and industry operators. As the OGC operates as a single-window regulator, there is insufficient communication between ministries regarding long-term planning or shared objectives. Similarly, unless there is a need for coordinated emergency response, federal and provincial agencies do not collaborate or share information. All available information is available only through the agency that originally collected it, if at all. Finally, industry operators are the least likely to share information, and neither are they bound to do so (Jacquet, 2012). In BC, oil and gas companies are mandated to release the chemical contents of fracturing fluid only after extraction is completed and the well site abandoned. In most cases, industry trade secrets are protected under patent laws, and cannot be accessed. Oil and gas companies are fiercely competitive with one another, and show little initiative or interest in increased transparency.

Chapter 4. Methodology

I use available qualitative and quantitative data to perform a gap analysis to determine where strengths, weaknesses, and opportunities lie within the existing compliance management framework governing the natural gas industry in BC. I use publically available data from provincial and federal government sources, industry, academia, provincial and federal courts, and the natural and social sciences to describe the current risk and risk management regime for wastewater spills and leaks in BC's natural gas sector.

I use examples and statistics from other jurisdictions and other industries where they are able to provide applicable policy direction. The cross-jurisdictional case studies used in this research are Alberta, Canada; the Marcellus Shale Play in the Eastern United States; and the Bakken Shale Play situated primarily in North Dakota. I chose these shale plays because their ultimate resource potential is similar to that of BC. The cross-industrial case studies used are the Canadian pulp and paper industry; the Insurance Corporation of British Columbia (ICBC); and the international airline industry. Each case study is examined on the extent to which they have effective accident prevention mechanisms in place. These include industry compliance rates, inspections done on pipeline infrastructure, robust regulation and legislation, comprehensive risk assessment instruments, strong enforcement including fines, monitoring and data sharing, and industry operator performance and internal risk mitigation.

Finally, I use a multi-criteria decision-making process to weigh the costs, benefits, and trade-offs associated with policy options that best satisfy the objectives and mandate of the OGC, while improving compliance within the natural gas industry. Policy options are assessed according to criteria with well-defined measures to determine their efficacy, administrative complexity and cost, feasibility in terms of acceptability to

stakeholders and First Nations, and the extent to which they result in robust improvements to the regulatory framework.

At the outset of this project, my intent had been to conduct expert interviews with industry operators and representatives from oil and gas companies. I planned to gauge their response to my proposed policy options, and comment on the validity of my research questions. I sent e-mails to experts to invite them to participate, and followed up with phone calls; however, all of the individuals I contacted declined my invitation to participate.

Chapter 5. Case Studies

5.1 Cross-Jurisdictional Case Studies: North American Shale Plays

Comparison between jurisdictions can be difficult. When measuring pipeline failures and produced water leaks and spills regulators collect, review, and publish data according to different criteria. Some jurisdictions only require reporting for incidents exceeding certain thresholds for product releases or monetary damages incurred, or if there are injuries or fatalities associated with the event. Currently no federal agency in the United States or Canada requires operators to track produced water volumes. In a perfect world oil and gas operators recognize that proactively managing social and environmental risk can, in the long run, help to achieve competitive advantage by managing resources most efficiently and preventing costly ventures. Indeed, many do, however managing compliance is targeted toward operators that do not entirely share the same values as well as the recognition that error and accidents happen.

Compliance theory suggests that industry operators are rational. The decision to comply is made implicitly or explicitly according to costs associated with maintaining a compliant status vis-à-vis the costs of being non-compliant that may come in the form of litigation or financial penalty (OECD, 2009). Simply put, industry operators will intentionally violate compliance standards if there is a benefit of doing so. Violations may be in the form of a deliberate contravention of regulations, or even making the choice to invest fewer resources in employee training knowing that the outcome may be increased incidence of human error and accidents. Because most accidents and the prevention of accidents is closely linked to an operators preference for high corporate social responsibility, compliance and non-compliance is closely linked to an operator or company's preference for mitigation and prevention (Wagner & Armstrong, 2010). Hence, focusing on tools to induce compliance among those least likely to demonstrate

a preference to be fully compliant is the most effective allocation of regulatory resources to reduce the frequency and severity of leaks and spills. The following three case studies provide a cautionary tale of development for BC to consider as development and extractive activities intensify. Because these shale plays are farther along than BC in terms of resource development, but have comparable output potential they provide valuable examples of ways that weak enforcement and monitoring can become problematic and costly. BC is in a position to learn from the mistakes made in other jurisdictions and develop a sound regulatory framework based considering both what has worked and what has not.

5.1.1 Alberta, Canada

Alberta has kept detailed records of incidents broken into product types and the volume released since 1990. Estimates are conservative and understated as some pipelines, particularly water lines, are not equipped with meters. The most realistic estimates of spill volumes are derived from production rates, pipeline capacities, metering, and measurement of contaminated areas, although it is not always possible to determine when a leak began (Alberta Energy Regulator, 2013). The degree to which industry operators comply with regulations is exacerbated by criticism that the existing regulatory framework is weak and underdeveloped (Ernst Environmental Services, 2013). Tailings ponds holding liquid waste and produced water from oil and gas activities cover an estimated 130-170 km² of Alberta (Jeffries, 2012). They are frequently situated nearby watersheds and are accident-prone. The Alberta government has attempted to initiate programs to improve scientific monitoring and industry transparency; however, the Cumulative Environmental Management Association (CEMA), and the Regional Aquatics Monitoring Program (RAMP) have lacked the resources to conduct comprehensive reviews, and because they are industry-funded initiatives have been criticized for lack of independence (Jeffries, 2012).

Alberta currently administers an Environmental Security Protection fund drawn from industry operators paying a security bond. The holdings of the fund were \$820 million in 2009, and increased to \$1.3 billion in 2012, assigning an approximate reclamation amount of \$12,000 per hectare of disturbed land in the province (ESRD,

2012; Lemphers et al., 2010). According to calculations made by the Pembina Institute reclamation costs for land, tailings and produced water will total \$9.4-\$13.7 billion (Lemphers et al., 2010), leaving approximately \$8.1-\$12.4 billion unaccounted for and likely passing on an additional \$2,200-\$3400 to every resident of the province in liability costs.⁸ Aside from the issue that current levels of security bonds in Alberta are insufficient to cover remediation costs, the existing regulatory structure is problematic. Emphasis is placed on site closure and remediation, but very little has been done to effectively prevent environmental degradation. Rather, existing programs and policies such as Alberta's *Emergency Management Act* are reactive rather than preventative. Furthermore, court rulings have found that the Alberta government exerts a bias in favour of oil and gas development where environmental concerns are cited (*Pembina Institute v. Alberta (Environment and Sustainable Resources Development)*, 2013 ABQB 567).

5.1.2 United States – Bakken, ND

Shale gas activities in North Dakota are co-governed by the North Dakota Industrial Commission and the state Department of Mineral Resources Oil and Gas Division. Because there are numerous state regulations and laws that govern extractive activities, as well as overarching federal laws and administrative bodies fully understanding shale gas laws on a state-by-state basis can be confusing, although matters become most complicated when shale plays cross numerous state boundaries that may have different performance standards and operating practices for industry operators. In 2005, Congress amended the *Safe Drinking Water Act* and the *Energy Policy Act* to permit fracturing fluids to be injected underground provided they do not contain diesel fuel⁹. Since then, hydraulic fracturing falls almost exclusively under state jurisdiction.

⁸ The Pembina Institute estimates \$6300 in liability per Albertan based on the provincial tax base, rather than population demographics and calculated in 2010 dollars (Lemphers et al., 2010).

⁹ Also referred to as “the Halliburton Loophole” based on allegations that President Bush and Vice President Cheney exempted hydraulic fracturing activities from environmental protection legislation in order to benefit oil and gas supply companies such as Halliburton; however, despite having prohibitions in place, Halliburton used 807,000 gallons of diesel in fracturing fluids between 2005 and 2007 alone (Independent Water Testing USA, 2011).

The Bakken shale formation is second only to Texas in terms of oil production. Large volumes of natural gas are coproduced with oil, although the state regulator estimates that at least 30% of North Dakota's natural gas is flared as a waste product, in part because of a weak legislative framework, but also because of a lack of reliable infrastructure (Salmon & Logan, 2013). While some companies have made commitments to improve their environmental record, there are many that lack the incentive to do so. Like GHG emissions, produced water is only weakly regulated – state compliance laws and regulations governing hazardous materials and waste do not even mention oil and gas by-products or wastewater. Thus far environmental initiatives are voluntary in North Dakota, as well as other major nearby oil and gas producing states such as Colorado, Wyoming, and Montana. Within the voluntary framework there are provisions for risk management and remediation programs, however formalized efforts are lacking or non-existent, and there are minimal thresholds by which to establish best practices (EPA, 2008: ES-7). Since 2008, North Dakota has attempted to regulate some unnecessary flaring, however produced water remains an area that requires further study given that 96% of produced water is injected, but there is little data regarding how it is managed prior to disposal or how it is transported (Clark & Veil, 2009).

5.1.3 United States – Marcellus Shale

The Marcellus shale play is the most extensive of all plays and spans over five states: New York, Pennsylvania, and West Virginia, Ohio and Kentucky. It is roughly twice the size of the Barnett shale play and is estimated to hold more than 500 tcf of natural gas (IOGA, undated). Development in the Marcellus region is complicated by higher population density and relative ignorance of best practices developed in the Western US and has resulted in contamination issues and loss of social license in many cases (Jaquet, 2012). Fracturing fluids in Pennsylvania are subject to minimal treatment levels before being injected into underground wells. If produced water is treated in an accredited wastewater plant, it may be discharged into surface water in accordance with the federal *Clean Water Act*. High cost is a significant barrier to produced water treatment. Deep well injection with minimal treatment costs between \$0.59 to \$13/m³ of produced water, whereas remediation for surface water disposal may cost as much as \$53-\$71/m³ (Clark & Veil, 2009; Jiang et al., 2014). Litigants claim that these high costs

and weak enforcement practices result in numerous cases of non-compliance for industry operators where produced water is spilled or discharged without adequate treatment. Shale gas operators in the state of Pennsylvania are subject to bonding instruments prior to drilling activities. They must post either a one-time bond of \$2500 for each individual well, or a blanket bond of \$25,000 to cover all wells drilled in the state, which has been problematic given that most sites require extensive remediation costing between \$100,000 to \$700,000 (Mitchell & Casman, 2011: 9508). Similar to BC's LMR program, the bonds posted in the Marcellus region to address liability are wholly insufficient to cover costs if an industry operator is not able to.

Public opposition has significantly curtailed fracturing activities in New York State, and as a result New York's annual gas production was less than one third that of Pennsylvania (Clark & Veil, 2009), and then subject to moratoria bills beginning in 2010. None of the states in the Marcellus region collect data regarding produced water management. Although state regulators are able to provide estimates for volumes generated, there is no additional data given for what percentages are discharged into local water bodies, injected, or reused on or off site (Clark & Veil, 2009). Lack of data and reporting represents only one problematic component of produced water management in the Marcellus shale play. According to residents, the general lack of attention and oversight has resulted in numerous cases of groundwater contamination and affected the balance of local ecosystems. Many Marcellus residents are formally bringing lawsuits against natural gas companies, either as individuals or class actions, for a host of grievances including negligence, damage to property value, public nuisance, medical monitoring and adverse health impacts, and exposure to dangerous activities (Mullady et al., 2012). Because of the enormous burden of proof on plaintiffs, and the reality that produced water constitutes nonpoint source pollution, it is not clear if litigation will accomplish much for Marcellus residents; however, industry operators might find that social licence improves with better reporting, monitoring, and accountability (OECD, 2009).

Similar to other jurisdictions, New York state law is inherently contradictory in its legislation governing oil and gas extraction, and would make compliance nearly

impossible should the moratorium be lifted (Siler, 2012). Article 23 of the *Environmental Conservation Law* states that it is in the public interest to:

“regulate the development, production and utilization of natural resources of oil and gas in this state in such a manner as will prevent waste; to authorize and to provide for the operation and development of oil and gas properties in such a manner that a greater ultimate recovery of oil and gas may be had, and that the correlative rights of all owners and the rights of all persons including landowners and the general public may be fully protected” (ECL, Article 23).

The data presented in this paper so far suggests that it is not possible to prevent waste while also maximizing natural gas recovery. Almost all jurisdictions suffer from similar or worse contradictions or vagueness in natural gas regulation. In many cases, including BC, this is due to the inability of dated legislation to address contemporary technologies and issues. Nevertheless, compliance is nearly impossible in cases where thresholds and objectives are not clearly defined, or open to wide interpretation. Industry operators and development at large benefit from innovation and flexibility in achieving performance measures however, growth of extractive industries must also be met with similar improvements in regulatory oversight.

5.2 Cross Industrial Case Studies

Data from jurisdictions exploiting commercially viable volumes of shale gas indicate that existing regulations and operating practices are not robust and do not induce compliance. Furthermore, where data exists it does not indicate that minimum criteria to prevent spills and leaks are met. Because of this risks to environmental and human health are widespread and systemic across shale plays. In order to identify best practices that BC can consider to mitigate the probability and consequence of spills and leaks, I present three case studies of other industries and regulatory mechanisms that have high compliance and safety rates. The following subsections discuss the instruments used in the pulp and paper industry, the Insurance Corporation of British Columbia, and International Airline Safety Standards that have proven effective in stimulating compliance through robust regulation and reducing the frequency and severity of accidents.

5.2.1 The Pulp and Paper Industry

The pulp and paper industry provides one of the best examples of how robust regulations and enforcement have been used to improve compliance and reduce pollution emissions in North America. In the 1980's governments in Canada and the United States determined that intervention was necessary to control two different water pollution types emanating from pulp and paper mills – Total suspended solids (TSS), a measure of the concentration of solid waste and biological oxygen demand (BOD), an indirect measure of the interactions of a number of different contaminants that are present in pulp and paper wastewater. Command-and-control type regulations stipulating allowable pollution levels, and enforced through inspections with fines and other penalties were widely used across jurisdictions as a means to address the problem of water contamination and their effectiveness has been the focal point of study over the last three decades (Lanoi et al., 1998; Laplante & Rilstone, 1996; Liu, 1995; Magat & Viscusi, 1990). These studies agree with government agencies in suggesting that: “inspections remain the backbone of agency compliance monitoring programs. Government officials make independent judgments as to the compliance status of a facility. Even with widespread requirements for self-monitoring, inspections play a major role in assuring quality and lending credibility to self-monitoring programs” (Wasserman, 1984).

The Municipal Industrial Strategy for Abatement (MISA) in Ontario, and the *Environmental Quality Act* in Quebec have been guided by the federal *Fisheries Act* and its related *Pulp and Paper Effluent Regulations*, which provide guidelines by which compliance and enforcement have been carried out in Eastern Canada. Similarly, in the United States the EPA has used the *Clean Water Act* to regulate effluent emanating from pulp and paper mills. Among other things, these statutes and regulations provide for permitting, and inspections to ensure compliance, and levy penalties in cases of non-compliance. Magat and Viscusi (1990) note that penalties for infractions in the US may be civil or criminal. Average fines levied between 1975 and 1985 were \$89,437, and violations could result in one year of imprisonment for a first offense and two years in prison for a second case of non-compliance (Magat & Viscusi, 1990). Opportunities to cheat by making false self-reports were mitigated by annual inspections and all of the

research papers considered by this case study found that inspections significantly improved industry compliance and lowered pollution emissions.

Magat and Viscusi's study (1990) found that inspections and subsequent enforcement actions reduced pollution by about 20%, and that the reduction was likely permanent; moreover, the results of their study suggest that inspections improve the non-compliance rate to 25%, whereas they predict a non-compliance rate of 48% in the absence of inspections. Liu (1995) extended the work of Magat and Viscusi to differentiate between regular or discretionary inspections and the kind of industry behaviour that each induces.¹⁰ Because there are different probabilities of inspection depending on the type of inspection utilized, the ensuing behaviour of the industry operator is driven by the benefits and costs associated with its likelihood of actually being inspected. Thus Liu (1995) finds that regular inspections not only result in improved compliance, but also that the self-reports issued by firms are more likely to be truthful.

Pulp and paper mills in Quebec exhibit similar trends. Similar to Magat and Viscusi (1990) and Liu (1995) Laplante and Rilstone (1996) find that inspections improve industry compliance and the quality and truthfulness of reporting; furthermore, they add that the threat of inspections may have a similar effect on the behaviour of industry operators as actual inspections reinforcing Liu's (1995) hypothesis that the probability of incurring inspection has an effect on compliance. Laplante and Rilstone (1996) note a 28% improvement in compliance and suggest that the trend may be "persistent if not permanent." They attribute this to technological investment, better understanding of regulations, or a combination of these factors and others. The most significant finding is the threat or expectation of incurring inspection has a large positive effect on improving compliance. Using the same model adapted from Magat and Viscusi (1990) Lanoi et al.

¹⁰ Liu (1995) suggests that regular, un-induced inspections will cause firms to be more likely to self-report violations in order to mitigate the risk of being subject to civil or criminal punishment for non-compliance. Discretionary inspections based on self-reports of non-compliance and targeting firms with poor compliance history will have the opposite effect on reporting. Liu (1995) suggests that industry will be less likely to report violations in order to avoid triggering inspection if there is zero probability of incurring inspection otherwise; however, discretionary inspections may be useful in terms of identifying and rectifying root causes of non-compliance when and if they occur. Many regulations and regulators that serve to reduce pollution and contamination use both kinds of inspections.

(1998) conduct a similar analysis of Ontario's pulp and paper regulations, yet they do not observe the same correlation between inspections and improved industry compliance. They attribute the difference in behaviour of Ontario's pulp and paper industry from the other jurisdictions described here to the Ontario government primarily utilizing discretionary inspections to monitor compliance and failing to impose sufficiently large fines when non-compliance was determined (Lanoi et al., 1998).

5.2.2 Insurance Corporation of British Columbia (ICBC)

Insurance protects against a possible eventuality. It is an effective form of risk management where an actor (or client) pays premiums, and abides by certain obligations in order to be protected against liability and loss in the event of an accident. The concept of insurance is more than a thousand years old, and was first codified under the Amalfi Sea Code. According to the Code, trade merchants paying into a common fund could be reimbursed in the event that their fleet suffered losses or damage from storms, piracy, or poor navigation (Insurance in Canada, undated). Many years later it is a fundamental risk mitigation tool that moderates the effects of loss for private individuals and corporations.

In BC, insurance operates according a full tort system under Canadian law and the criminal code. This means that at fault parties may be sued for damages in serious cases. Car insurance, in particular makes use of this system by assigning premiums to clients based on their risk class, and these premiums may change in response to the client's behaviour (ICBC, 2014). Beneficial attributes such as experience or an accident-free history are rewarded by lower premiums, whereas negative or risky attributes are penalized by higher premiums and restrictions. The most serious repeat offenders, or claimants, may be refused insurance. Increasing premiums in accordance with risk is an effective incentive to help reduce risky behaviour. Increasing costs and restrictions provide a series of accident barriers; however, clients with higher ability to absorb increased costs may be less economically affected than those who are of lower socio-economic status. Combining economic incentives with strong enforcement such as legal sanctions has proven highly effective as a deterrent of risky behaviour (ICBC, 2014). An additional benefit of insurance schemes is that they are reviewed on short time frames.

In the case of auto insurance it may be monthly, whereas home insurance is annual. Frequent review permits risk to be assessed in real time and rewarded or punished so as to change current behaviour. Establishing a history of review enables an auditor to assess whether or not a claimant is becoming more risky or if the incident was indeed accidental.

Moral hazard is the primary limitation of the effectiveness of insurance. An actor may be willing to engage in more risk if they know that they will not bear the full cost of their actions. The Insurance Corporation of British Columbia effectively mitigates this risk through comprehensive review, access to data and driving records, inspections done by their own auditors as well as others such as the police, and strong punishments for non-compliance including fines and sentencing (ICBC, 2014). Other jurisdictions including Alberta have liability insurance, but it does not typically cover environmental accidents. Insurance against leaks and spills would not conflict with BC's "polluter pays" principle, but rather could support it. Annual earned premiums provide the basis for protection against serious accidents by ensuring that remediation will happen, that it will not be at the expense of the Crown, and that actions of insured parties are appropriately encouraged or deterred.

5.2.3 International Airline Safety Standards

Air travel is one of the least risky activities one can engage in. In 2013 the International Civil Aviation Organization published that there are 3.2 accidents per million departures (ICAO, 2012). Put another way, the probability of being in an aircraft accident is less than 0.0001%. Aviation safety and risk management is unparalleled among industries. They do this by implementing robust regulations and standards including enforcement, acting on a zero-tolerance policy for risk, widely sharing and distributing data, and frequent inspections and maintenance on all aircraft and infrastructure (IATA, 2014; ICAO, 2013; Transport Canada, 2014).

The airline industry is well coordinated. Within Canada alone, there are numerous public and private entities working under Transport Canada to ensure that national and international criteria are met for safety and security. Agencies including the

Canadian Air Transport Security Authority, NAV Canada, Canadian Border Services Agency, and their international counterparts have different functions yet effectively collaborate to deliver safe and efficient airline services. Within this framework there is significant data sharing and transfer. In the interest of security, airlines share data regarding individual passengers, but they also share innovations and technological improvements. Unlike the oil and gas industry where proprietary secrets are commonplace, 90% of the aviation industry shares its data voluntarily based on a milestone agreement made by major carriers in 2010 who realized how crucial it is “to understand safety trends, not just from the handful of accidents each year, but by bringing together and analyzing data from millions...” (ATW Air Transport World, 2010; IATA, 2014). Because of this experts are able to analyze statistics and trends from millions of hours of flight time, and determine the kinds of safety interventions necessary before an accident happens. Assuming that oil and gas operators will not find it beneficial to share information, the regulator can use incident reports to identify best practices and opportunities for improvement.

Like oil and gas companies, airlines are competitive. However, there is a collective realization that anything less than perfect safety affects the confidence of passengers and thus their revenues. After 9/11, the airline industry lost an estimated \$9.1 billion US in revenue in the first year, and since then the demand for travel has been permanently reduced by 7.4% (IATA, 2006). There may be other factors contributing to fewer people flying, but airlines accept that public anxiety is not good for business. Accidents or poor environmental safety do not affect oil and gas operators' revenues as significantly as accidents in the airline industry however, public disclosure of pollution can affect capital markets. Studies have found that poor environmental performance can adversely affect stock prices (Lanoie et al., 1997), and both British Petroleum and Halliburton's share prices fell after the Deepwater Horizon spill in the Gulf of Mexico in 2010 (Economist, 2010).

Safety management systems (SMS) are a standardized and systematic mechanism for managing safety, and ensuring that policies and procedures are met regardless of what jurisdiction an aircraft and crew may be operating in (IATA, 2014). Individual airlines are obligated to implement effective SMS that identifies hazards,

immediately addresses them, and provides ongoing monitoring that conform to the provisions made by regulatory bodies such as the United States Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA), and the International Civil Aviation Organization (ICAO) (IATA, 2014; Transport Canada, 2014). Regulations and enforcement is strict. Audits are frequent. If crews identify a deficiency or hazard, the plane does not fly. Standards and rules between regulators are very similar so as to provide clarity and cohesion across borders, and to maintain a single iteration of gold standard best practices.

The airline industry's exceptional risk mitigation is further supported by extensive employee training for all staff working in proximity with aviation hardware, and a strong enforcement regime. Airline employees must meet or exceed mandatory criteria in a number of categories including: certifications, training, experience, and physical criteria (for example age thresholds for pilots) in order to be employed by an airline and maintain good standing (ICAO, 2013). Enforcement for airlines is another matter that is taken very seriously. Nations may refuse to permit certain airlines within their borders if they have an unsatisfactory safety rating. This practice of "blacklisting" is commonplace with regard to airlines that do not meet mandated safety levels or have an unacceptable accident rating. Currently the European Union has banned 287 unsafe airlines from operating in their airspace or landing at their airports, and the US Federal Aviation Administration considers the extent to which an airline meets criteria set out in the ICAO as a safety precaution (Davies, 2013).

5.3 Conclusions

Reviewing the successful use of inspections as a driver of improved compliance rates identifies gold standard best practices to consider when implementing a similar monitoring framework in the same or different industries:

1. Regular inspections are more effective than discretionary inspections.
2. Monitoring must be accompanied by parallel enforcement such as civil or criminal punishments that provide effective deterrence for re-offense. Blacklisting or refusing access to the worst offenders is an effective recourse for dealing with recidivists.

3. The threat or expectation of inspections can have as beneficial an effect as an inspection itself.

These findings prove useful for regulators deciding where to allocate scarce resources and how to prioritize actions to best mitigate risk. This proved effective in the pulp and paper industry, and its features are highly exportable to other jurisdictions and industrial sectors that are at risk from contamination or pollution.

Similarly, while insurance structures prevent against loss or liability, they also induce and respond to behaviours. Like the pulp and paper industry in the United States, insurance in BC punishes non-compliance and risky actions with civil and criminal penalties. All three industries illustrate a propensity for actors to avoid penalties provided the penalties are severe enough to warrant avoidance. Fines, in particular must be set sufficiently high for actors to determine value in preventative behaviour. Mitigating the effect of moral hazard is effectively abated by increased scrutiny and the probability of false reporting being detected and punished.

All three case studies combine common elements of monitoring and enforcement to reduce the risk of incidents. The consequences associated with airline incidents can include large numbers of fatalities. Because of this, prioritizing human health and safety trumps all other considerations including economics and protection of trade secrets. While some features of airline safety standards may not be realistic for the oil and gas industry's purposes, others such as comprehensive employee training and blacklisting risky operators may be highly effective.

Chapter 6. Criteria and Measures

The goal of this research is to identify the most effective policy instruments for reducing the frequency and severity of produced water spills and leaks by improving compliance by industry operators. I identify criteria to help assess the effectiveness of policy options and fulfil other important regulatory and compliance objectives that include:

- Ensuring that all stakeholders receive equitable treatment in the distribution of costs, risk, and net benefits;
- Ensuring that produced water management is made as sustainable as possible;
- Managing costs for both the regulator and industry;
- Deter future non-compliance.

Measures are derived from both qualitative and quantitative data and are aggregated and scored. Policy options will be adjudicated on the basis of options being non-dominated and their overall performance vis-à-vis the performance of other options.

6.1 Effectiveness

The effectiveness criterion will assess the change in compliance rates at the time of initial inspection. Higher rates of compliance, or improvements to the status quo are desirable, whereas declining compliance rates may indicate that policy options are ineffective or being implemented incorrectly. As per the Auditor General's suggestion noted in this paper, obtaining compliance rates prior to remediation efforts would be useful in determining real compliance rates within the natural gas industry at large, and between industry operators in particular (Doyle, 2010). This information would provide the baseline by which performance is measured and function as the primary measure for the effectiveness of the policy. In the absence of BC specific data, I estimate the

effectiveness of policy options by observing effects of the same, or similar, policies in other jurisdictions or cases.

A secondary and more long-term measure of policy effectiveness is the change in frequency of pipeline spills and leaks, and the severity of individual pipeline spills and leaks. By using statistics from past years we can create an intervention point where policy is implemented, and build a counterfactual measuring the incident rates and severity with the policy, and without it. Both cases should consider rates of industry growth, and consider a range of scenarios for resource extraction and risk. Effective policies will see a reduction in frequency and severity below that of the status quo in all of the scenarios over time.

6.2 Robustness and Flexibility:

Implementation can distort proposed policy both intentionally and unintentionally by submitting options to rigid bureaucratic, legislative, and partisan processes. Because of this and the danger that the final articulation of a policy may be ineffective or differ substantially from its original form, a policy option itself must be robust enough in its objective that if the process becomes cumbersome, the outcome will still be acceptable. Therefore, policies governing oil and gas activities must satisfy a number of institutional objectives and realities in order to be functional. From a legal standpoint, the policy must be transparent and easy for industry operators to understand. It must also be enforceable. In order to avoid contradictions and weak regulation as has been observed in the Marcellus shale region, threshold levels, what constitutes non-compliance, and resulting consequences must be clearly defined, easily obtainable, and widely distributed. The policies must apply equally to all industry operators, and be enforced without prejudice. This criterion also provides for fairness and horizontal equity between industry operators by ensuring that the policy is administered to all operators on the same basis, and that regulations apply equally to each individual operator. Because this criterion addresses equity, I do not include an additional equity or fairness criterion in order to avoid double counting.

The BC OGC operates according to a set of values and objectives. Among other things they include:

- Protecting public safety;
- Environmental preservation;
- Support of resource development;
- Engaging with stakeholders and business partners to provide fair and time-sensitive decisions within the regulatory framework;
- Demonstrating accountability, efficiency, transparency, and respect. (OGC, 2014)

Therefore, policy options must be congruent with the objectives of the OGC, and result in overall improvements to the regulatory network while conforming to provincial and federal laws. At times, facilitating resource development may conflict with the other listed objectives. This is common among jurisdictions that exploit oil and gas and New York State law was offered as an example in section 5.1.3 where legislation was contradictory in its provisions. Choosing policy options that best conform to these criteria will be better equipped to respond to challenges and trade-offs presented by tensions between development and safety. In response to the OGC's commitment to support resource development, but also work with stakeholders, the flexibility criterion will measure the extent to which industry is able to innovate and permits operators to select among technologies to achieve performance standards. Allowing flexibility within regulations, albeit binding operators within Canadian regulatory and legal parameters will enable industry operators to identify and apply on a case-by-case basis the most effective mechanisms to maintain the highest levels of compliance within the bounds of site and geological factors. The additional benefit of a flexible regime is that by setting the performance standard without prescribing what technology must be used, there is ability for operators to make adjustments to equipment or protocols without requiring legislation to change.

6.3 Community and Stakeholder Support

Oil and gas exploration and production is a politically charged topic in British Columbia, and globally. Because there are many strong views on how and when shale

gas reserves should be developed, it is prudent for policy makers to assess the support for policy from communities and stakeholders. Assessment will be based on the level of support a policy receives as indicated by opinion polls, media information, and statements by stakeholders. This study distinguishes between stakeholder groups with a relevant interest in the issue of produced water management, and nations who negotiate on a nation-to-nation basis. First Nations will be considered separately from other stakeholder groups due to the Crown's duty to consult under the constitution. Northeastern BC's First Nations are organized into an ethno-linguistic political association between five of the eight Treaty 8 Nations. The group includes the Sicanni (Sikanni), Slavey, Beaver (Dene Tha'), Cree, and Sauleau Nations. Treaty 8, like the Dene Tha' are not opposed to development *per se*, but have legitimate concerns regarding gas development in the region. Other First Nations in the province are publically opposed to pipelines, but do not hold Aboriginal title or traditional territory in Northeastern BC. For the purposes of this study, I focus on the positions articulated by the Treaty 8 coalition, or by Nations that hold lands and aboriginal title in Northeastern BC.

Key stakeholder groups include industry operators in BC's natural gas industry, environmental advocates, and residents of Northeastern BC. For this criterion I consider only companies that have natural gas projects in BC. The OGC lists 43 active natural gas operators on its Fracfocus website, although there are more than 100 oil and gas companies currently paying royalties in BC (OGC, 2013; R. McManus Consulting Ltd. & Salmo Consulting Inc. 2004). Support for a policy by industry operators will be gauged by actual and anticipated responses of BC working operators.

BC is home to numerous well-organized environmental groups who have been effectively opposing resource extraction projects for more than thirty years. The earliest conflicts were over logging activities, and obliged the government to review its resource management practices as well as protect certain areas of wilderness and parklands including the Muskwa-Ketchika Management Area. Gauging the level of support by this stakeholder group will be based on actual and anticipated positions made public by key environmental think tanks and organizations.

Risk and the acceptance of risk is a subjective and individualized process; moreover, the level of acceptance for any given risk scenario depends greatly upon whether or not the acceptance is voluntary or involuntary. Involuntary acquisition of risk, with particular reference to risks that have public and extreme consequences, is generally unacceptable to most people matter how low the relative frequencies of such events might be. Residents in Northeastern BC have expressed concern about the health and environmental involuntary risks posed by all phases of natural gas exploration and extraction (Fraser Basin Council, 2012). Public understanding and acceptance of risk vis-à-vis net benefits of projects is highly variable, and is not always correlated with the level of risk a particular hazard actually poses (Fischhoff et al., 1984). Because obtaining and maintaining social license is increasingly important for operators whose projects may have environmental consequences it is critical for both industry and the regulator to effectively understand and respond to public opinion. Similar to the previous measures, feasibility for residents of BC's northeast will be determined by actual and anticipated responses.

6.4 Administrative Complexity and Cost

Administrative considerations for how and when a policy is implemented are significant drivers of its likelihood to be put on the policy agenda; moreover, its resource burden affects the likelihood of adoption by decision-makers. For example, a given policy might be highly effective at improving compliance amongst industry operators, but be cumbersome or expensive to implement and maintain. Rather than include a cost or budgetary criterion, I avoid the risk of double counting by assessing all resources required for implementation of the options. This way I am able to consider cost as the number of additional person hours or personnel the OGC will require to successfully implement and sustain the chosen option over time. I also consider the effect on other applicable ministries if the burden of implementation is to be shared cross-jurisdictionally.

6.5 Criteria Matrix:

Table 6.5 lists and defines each criterion used to assess options and the sources of data used to inform the measure. Each criterion is measured by an index of high, medium or low. A score of 'high' indicates that the option performs to a level identified as best practice or excellent. A score of 'medium' indicates satisfactory performance. A score of 'low' indicates poor or unsatisfactory performance when addressing the specific criterion. With administrative complexity and cost, 'low' indicates a lower level of costs and complexity, although 'high' complexity and cost may also produce high levels of performance. The policy problem addresses compliance and accident prevention mechanisms as a means to reduce the frequency and severity of produced water spills and leaks. Therefore I weight the effectiveness criterion double that of the other criteria because its components directly measure the change in compliance, and also the change in frequency and severity of accidents. Policies that score high in effectiveness will have the greatest effect on addressing the identified problem.

Table 6.5: Summary of Criteria and Measures

Criterion	Definition	Measure	Data Sources
Effectiveness	Does the policy result in fewer cases of non-compliance among industry operators?	High/Medium/Low	Reduction in cases of non-compliance from status quo
	Does the policy result in reduced frequency and severity of produced water spills and leaks?	High/Medium/Low	Change in frequency Change in m ³ of annual spilled product
Robustness and Flexibility	Is the policy transparent, fair, and easy to understand?	Are threshold levels and consequences for non-compliance well understood? High/Medium/Low	Clearly defined performance measures and punishments for non-compliance
	Horizontal Equity	Does the policy option and its consequences or rewards apply equally to all industry operators? High/Medium/Low	No industry operator is exempt from or above the policy. (Rule of Law)

Criterion	Definition	Measure	Data Sources
Robustness and Flexibility	Does the policy meet the objectives of the OGC and federal and provincial laws?	Congruent with OGC mandate, objectives, and legislation? High/Medium/Low	Supports OGC objectives and balances conflicts between competing objectives. Does not break any laws.
	Is there flexibility within the policy to encourage innovation and permit choice among methods to achieve performance standards.	High/Medium/Low	Operators are able to select tools and/or technologies to meet performance standards. Choice is not restricted to certain design.
Community and Stakeholder Support	Degree to which the policy is acceptable to major stakeholder groups: Industry Operators Environmental Advocates Residents of Northeastern BC	High/Medium/Low support	Degree of agreement/disagreement with the option by stakeholder groups.
	Degree to which the policy is acceptable to First Nations in the Treaty 8 coalition.	High/Medium/Low support	Is the duty to consult met? Degree of support for a policy
Administrative Complexity and Cost	What is the administrative burden on the OGC?	High/Medium/Low	Number of person hours/additional persons required to implement the policy
	What is the administrative burden on other ministries?	High/Medium/Low	Number of person hours/additional persons required to implement the policy

Chapter 7. Options

The options that I consider are identified in the case studies. The cross-jurisdictional case studies have identified that regulatory deficiencies are systemic and widespread; moreover, they highlight that there are significant opportunities to improve legislation and regulations to prevent the probability and consequence of accidents. Because BC's natural gas industry is still young in terms of development potential, it does not yet manifest some of the more serious implications of weak regulation, compliance, and enforcement practices. Bonding and closure agreements are utilized in other jurisdictions, but have variable effectiveness because bonds are typically set too low to remediate serious cases and only address *ex post* effects of operations decisions. Hence I consider bonding instruments as an option albeit with modifications.

Cross-industrial case studies identify what I consider to be gold standard best practices for risk mitigation and abatement. The pulp and paper industry in Canada has used inspections and the threat of inspections to reduce pollution. The airline and insurance industries use a variety of mechanisms to induce industry compliance and extensive data sharing within a robust legislative and regulatory framework. Because of their low risk tolerance and ability to encourage risk-averse behaviour these industries are successful in attaining high safety performance standards.

The options I consider are: maintaining the status quo, increasing inspections on pipeline infrastructure, bonding instruments, and an insurance framework, which I refer to as a "Industry Funded Risk-Based Premium" (IFRBP). There are other beneficial options identified in the case studies that I consider to be best practices. They are better mechanisms to share data, improve training for industry employees, and improved transparency in the regulatory regime. Employee training is particularly beneficial to ensure that liners, automated monitoring systems, pipeline inspection gauges (PIGs), and meters are installed and operated properly. Employee knowledge and training is a

crucial component of compliance and meeting performance standards (OECD, 2009). Improving transparency could involve numerous different initiatives, but in BC, the Forest Practices Board (2011) has specifically suggested that publishing actual compliance rates prior to remediation. A second way to improve transparency is to improve disclosure and publication of fracturing fluids and additives. West Coast Environmental Law (2013) suggests that produced water should be subject to publishing in the National Pollutant Release Inventory. There are many other mechanisms that could be effective in improving compliance or accident barriers; However, I focus on setting performance standards and ensuring that they are met through improving monitoring and enforcement. By emphasizing performance without setting standards for technologies or design, operators are able to choose the best or lowest cost option to meet the standards. Provided the standards are met, the OGC is not over-burdened with enforcing how they are met. For example, one commonly cited option to improve the safety record of pipelines is to mandate minimum criteria for diameters. However, because of the chemical composition of produced water, the rate of corrosion and scale tends to occur at a constant rate (Yucheng et al., 2013). Thus stipulating thicker pipelines would not prevent accidents, but rather buy time until they happen. If performance measures are mandated and enforced, operators will find ways to meet them regardless of whether or not the design mechanism is also mandated. For this reason, I focus specifically on policy options that will induce better performance, without imposing unnecessary resource burdens on the OGC or industry operators.

7.1 Option 1: Status Quo

Maintaining the status quo in BC would mean continued use of existing pipeline integrity management (IMPs) and the liability management rating (LMR) programs, as well as the existing risk assessment process used to trigger inspections that includes the “OSI model” measuring operator compliance, the site sensitivity, and inherent risk of infrastructure. Although it is expected that legislation and regulations will become better equipped to respond to an expanding natural gas sector, there is no guarantee that this will be met with improvements in information sharing, transparency, or improved

compliance rates. For example, the *Water Sustainability Act* (WSA) is a revision of the *Water Act* underway at this time. There is no certainty that the WSA will fully address water use and discharge from increased upstream natural gas activities beyond regulating groundwater for the first time.

The OSI Model selects the 1000 most high-risk sites provincially based on compliance history, site sensitivity, and inherent risk. Among other things, this computer simulation program assesses risk according to past operator performance, proximity to human population, type of equipment on site, and levels of hydrogen sulphide (H₂S) used on site (OGC, 2007). Notably, an external review made the following observations:

- The selection process could not break apart distinct activities (such as pipeline transport vis-à-vis drilling activities) with different risk profiles;
- While the type of equipment used on site was considered, its age was not;
- Risk identification was conducted solely on the basis of potential human health effects, and does not address or recognize environmental features or their relative sensitivity (Forest Practices Board, 2011)

7.2 Option 2: Increased Inspections on Pipeline Infrastructure

The OGC completes a significant number of inspections annually according to three objectives:

1. An industry compliance rate of 95%, which ideally will increase over time;
2. Completion of the top 1000 high risk inspections; and
3. Complete inspection of all sites within five years (Forest Practices Board, 2011).

Because pipelines are underrepresented as a percentage of inspections of oil and gas extractive operations (~4-11% annually) this option proposes an increase in the number of inspections performed on pipelines transporting all product types, but with

specific consideration for produced water. The pulp and paper mill case study described in Chapter 5 illustrates that inspections and the threat of inspections can significantly reduce pollution emissions. They are applicable to BC's natural gas industry due to common elements that include insufficient reporting and inspections, and make the assumption that the regulator relies on presumed initial compliance by the operator, and use of self-reporting mechanisms. Furthermore, both the natural gas and pulp and paper industries are subject to overarching federal environmental and hazardous waste standards, and comparable in terms of regulatory mechanisms and desired outcomes. Earnhart and Glicksman (2011) conduct a literature review of compliance and non-compliance cases across industries and find that threats of enforcement are particularly effective when combined with making examples of other non-compliant industry operators, and that increased inspections and threat of inspections within the oil and gas industry will lower both the volume of product released in spills as well as the frequency of spill and leak events.

The goal of inspections and the threat of inspections is to induce compliance. One desirable by-product may be that the quality and quantity of data improves concurrently with reduced frequency and severity of spills. I consider improving the data network to be an important means, and improved compliance an end.

7.3 Option 3: Bonding Instruments

There are numerous different kinds of bonding instruments, deposit-refund schemes, liability bonds, and refundable pollution/emissions payments. In the interest of simplicity, I focus on Prepaid Collateral Closure Accounts (PCCA) and Ex-Post Insurance Policies (EIP), which are kinds of financial bonds that have been used with mixed success in oil and gas operations throughout the United States, Brazil, the United Kingdom, and Australia (Ferreira et al., 2003). Bonds function as a kind of penalty-reward system.

PCCA is a three-way agreement made between the regulatory agency, a financial institution, and the industry operator. At the beginning of an agreement, for example when a land parcel is sold, the buyer (or industry operator) transfers a sum of

money or assets to the financial institution responsible for management during the tenure of operations. In principle, this arrangement is similar to the existing LMR program; however, does not differentiate between industry operators ability to pay. Rather, the bonding agreement is applied equally to operators and the collateral account is only released at the end of site remediation upon approval of the regulator. EIP is very similar to PCCA with the exception that the third party is an insurance agency rather than a financial institution, and that liabilities are transferred rather than assets. For the purposes of this analysis, both kinds of bonding agreements will be treated as equivalent in terms of outcomes, although there is flexibility in how bonding can be executed.

Bonding instruments are already widely used across Canada, the United States, the United Kingdom, Australia, and Brazil with variable success dependent upon how the regulator implements the bonding agreement, and the estimated output of the proposed project (Ferreira et al., 2003). Bonding agreements are, in part, successful because they do not specifically levy a penalty that must be enforced, but incent industry operators to behave in such a way so as to have their bond returned. There are, however, drawbacks to the industry. PCCA typically requires paying a substantial upfront bond. A large payment can negatively impact cash flow, and may serve as a deterrent to invest in certain projects (Ferreira et al., 2003). Additionally, bonding instruments tend to be more favourable to companies with higher net worth vis-à-vis another company, because the opportunity cost of capital is far lower for the operator with the higher revenue stream (Davis, 2012). Another significant drawback to the effectiveness of bonding instruments is that they assess only observable damage. Because produced water damage is often nonpoint source or dispersed, it can be very difficult to assign full liability and enable the government to claim the bond.

Potential loss of investment may be one trade-off considered by government in implementing bonding instruments. Bonds and letters of credit in BC are set to \$7500, and \$50,000 per kilometer of pipeline respectively. Studies done in the United States suggest that bond amounts set at a minimum of \$60,000USD would be a reasonable start to improved environmental security, although the same studies also note that the bond amounts would be insufficient to cover the cost of remediating a serious accident (Davis, 2012), while the Auditor General of BC suggested that the bond required in BC

would function best if it were a minimum of \$100,000 (Doyle, 2010). At minimum, this option would require setting any kind of performance bond to an amount that would cover the costs of remediation.

7.4 Option 4: Industry Funded Risk-Based Premium

The Industry Funded Risk-Based Premium (IFRBP) would review performance records of industry operators on a yearly basis and levy a surcharge according to their level of compliance. The lowest tier of the surcharge would be applied to industry operators having the best compliance rates prior to remediation orders, and also the lowest incident rates. Similar to the Insurance Company of BC (ICBC), and other insurers, this policy option would have a tiered structure of rates based on performance. For example, industry operators could be granted one free case of non-compliance or very minor product release, and the surcharges would become part of yearly operating costs. Such a structure enables the regulator to reward industry operators for good behaviour, perhaps granting discounts for exceptional continual compliance rates, and effectively punish those who do not. Recidivist companies may be refused consideration when awarding future contracts and land parcel sales. Like bonding agreements, this mechanism avoids the problems inherent with levying *ex post* punishments or attempting to collect large fines. Companies that refuse to pay fines for non-compliance may be assigned a higher risk status and thus a higher yearly surcharge, or refusal of insurance.

Similar to auto insurance structures the IFRBP would constitute mandatory coverage that all industry operators must carry. There are many ways that the system could be implemented ranging from coverage for an entire company, or issue policies on a per wellpad basis. Insurance for companies would incur less administrative costs, but may be less effective because risk is distributed among sites and also the costs of accidents. Surcharges for individual wellpads function similarly to ICBC requirements for individual vehicles carrying insurance. A beneficial attribute of individual well coverage enables consideration the local geology, regional risk identification, and social cost of impacted land to assess the value of individual wellpad policies. Similar to the Orphan Site Reclamation Fund and the existing LMR program, collected revenues from the program would be used to fund site remediation or provide the basis for starting a BC

Heritage fund or trust account. The primary drawback of insurance mechanisms is that of moral hazard. Because implementing IFRBP may insulate industry operators, at least in part, from the consequences of riskier actions there is no guarantee that trade-offs made between mitigating risk and a company's temptation to cheat will always be balanced; however there is increased capacity for premiums to be adjusted where claims, inspections, or reports are made (Davis, 2012). Enforcing maximum penalties under BC laws would provide additional deterrence for moral hazard. The *Environmental Management Act* allows for fines up to \$200,000 or up to six months in jail for infractions. Gross negligence or malicious actions may incur fines of up to \$3 million or 3 years in prison.

Chapter 8. Analysis of Options

This chapter assesses the performance of the options described in Chapter 7 according to the criteria and metrics described in Chapter 6. The goal of the analysis is to determine the best recommendation(s) for the BC Ministry of Natural Gas Development and the BC Oil and Gas Commission to mitigate the probability and consequence of produced water spills and leaks during transport. The provincial government has stated that it intends to implement “world-class” protocols to mitigate risk and remediate spills when they happen (MOE, 2013). In the analysis of the aforementioned options, I propose that a “world-class” safety and risk framework will meet the criteria outlined in Chapter 6 and make recommendations accordingly.

8.1 Status Quo

Maintaining the status quo is expected to maintain the same levels of compliance for industry operators. There will be some variation from year to year dependent upon conditions and technological advances, but the policy itself will not produce better rates of compliance. While some industry operators may consider improved social license to be a benefit, Liu’s (1996) case study on the pulp and paper industry indicates that industry requires incentives to take action to become more compliant. Because of this, we can assume that the frequency and severity of spills will remain the same with annual variation dependent upon operating conditions, production rates and volumes, and operator skill. Additionally, the status quo does not make compliance numbers prior to remediation orders public making it difficult to assess whether or not industry is improving or degrading in accordance with its obligations.

Robustness and flexibility of the regulatory framework is adjudicated according to four distinct sub-criteria. Operators should fully understand threshold levels for non-compliance and expected actions from already having worked in accordance with the

regulations. This requires no change in operating practices; however, the existing regulatory regime arguably lacks horizontal equity within the LMR program because it assesses companies on the basis of their ability to pay for remediation, rather than rewarding good behaviour and compliance with regulations. Smaller companies with fewer holdings are penalized on the basis of their lack of assets, further discouraging other small companies to enter the market. Lack of strong enforcement and punishments for non-compliance do not provide strong enough checks against future negligence. The OGC has a strong stewardship and sustainability objective, however some aspects of the current regime do not fully support their mandate for environmental protection. Clear areas for improvement lie in the methods applied to inspections. Lack of coverage of remote wellsites and pipeline infrastructure is one clear deficiency in the existing framework and does not satisfy the OGC's mandate for risk mitigation. Finally, the status quo does allow for flexibility and operator innovation, so much so that fracturing fluids are protected under copyright laws so as to protect the intellectual property of individual operators. The downside to this practice is that particularly effective improvements and innovations are not shared and beneficial changes cannot go industry-wide.

The existing regulatory regime combines the LMR program with frequent inspections of high-risk sites, external audits, and industry implemented IMPs. In terms of its community and stakeholder, maintaining the status quo receives mixed results from stakeholders. Industry proponents are likely to be supportive given that this policy option is the least intrusive and IMPs enable industry operators to maintain considerable autonomy when making decisions and solving problems in the field. Reporting is also at the discretion of industry operators, although regulations stipulate that all incidents must be reported. Environmental advocates are generally highly critical of the existing regulatory regime in BC, and suggest that the current framework is made weak by ineffective environmental legislation. Organizations such as West Coast Environmental Law and the Suzuki Foundation have issued publications calling for transparent disclosure of fracturing fluids, and argue that produced water should be subject to reporting through the federal National Pollution Release Inventory, and also that keeping to the IEA's carbon budget likely means keeping the bulk of BC's reserves in the ground (Suzuki Foundation, 2013; WCEL, 2014). Finally, residents of Northeastern BC have mixed feelings regarding shale gas development. On the one hand, residents are

optimistic that increased natural gas activities will add to the local economy; however, but there is also concern that increased shale gas activities may present negative health, social, and environmental outcomes (Fraser Basin Counsel, 2012). For these reasons the political feasibility criterion receives a rating of high feasibility for Industry, medium feasibility for Residents, and low feasibility for Environmental Advocates. First Nations have expressed that they are not opposed to development *per se*, but have found some of the actions taken under the current management plan to be troubling. In particular, their questions regarding the long-term effects of land disturbance, habitat and hunting grounds, and growing zone of influence suggest that their support for the status quo would be no more than low-medium (*Dene Tha' First Nation v. British Columbia (Minister of Energy and Mines)*, [2013] BCSC 977).

Maintaining the status quo has low administrative complexity implications for both the OGC and other BC Ministries. With the notable exception of the *Water Sustainability Act*, which has yet to be passed and is already an important provincial initiative, maintaining the current regulatory regime as it is or with minor modifications has a very low administrative footprint. This has significant benefits as it does not require lengthy or cumbersome modifications to legislation and does not compete for scarce resources in times of fiscally tight budgetary policy.

8.2 Increased Inspections on Pipeline Infrastructure

At least in the beginning of implementing this policy option, one could expect that far more cases of non-compliance will be recorded. Rather than indicating that the policy is not effective, higher rates of initial non-compliance indicate that targeting pipelines for inspections will reveal industry deficiencies. As pipeline operators begin to expect inspections, they will allocate a greater percentage of resources toward pipeline maintenance and rates of initial non-compliance will stabilize, and eventually fall. This policy option has the added benefit of applicability to pipelines transporting all product types, and will induce reductions in the frequency and severity of all spills and leaks.

Pipeline inspections are standardized according to compliant or non-compliant criteria. In this way, they and their permissible thresholds are easily understood. All

operators are equally bound to achieving compliant status, and provided all industry operators hold an equal chance of being subject to inspection, the policy achieves horizontal equity between operators in the same risk class. Operators with high risk profiles will be subject to intrusion and punishments. This way, the policy also satisfies OGC objectives by encouraging oil and gas development, but adhering to its mandate of “no leak is acceptable regardless of product type” (OGC, 2010). If an operator is found to be non-compliant, they are able to exercise their preference for any given technology or method to return to compliant status. Similarly, if the operator wishes to implement an innovative solution, the policy only stipulates that it must be effective and focuses on the end rather than the means.

Expanding the inspection network to have better coverage of pipelines would be beneficial for compliance management in BC. The Forest Practices Board identified this as a key opportunity for improvement in their 2011 audit of the BC OGC, and recommends that more above ground inspection, pressure testing, and construction integrity inspections be administered (Forest Practices Board, 2011). Expanding the pipeline inspection network may incur higher transaction costs and require more resources to effectively implement, but the long-term implications are favourable; moreover, inspections are widely considered to be the backbone of any compliance management program (OECD, 2009; Wasserman, 1984). Based on success rates for identifying non-compliance cases and greater levels of accountability for industry operators this option is assumed to have high levels of support from environmental advocates and residents of Northeastern BC. Residents of Northeastern BC have expressed in focus groups that insufficient numbers of inspectors and inspections is an area of ongoing concern (Fraser Basin Counsel, 2012) Industry operators may exhibit less support, on the basis of convenience. The existing cycle subjects sites to inspection every five years does not account for the short (<5 years) lifespan of projects, nor reflect the fluctuation in risky behaviour that some industry operators may experience (NEB, 2006). Some of the most effective site inspections are those that are unannounced (OECD, 2009). Currently the OGC does some unannounced site inspections in response to complaints, but could increase this number as a means to improve compliance.

Expanding the pipeline inspection network will require additional resources from the OGC to train and retain personnel to conduct field inspections. Over time, the threat of inspections for non-compliant companies will help to induce better rates, however the benefit of frequently examining infrastructure cannot be understated. If industry operators are expecting to receive more frequent attention, and if penalties are sufficiently high, the cost of conducting more off-site inspections will result in better overall pipeline performance. One significant trade-off inherent with increased enforcement of non-compliance cases is the ability to enforce punishments. Some industry operators may use litigation to challenge regulations as a way to avoid large fines or criminal charges. The OGC may be able to make use of alternative dispute resolution mechanisms such as tribunals or mediation as a means to enforce penalties without expending resources on lengthy court proceedings. A secondary, but important benefit of increasing administrative capacity is its expected contribution to improving data and research. Standardized reports and industry statistics will enable the OGC to improve its network of accident prevention mechanisms as a long-term objective.

8.3 Bonding Instruments

Bonding agreements have no effect on compliance *per se*. Industry operators are less inclined to worry about maintaining compliant status, and more likely to allocate resources toward emergency response and cleanup. In this way, the policy instrument may result in less severe spills, but not necessarily impact their frequency. Bonding instruments address the state of a site at the end of its life according to specific remediation criteria. Hence, bonding instruments are not concerned with the environmental performance of a project prior to closure. Thus incidents that receive remediation are not considered when negotiating the terms of the closure agreement even if they are severe or frequent. Because of the cumulative effects this may have on the local environment over time I make a distinction between satisfactorily fulfilling the obligation of the closure agreement and preventing contamination.

Bonding agreements are beneficial because there are very clear consequences for failure to comply with the terms – ultimately, the operator can lose the bond. The terms are both clear and easily understood, as are the consequences. Furthermore, the

policy is equally applicable to all industry operators and the consequences do not show favoritism apart from the ability to fulfill one's obligations. The policy is mixed in terms of how it serves to support OGC objectives. On the one hand, it ensures that damage to the environment is remediated; however, the OGC and the MNGD may be concerned that bonding instruments might be unfavorable to investors and hamper development in BC's natural gas industry. This option is highly flexible and offers clear performance standards, but sacrifices effectiveness for inducing compliance. Because bonding instruments emphasize cleanup rather than prevention, there is maximum flexibility for a full range of technological innovations and remediation schemes to be employed at all phases of exploration, production, and closure.

Implementing bonding agreements is beneficial in that they provide a guarantee that environmental degradation will be remediated, and that it will not cause expense to the public sector. Bonding agreements address the entire lifespan of upstream natural gas extraction, and effectively address reclamation and remediation for infrastructure beyond pipelines. Furthermore, depending upon the deposit structure, funds collected could be deposited in a trust and establish the basis for a provincial Heritage Fund. Because of widespread concern for serious environmental degradation and cumulative impact management, residents of Northeastern BC are expected to respond favorably to bonding agreements, but exhibit the same reservations as environmental advocates in terms of the frequency of smaller contamination events. Environmental advocates will also see the benefits, but will be less inclined to offer full support given that bonding agreements target cleanup rather than prevention, and that some industry operators may be inclined to underreport, or not report contamination events to avoid losing the bond. Industry operators will be unlikely to fully support bonding agreements for different reasons. As Davis points out (2012), most bonds are set at amounts insufficient for covering the full costs of remediation. Assuming BC were to adopt the Auditor General suggestion of setting a bond to >\$100,000 we could reasonably assume that investors and developers might be deterred by the upfront cost (Doyle, 2010). I suggest that First Nations would have similar problems with bonding agreements as they do with the current status quo. First Nations support will be low because there is no capacity to address the effects of development on the region.

Administrative complexity of implementing bonding agreements is low for both the OGC and other ministries because of the primacy of the third party role in negotiating and collecting on the bond. Once the sale of a land parcel has been negotiated between an operator and the OGC, communication shifts to between operator and insurer, or operator and financial institution. The OGC only becomes involved upon closure of the site, final inspections, and assesses whether or not the bond will be released.

8.4 Industry Funded Risk-Based Premium

Implementing a Industry Funded Risk-Based Premium (IFRBP) has numerous benefits. IFRBP is expected to be effective. In the same way that car insurance promotes good behaviour and punishes bad, implementing an annual surcharge based on compliance should have immediate positive effects on industry compliance rates. Over time, recidivists will be forced to modify their behaviour, or will significantly lose competitive advantage by increasing operating costs or losing the ability to bid on new contracts. Because of an overall improvement in compliance, the frequency and severity of spills will be reduced. It is not possible to completely remove the risk of accidents, but by including provision for a compliant company to experience one such rare and extreme event without harming their overall status IFRBP can be flexible and fair in its treatment of incidents.

Threshold levels and consequences are very clear and subject to operator behaviour. Unlike the existing LMR program, the IFRBP assess compliance on an ongoing basis and will utilize performance records to identify how risky a particular operator or site is at a given point in time, as well as its past history of compliance or non-compliance. Penalties and rewards are clearly enumerated and reviewed annually. All industry operators are equally affected by and subject to IFRBP; however, not all are equally impacted by its application. Industry operators that have a smaller net worth or revenue stream vis-à-vis another industry operator may be more affected by the penalties of non-compliance because it will demand a greater percentage of a company's revenues. Balancing long-term environmental sustainability with developing a vibrant natural gas industry are key objectives of the OGC, and the existing LMR framework is prejudicial in terms of ensuring that all industry operators be capable of

fulfilling obligations according to the polluter pays principle. If in the long run the policy is shown to be unfair to smaller gas companies that can prove adherence to performance standards, and if this has detrimental effects for BC's natural gas sector, then modifications may be considered; however, in the interest of improving compliance rates and reducing risk of contamination events imperfect horizontal equity is acceptable and justified.

Gathering detailed industry records and statistics over time will provide context for policy improvements in the future, identify trends that will help to establish industry best practices, troubleshoot, and support the OGC's transparency objective. While penalties for legal infractions and non-compliance are well defined, the means to achieve them are relatively flexible. Industry operators are encouraged to employ any and all technologies and methods to achieve and improve compliance, and may find it prudent to allocate resources toward research and innovation expecting to reap the benefits of lower IFRBP'. In addition to economic benefits, industry operators who are particularly successful at achieving ongoing compliant status may be more successful at obtaining social license than those who do not.

Similar to bonding instruments, IFRBP is most effective when combined with comprehensive inspections carried out by an independent agency, but is appealing in its ability to assess initial and continued compliance. IFRBP also suffers from the same drawback as bonding instruments in that operators may underreport incidents in order to secure better premiums, but may be easier to mitigate because of increased exposure and consultation with industry. Industry operators may have mixed responses to IFRBP, although it most effectively utilizes a reward-punishment model that enables compliant companies to reap benefits and successfully punish those that are not. This model acknowledges residents of Northeastern BC's desire to see reform in BC's institutional model for reporting, data gathering, and accountability for industry operators (Fraser Basin Counsel, 2012). Environmental advocates will approve of the emphasis on continued compliance, iterative review, and harsher penalties for companies that do not adhere to regulations, although I acknowledge that for some the risk of environmental damage is too great to accept any option. IFRBP appeals to the "best in class," therefore

it also has benefits to industry operators who are able to maintain superior performance standards by offering them social license to operate.

Because IFRBP operates on an annual basis, administrative complexity may be high. Implementing such a framework will require significant resources and personnel to conduct field inspections and handle administrative duties. The initial phase of implementing the policy will be the most resource intensive. For this reason it may be preferable to begin with a multi-year assessment cycle to ensure that ministry personnel are adequately trained, all industry operators are given time to prepare for changes in the evaluation process and given a comprehensive initial review, and beneficial elements of the existing regulatory framework including existing licensing and permitting protocols are integrated into the IFRBP model. Utilizing IMPs and the OSI risk simulator will be useful contributions to the IFRBP operational framework. Using the OSI model to continue generating predictive data to identify the top 1000 high-risk sites will support administrative services during the transition to an annual IFRBP. Other ministries may also play a role in providing independent review. The Forest Practices Board, for example may be particularly instrumental in conducting inspections and audits to assess both industry operators in terms of their level of compliance, but also to provide perspective on the overall positive and negative effects of IFRBP on the natural gas sector. Criteria will be determined by the *Water Act* (to be replaced by the *Water Sustainability Act*), *Environmental Management Act*, *Land Act*, *Heritage Conservation Act*, and *Forest Act*, as well as the latest safety and engineering standards. Inspectors will be required to demonstrate competency in a variety of fields.

Table 7.1 illustrates the results of this analysis. Scores are colour-coded to enable the reader to easily identify the strengths and weaknesses of a given option, and to identify the advantages and disadvantages of an option vis-à-vis the other options. This summary helps support the recommendations presented in the next chapter.

Table 7.1: Performance of Options against Criteria

Criterion	Specific Criterion	Status Quo	Inspections	Bonding Instruments	IFRBP
Effectiveness	Reduces non-compliance	Low-Med	High	Low	High
	Reduced Prob. and conseq.	Low-Med	High	Low	High
Robustness & Flexibility	Transparent and clear	Med	High	High	High
	Horizontal equity	Med	Med-High	Low	Med
	Congruent with legislation and objectives	Low-Med	High	Med	High
	Flexibility	Med	Med-High	High	Med
Community/ Stakeholder Support	Industry Operators	High	Med	Low	Med
	Environmental Advocates	Low	High	Low-Med	Med-High
	Residents of NE BC	Med	High	Med	Med-High
First Nations	Acceptable	Low-Med	High	Low	Med-High
Administrative Complexity & Cost	Burden to OGC	Low	High	Low	High
	Burden to other ministries	Low	Low	Low	Medium

**Colours are coded according to the following values. Purple represents the least optimal performance of the option, yellow signifies satisfactory performance of the option, and the best performing options are coloured green. In some cases the performance of an option is best described by 'half scores' or fits some of the criteria for two rank categories. For these cases orange is used to identify options that performed less than satisfactorily, but not poorly. Light green identifies options that performed better than satisfactory, but lacked one or more qualities that might make them gold standards.

Chapter 9. Recommendations

9.1 Short-term and Immediate Recommendations:

BC's natural gas industry would benefit from three easily implemented recommendations expected to have an immediate and permanent positive and direct effect on compliance and safety. These recommendations have an indirect effect on improving compliance, therefore they are not analyzed rigorously with the other options; however, they are opportunities for improvement that are not industry specific.

1. Improvements to the quality of training for industry employees
2. Publish compliance rates prior to remediation orders.
3. Stricter enforcement of the provisions and penalties under the *Environmental Management Act*

Better training for industry employees can be done incrementally and implemented many different ways and at different intensities. Publishing compliance rates requires very little additional administrative effort on the part of the regulator other than to make the numbers available and accessible. Improving the overall quality and access to data enables the OGC to improve its transparency and accountability while also utilizing the effects of public scrutiny to induce better behaviour from industry.

Section 3.2 illustrated that BC does indeed have some robust mechanisms to enforce compliance. However, the OGC has been reluctant to levy large fines or criminal charges. Other industries and jurisdictions have successfully used strong civil and criminal enforcement as a deterrent for polluters. I discussed this specifically in section 5.2.1 using the EPA's regulation of the pulp and paper industry. Rather than viewing strong enforcement as curtailing oil and gas development, punishing offenders indicates that failure to achieve performance measures will not be tolerated. Some industry operators will find this unacceptable. Another barrier is that collecting fines or convicting individuals for offenses can be arduous and resource intensive. However, strong

enforcement regimes effectively induce compliance in offenders and other operators witnessing the example (OECD, 2009).

9.2 Recommendation to Implement Complimentary Options

Based on the data presented in case studies and the analysis of the options according to criteria and measures, I recommend that the BC Government implement a combination of two options:

- **Increased inspections on pipeline infrastructure**
- **Industry Funded Risk-Based Premium (IFRBP).**

Implementing both options together would be the most beneficial model to improve compliance and performance in BC. In particular, the revenues from the IFRBP support an industry-funded framework to support enforcement and monitoring. Additionally, the increases in capacity required to effectively implement and sustain the policy option will be covered by the premiums collected through IFRBP. The premiums are assessed on the basis of risk. Thus, the industry is funding its own inspections in order to reduce the risk from natural gas extractive activities and make them as sustainable as possible. Beneficial spillover effects will impact all components of upstream natural gas activities, not only pipelines and produced water management. Less effective components of the insurance scheme are mitigated by increased inspections and improvements made to the province's capacity to monitor and enforce regulations. Similarly, an insurance model permits the province to perform ongoing and iterative reviews of performance, and also to incentivize good behaviour while punishing recidivists. Despite the high administrative complexity of implementing these options, their effectiveness and high performance on other criteria make them a viable policy option for BC as it attempts to rapidly develop natural gas in such a way that captures the most benefits while mitigating the risks posed by accidents.

Both options scored high in effectiveness, but have different implications for how they improve compliance. Increasing inspections targeting pipelines improves monitoring

and expands the OGC's range of oversight. Wasserman (1994) identified that inspections are the backbone of any effective compliance regime. Insurance mechanisms provide the ability to enforce the findings made through monitoring, and have the added benefit of providing ongoing iterative review of operators. Accessing risk histories could become an important part of consideration for future oil and gas contracts. Thus the data provided through inspections and insurance claims have potential to impact other aspects of oil and gas regulation in the province. These two instruments' strength is reinforced by the civil and criminal penalties that can be enforced under the *Environmental Management Act*.

Both of these options satisfy the sub-criteria of robustness and flexibility. Both options are highly congruent with legislation and OGC objectives. Implementing better monitoring and enforcement through these policies enables both punishment and reward based on the behaviour of operators. In a previous section I enumerated the OGC's objectives:

- Protecting public safety;
- Environmental preservation;
- Support of resource development;
- Engaging with stakeholders and business partners to provide fair and time-sensitive decisions within the regulatory framework;
- Demonstrating accountability, efficiency, transparency, and respect. (OGC, 2014)

The overview of BC's regulatory framework and shale gas case studies examined in this paper have provided a basis for doubting whether supporting resource development is being done while balancing other objectives. Using a robust monitoring and enforcement framework will enable BC to support shale gas exploitation, but concurrently demand that it be done in a way that fulfills the other objectives. In particular, environmental preservation and protecting public safety cannot be subverted by economic priorities. Rather, a hybrid IFRBP/Inspections option enables social and environmental costs and benefits to be considered vis-à-vis economic ones.

Inspections particularly have the ability to inspire public confidence. Because of this, inspections have high support from all stakeholder groups with the exception of

industry operators. BC's oil and gas industry is accustomed to inspections however, and changes made to inspections protocol and its expected outcomes are acceptable trade-offs to diminished industry support.

The most significant trade-offs made in implementing a hybrid IFRBP/inspections model is that they individually and together have high administrative complexity and associated costs. Given the uncertainty associated with the timing, location, and consequences of produced water spills and leaks it is paramount to implement policies that will have the greatest effect on risk mitigation and accident prevention. There will be costs associated with implementing this policy. I anticipate that effective implementation will require additions to OGC staff and other ministries providing personnel for inspections, auditing, and other monitoring and enforcement activities. Fines collected for non-compliance or the revenue from the insurance premiums could recoup some of the costs of implementation. The greatest benefits are difficult to calculate because they require predicting the aversion of negative externalities. However cost should not be considered a significant barrier to implementing this option, particularly given its ability to address the policy problem. Because of the risk profile of pipeline infrastructure in general, and produced water transport in particular, I identify these options as the best use of Crown funds to improve compliance and performance in the oil and gas sector.

9.3 Study Limitations

This study was limited by the newness of the industry and the lack of comprehensive data. Little research has been undertaken to determine the impact of produced water and its wider implications within shale gas producing regions. Additionally, existing data become out of date very quickly. There are data and a body of knowledge pertaining to the costs, effects, and remediation options for hydrocarbon spills as a category, but in many cases produced water has not yet been treated as a separate product type if it is acknowledged at all. A second issue is that because of the relative newness of the technologies of hydraulic fracturing and directional drilling, the existing data and research done on produced water is less than a decade old. This has highlighted the urgency of further study and many academic and government institutions

that include the EPA have initiated projects to determine the environmental and human health effects of hydraulic fracturing.

I was not able to find industry operators willing to participate in interviews about produced water. I infer that this may not be true for all operators, but at the present time the operators I contacted were not willing to contribute to my research beyond what was publically available. I had anticipated that protection of trade secrets and desire of industry operators to maintain competitive advantage might hinder my ability to obtain interviews. Future studies that capture the opinions and expertise of industry operators and contractors working with produced water would improve the quality of existing produced water data.

Legal studies and particularly environmental litigation studies have produced some analysis regarding the implications of the many court cases and claims associated with produced water and hydraulic fracturing, but because most of these cases have not yet been decided in the courts, their analyses are speculative. In many jurisdictions that include BC, legislation was created well before the inception of hydraulic fracturing and directional drilling. Because of this, statutes are frequently unable to deal with the effects of natural gas extraction in their current form. This has limited my research and others by providing a conceptual framework that is unclear and likely to change. These changes are not always predictable.

This study reaffirms the need for more research on produced water to improve both the quality and quantity of data.

9.4 Next Steps and Conclusion

Developing natural gas in BC entails risks of significant environmental damage from poor handling of produced water from the fracturing process. This study has highlighted the importance of using improved compliance and enforcement to mitigate risk. Case studies have illustrated the benefits of implementing a robust regulatory regime that is able to respond to stakeholder concerns, deliver transparency, and generate proactive disaster prevention plans rather than reactive ones. Case studies are

used to highlight beneficial aspects of policy regimes that can be imported to BC to address the deficiencies in the current policy regime. BC tends to perform well among North American shale plays, but that may be more indicative of an emerging industry that has not yet reached the size and production potential of other plays, rather than best practices. Critical next steps for produced water management in BC will emphasize performance measures and outcomes for industry that will improve environmental protections, but concurrently facilitate development. Regulatory oversight must make parallel improvements on pace with industry expansion, and must send clear legislative signals. Transparent and clear legislation is a worthy goal.

Implementing the IFRBP and Inspections model provides the basis for forward-looking risk management in the natural gas sector. In order to effectively become operational I recommend that the following considerations be addressed in the immediate planning phase of next steps: The Province should immediately communicate with industry operators and provide education regarding the policy and its purpose. This provides transparency for all stakeholders and opportunities to prepare industry for what can be expected in terms of performance measures and begin to make changes accordingly. I expect that implementation will require some changes to legislation. At the very least, adding a sub-section to the *Oil and Gas Activities Act* will be required to bring the IFRBP into force. Additionally, implementation will require deciding whether or not to grandfather existing sites, and how to best integrate the new policies with the existing framework. A review of existing licenses and permits should be undertaken to determine whether or not the terms of existing agreements are congruent with IFRBP. Because natural gas wells have such a short production life (3-5 years), grandfathering some sites will not detract from the risk management objectives posited in this paper. Where sites are grandfathered, they continue to be bound by the legislative requirements held in the *Water Sustainability Act*, *Environmental Management Act*, *Land Act*, *Heritage Conservation Act*, and *Forest Act*.

BC has yet to have experienced a severe produced water leak of more than 10,000 cubic meters of product; however product releases of even 100 cubic meters have the potential to incur substantial environmental degradation, particularly if remediation is not immediate. Thus far, all accidents have been of medium size ranging

from 100-1000 cubic meters of produced water released (OGC, 2010); however, this paper has demonstrated that the current regulatory framework does not provide enough robust barriers to maintain this trend as natural gas production intensifies in the province. The most significant finding of this study is that the BC government and OGC have an opportunity to set a global example for best practices in produced water management, and also in regulatory practices. Industry operators and regulators in other jurisdictions have yet to successfully implement a robust regulatory framework based on monitoring and enforcement. While this paper has focused on reducing risks during produced water transport, improving industry compliance will have beneficial effects on all phases of operations. The implications of development in the province are yet to be seen; however, implementing effective barriers to accidents in the oil and gas sector will have social, economic, and environmental benefits.

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Appendix A.

What is Natural Gas?

Raw natural gas (or gas extracted from the ground, prior to processing) consists primarily of methane (70-90%), but also contains ethane (1-10%), propane (trace-1%), butane (trace-2%), carbon dioxide [CO₂] (trace-4.5%)¹¹, pentanes, condensate, nitrogen, hydrogen sulphide [H₂S], Helium [He], Hydrogen [H], Oxygen [O₂], other rare gasses [Ar, Ne, Xe], water vapour, and minor impurities (CAPP, 2008; Jaccard & Griffin, 2010; Spellman, 2013: 27-29; Talisman Energy Inc., 2014). The primary compounds vary according to the number of carbon atoms they contain.

Natural gas is colourless and odourless, and provides very high levels of energy density and quality when burned. Additionally, natural gas is cleaner-burning than coal or oil. Dependent upon the combustion system used to burn natural gas it produces less sulphur dioxide and half as much carbon dioxide as coal, per unit of electricity produced (EIA, 2012; Moniz, Jacoby, and Meggs, 2011).

¹¹ Natural gas extracted from the Horn River Basin is richer in CO₂ (11-12%) than other national gas plays (2-4.5%) (Jaccard & Griffin, 2010), which raises concerns regarding GHG emissions and overall effects contributing to accelerated climate change.

Appendix B.

Beneficial Reuse of Fracturing Fluids in other Jurisdictions

Elsewhere, spent fracturing fluid has been used for a myriad of other activities including irrigation, livestock watering, dust control, cooling water used for power generation (a cogeneration plant in California as well as other experimental sites), oil field use, and washing commercial vehicle fleets (Clark & Veil, 2009; Spellman, 2013; Veil et al., 2004) after varying levels of treatment. This is referred to as “beneficial reuse.” In most cases, there have been problems associated with these methods of disposing of produced water. Because 92% of the chemical compounds present in flowback water are potentially lethal to human health and also water-soluble there is an imperative to ensure that water is adequately treated and tested before reuse (Ernst Environmental Services, 2013). Other jurisdictions such as Alberta and Pennsylvania have reported cases of livestock, family pets, and wild animals becoming ill or dying after exposure to produced water. Salinity also presents problems in terms of soil quality and in some cases crop yields will suffer as a result of being irrigated with treated fracturing fluids (Veil et al., 2004). Additionally toxic particulates affect air quality when fluids are sprayed for dust control and for washing vehicles (Spellman, 2013).

Appendix C.

Fracturing Fluids and Additives

Acids	May constitute 3-28% of the chemicals added to fracturing fluid, the most commonly used acids in hydraulic fracturing are hydrochloric acid and acetic acid. Acids are used to dissolve pathways in limestone/shale formations to facilitate better flow of fracturing fluids and proppant, and to strip away excess cement and drilling mud prior to fluid injection (Spellman, 2013). Acids may also be used as breaker fluids, and are corrosive and poisonous. Common side effects include skin, respiratory, and tissue damage and severe burns.
Biocide.	Fracturing fluid is pumped underground at high pressure, and emits heat as a byproduct. Biocides are used to inhibit the growth of bacteria, mould, and microbes encountered within the formation that might contaminate natural gas products and reduce the viscosity of fracturing fluid (Wethe, 2010). Biocides can cause skin and eye irritation, and are harmful if ingested.
Breaker	Reduces the viscosity of fracturing fluids to enable proppant to travel and remain suspended in shale bed fractures. Common breakers are acids and variants of ammonium that cause skin irritation, and are harmful if ingested.
Clay Stabilizer	Prevent clay from swelling in shale during fracturing and impeding the flow of gas and fluids. Salts and potassium chloride are commonly used as clay stabilizers and are mildly irritating to the skin and eyes. Clay stabilizers may be harmful if ingested.
Corrosion Inhibitor	Prevents acids from corroding equipment, pipes, and well casings, and are used in proportion to the concentration of acid used in fracturing fluid (Spellman, 2013). Acetone (paint thinner) and methanol (used by the ancient Egyptians in embalming processes; currently used as a solvent and in antifreeze) are the most common corrosion inhibitors used in fracturing. They may cause blindness, nerve damage, heart, liver, and kidney failure, and most are flammable.
Crosslinker	Increases the viscosity of fracturing fluid and suspend proppant. Common crosslinkers include Boric acid (often used as antiseptic or flame retardant) or ethylene glycol (primary ingredient in antifreeze and hydraulic brake fluid). Crosslinkers are harmful if ingested, cause skin and eye irritation, and are combustible. Serious effects from exposure include birth defects, organ failure, and central nervous system damage (Spellman, 2013).
Defoamer	Used to remove foaming agents after they have served their purpose and increase the size of pathways for gas migration.

Foaming Agent	Foam or dense bubbles used to transport proppant deep into fractures. Foams use nitrogen or carbon dioxide as a base gas, and may also utilize harmful substances such as 2-butoxyethanol (paint solvent, herbicide, fire fighting foam, and degreaser) or glycol ethers (cleaners, degreaser, aerosol paint). Exposure to some foaming agents can cause liver and kidney failure (Severtson, 2013; Spellman, 2013).
Fluid-loss Additive	Prevent fracturing fluid from leaching into the porous rock formation associated with the fracture zone. Clays and plaster compounds are commonly used additives (Spellman, 2013).
Friction Reducer	Also referred to as “slickener.” Used to minimize friction caused by pressure and abrasiveness of proppant, and to facilitate efficient flow of fluids. Latex polymers are frequently used as friction reducers and are considered to be non-toxic although some individuals may experience allergic reactions or skin irritation.
Gellant	Used to increase the viscosity of fracturing fluid and suspend proppant. Guar gum is commonly used as gellant in fracturing activities, as well as a thickener in food products such as ice cream and condiments such as ketchup. Despite having no serious health implications, increased hydraulic fracturing activities in the United States led supply companies such as Haliburton and Schlumberger to stockpile enormous reserves of guar gum, causing prices to increase by more than 1000% in 2012 (Mishra, 2012).
Linear gels	Used in place of water as an effective and dense delivery system for gellant. Linear gels include diesel, BTEX (benzene, toluene, ethylbenzene, xylene), and Naphthalene (active ingredient in mothballs). Linear gels are harmful if swallowed, combustible, and will irritate exposed skin or the respiratory tract. More serious side effects include cancer, red blood cell death, irritation and lesions, and skin disorders.
pH Control	Maintains the effectiveness of chemical additives by maintaining fluid pH balance.
Proppant	Sand, ceramic, or other particles suspended in fracture fluid that are deposited into rock fissures to keep them open after the pressure from fracturing activities has abated. Because of the abrasive nature of grains of sand and other suspended particles, proppant contributes to accelerated degradation of pipes by acting in tandem with the process of corrosion.
Scale Control	Prevents the accumulation of calcified and mineral scale on the well that might impede the flow of gas and fluids to the surface. Scale inhibitors include ammonium chloride (salt, nitrogen source in fertilizer), and are a mild irritant. Some are weakly poisonous if ingested (Severtson, 2013).
Surfactant	Designed to decrease the surface tension of water in order to improve flows through pipes and fractures and increase fluid recovery. Common surfactants include methanol (used as antifreeze or solvent), isopropanol (becomes acetone when oxidized), and 2-butoxyethanol. Surfactants are flammable and harmful if swallowed. More serious side effects include blindness, heart, liver, and kidney failure, destruction of red blood cells, and death (USEPA, 2010).

Appendix D.

LNG Applications in British Columbia

Project	Period	Project Capacity: Bcf/Day	Date Approved	Location	Project Proponents
KM LNG Operating General Partnership	20 yrs.	1.28	Oct. 2011	Kitimat	Apache Can. Ltd. (50%) Chevron Can. Ltd. (50%)
BC LNG Export Co-operative LLC	20 yrs.	0.23	Feb. 2012	Kitimat	Douglas Channel Energy Partners
LNG Canada Development Inc.	25 yrs.	3.23	Feb. 2013	Kitimat	Shell Canada KOGAS (Korea) Mitsubishi Corp. (Japan) PetroChina Corp. Ltd.
Pacific NorthWest LNG Ltd.	25 yrs.	2.74	Dec. 2013	Prince Rupert	Petronus (Malaysia), Japex (10%), Petroleum BRUNEI (minority)
WCC LNG Ltd.	25 yrs.	4.00	Dec. 2013	Kitimat or Prince Rupert	ExxonMobil Canada Ltd. (50%) Imperial Oil Resources Ltd. (50%)
Prince Rupert LNG Exports Ltd.	25 yrs.	2.91	Dec. 2013	Ridley Island Prince Rupert	BG Group (UK)
Woodfibre LNG Export Pte. Ltd.	25 yrs.	0.29	Dec. 2013	Squamish	Woodfibre LNG Export Pte. Ltd. (Singapore)
Triton LNG Limited Partnership	25 yrs.	0.32	Under Review	Kitimat or Prince Rupert	AltaGas Ltd. (50%) Idemitsu Canada Corp. (Japan)

					(50%)
Aurora Liquefied Natural Gas Ltd.	25 yrs.	3.12	Under Review	Prince Rupert	CNOOC Ltd. (Nexen-China) INPEX Corp. (Japan) JGC Corp. (Japan engineering company)
Total Bcf/Day for approved projects only		14.68			

Information sources: David Hughes. (2014); National Energy Board (2013).

Appendix E.

Disposal and Injection Wells in British Columbia

At present, produced water in BC must be disposed of in an approved injection well. In order to prevent migration of contaminants and protect groundwater aquifers, approved disposal wells must be more than 1000 meters below the surface (OGC, 2014). There are numerous injection wells in BC consisting of two types:

1. Spent Hydrocarbon pools – Have already proved their capacity to hold volumes of fluids and prevent migration. Once commercially viable hydrocarbons have been removed, these reservoirs are largely empty and considered fit to serve as disposal units for hazardous waste including produced water.
2. Deep aquifers – Contain saline water and may be able to provide storage capacity in excess of current volumes in the reservoir depending upon the size of the aquifer and its geological features. In some cases, the saline water from these aquifers may also be suitable for use in fracturing fluid.

Operators may apply for permits to utilize injection wells and must prove that the wells are capable of preventing fluid migration. Permits are approved in accordance with geophysical testing, landowner consent (when applicable), and proximity to other injection wells and drilling activities (OGC: 2014). Once the disposal well is utilized, ongoing monitoring is required to ensure the integrity of construction and the performance of the formation. BC does not currently charge industry operators for wastewater disposal.

Many of the produced water pipelines that this research is concerned with terminate at injection sites. Transporting large volumes of produced water through a network of many pipelines to numerous disposal sites dispersed across the region produces elevated risk of accidents. Mitigating risk can be done by focusing on improving the performance of pipelines and industry operators, or by reducing the volumes of wastewater that are in transit. This research has identified the former as being the most effective mechanism for reducing pipeline accidents. Reducing wastewater volumes is desirable, and BC's natural gas industry operators have responded to pressure to reduce their water footprint by capturing and recycling 50-90%

of the fluids used in hydraulic fracturing (OGC: 2012). While this reduces the need for new water resources, it does not necessarily reduce the volumes of water that are in use. Some produced water may be used on site for subsequent fracturing jobs at the same well. This practice reduces both the consumption and transport of wastewater volumes. However, the quality of produced water eventually degrades from the build-up of solids and additives, which may render it unsuitable for subsequent fracturing jobs (Spellman, 2013). A second condition is that once a well loses productivity and is closed, produced water from that wellpad may be transported for use at another. Storage and transport of produced water is problematic. As the scope and intensity of BC's natural gas industry expands the volumes of wastewater in use will grow with it. Because of hydraulic fracturing's need for large volumes of fluids, it may not be feasible to reduce the amounts of produced water generated by the industry.

To view current maps of active disposal wells in Northeastern BC, please refer to the Oil and Gas Commission's section on "Subsurface Disposal" available on their website: <http://www.bcogc.ca/industry-zone/documentation/Subsurface-Disposal>

Appendix F.

Oil and Gas Regulatory Agencies by Province/State

Alabama	Geological Survey of Alabama; State Oil and Gas Board
Alaska	Alaska Oil and Gas Conservation Commission; Alaska Department of Natural Resources, Department of Oil and Gas
Alberta	Alberta Energy Regulator
Arkansas	Arkansas Oil and Gas Commission
British Columbia	BC Oil and Gas Commission; Ministry of Energy and Mines; Ministry of Natural Gas Development
California	California Department of Conservation, Division of Oil, Gas, and Geothermal Resources
Colorado	Colorado Department of Natural Resources; Oil and Gas Conservation Commission
Illinois	Illinois Department of Natural Resources, Division of Oil and Gas
Indiana	Indiana Department of Natural Resources, Division of Oil and Gas
Kentucky	Kentucky Department for Energy Development and Independence, Division of Oil and Gas Conservation
Louisiana	Louisiana Department of Natural Resources, Office of Conservation
Michigan	Michigan Department of Environmental Quality, Office of Geological Survey
Mississippi	Mississippi State Oil and Gas Board
Montana	Montana Department of Natural Resources and Conservation, Oil and Gas Board
New Mexico	New Mexico Energy Minerals and Natural Resources Department, Oil and Conservation Division
New York	New York Department of Environmental Conservation, Division of Mineral Resources
North Dakota	North Dakota Industrial Commission, Department of Mineral Resources Oil and Gas Division
Ohio	Ohio Department of Natural Resources, Division of Mineral Resource Development
Oklahoma	Oklahoma Corporation Commission, Oil and Gas Conservation Division
Pennsylvania	Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management

Québec	Quebec Oil and Gas Association / Association Pétrolière et Gazière du Québec
Tennessee	Tennessee Department of Environment and Conservation, State Oil and Gas Board
Texas	The Railroad Commission of Texas
West Virginia	West Virginia Department of Environmental Protection, Office of Oil and Gas

Appendix G.

Fines Levied by the Oil and Gas Commission in Quarters 1-3 of 2013¹²

	9.4.1.1.1. Operator	9.4.1.1.1. Legislation	9.4.1.1.1. Penalty	9.4.1.1.1. Description
	Chinook Energy (2010) Inc	s. 120 <i>Environmental Management Act</i>	\$575	Remediate sump
	Devon NEC Corporation	s. 22 <i>Water Act</i>	\$460	Fail to keep/produce water records
	Devon Canada Corporation Ltd.	s. 22 <i>Water Act</i>	\$1610	Fail to keep/produce water records
	Nova Gas Transmission Ltd.	s. 22 <i>Water Act</i>	\$690	Fail to keep/produce water records
	Painted Pony Petroleum Ltd.	s. 22 <i>Water Act</i>	\$1150	Fail to keep/produce water records
	Progress Energy Ltd.	s. 120 <i>Environmental Management Act</i>	\$575	Exceeded air emissions standards
	Husky Oil Operations Ltd.	s. 6 <i>Environmental Management Act</i>	\$575	Introduced business waste (air emissions)
	Olympic Seismic Ltd.	s. 22 <i>Water Act</i>	\$230	Fail to keep/produce water records
	Olympic Seismic Ltd.	s. 22 <i>Water Act</i>	\$230	Fail to keep/produce water records
	Delphi Energy Corp.	s. 22 <i>Water Act</i>	\$230	Fail to keep/produce water records
	Challenger Geophysical Ltd.	s. 22 <i>Water Act</i>	\$230	Fail to keep/produce water records
	Total Fines charged in Q 1-3, 2013:		\$6555	

¹² Data for Quarter 4 had not been released at the time this paper was accepted.

Appendix H.

Ecosystem Goods and Services

Purification services – for example cleansing functions provided by wetlands, air filtration, and carbon storage provided by both forests and watersheds. Waste cycling, assimilation, and treatment are vital contributions made by ecosystems to human populations (Anielski & Wilson, 2009; Stats Canada, 2013).

Regulatory functions – intact ecosystems contained balanced food-chains and feedback mechanisms that control pests and the carrying capacity of all other species in them; furthermore, they manage watershed flows and the effects of weather patterns so as to mitigate the risk of floods, soil erosion, sedimentation, and the effects of other disasters such as wildfire (Pearce et al., 2006).

Habitat provision – habitats contribute to the overall resilience of ecosystems and support the vitality and diversity of plant and animal species. Biodiversity has value in and of itself, however maintaining strong habitats have implications for food sourcing and security, scientific research, and recreational and aesthetic values (Pearce et al, 2006; Wagner & Armstrong, 2010).

Ecological cycling - ecosystems host a myriad of natural cycles, for example nitrogen or carbon, whose integrity and vitality have widespread effects on air, water, and soil quality. Impaired nutrient cycling can have widespread negative impacts on biodiversity, soil and water quality, and regulatory functions (Stats Canada, 2013).

Regeneration and production – energy cycled through ecosystems provides biomass and natural resources for human consumption. The Canadian economy is heavily dependent upon forestry, fishing, hydro-electric power, extractive industries seeking hydrocarbons and minerals, land assets, and fresh water. Since 1996 wealth derived from natural resources has contributed between 12-19% of total Canadian wealth, with a growth rate of 10% per year. BC consistently ranks in the top three provinces for cumulative resource production across every category, including planned investment (CICS, 2012; Statistics Canada, 2013).

Information and life support – ecosystems are a source of valuable scientific information and have provided many of the basic compounds used in pharmaceuticals and medicines (Wagner & Armstrong, 2010); furthermore, EGS are interconnected, thus economic valuations of distinct components may not fully reflect the importance of one good or service. An ecosystem is more than just the sum of its parts, hence the loss of one low-valued component may cause widespread disruption to the balance of the entire system (Pearce et al., 2006).

Appendix I.

Northeast British Columbia: Regional Overview

Northeastern BC is bordered by the Yukon and North West Territories to the north, and Alberta to the east. It is a mountainous region and includes both the Rocky and Carrier mountain ranges. It is BC's largest region and makes up a total of 21.8% of the province's land mass (20,494,470 ha.), yet contains only 1.6% of its population (69,068 permanent residents). The area is characterized by numerous biogeoclimatic zones, and two major river systems (the Liard to the north, and Peace to the south) that are further broken into many drainages and tributaries (Fraser Basin Council, 2012). The area is characterized by Boreal forest and Taiga that has varied climate and vegetation patterns dependent upon the elevation throughout the range, although the dominant zone consists of Boreal White and Black Spruce, slow-growing conifer forests, upland mixed-wood forest, wetlands, and poorly drained Muskeg (DeLong et al., 1990; R. McManus Consulting Ltd., Salmo Consulting Inc., 2004), as well as naturally treeless areas and grasslands (Natural Resources Canada, 2014).

Large mammals such as moose, caribou, Dall's and Stone's sheep, mountain goat, mule deer, black bear, grey wolf, and grizzly bear are found throughout the region, as well as small furbearers such as lynx, marten, and beaver. The numerous wetlands support many different bird species including trumpeter swans and large birds of prey (DeLong et al., 1990; R. McManus Consulting Ltd., Salmo Consulting Inc., 2004). Many parks and wildlife reserves have been established to protect the incredible biodiversity found in BC's rugged Northeast such as the Muskwa-Kechika Management Area situated directly west of Fort Nelson. Northeastern BC is also home to numerous First Nations who rely on the terrain for subsistence and spiritual purposes. Northeastern BC's First Nations are organized into an ethno-linguistic political association between five of the eight Treaty 8 Nations. The group includes the Sicannie (Sikanni), Slavey, Beaver (Dene Tha'), Cree, and Saulteau Nations, and according to Canadian Constitutional Law natural gas companies and the Crown hold a duty to consult with them regarding development projects.

Despite containing less than 2% of BC's population, Northeastern BC contributes to 12% of the province's total exports. 91% of BC's energy and fuels, and 14% of mining exports are derived from the region with lesser contributions made by the forestry industry (Fraser Basin Council, 2012). Tourism is a significant driver of the northern economy and the region offers outdoor enthusiasts both front-country and back-country recreational activities. Front-country tourism is easily accessible from the Alaska Highway and other local infrastructure and parks projects, whereas numerous guides and outfitters provide wilderness experiences in untouched habitats where they can access abundant fishing, wildlife, and cultural resources. These activities generate an estimated \$23 million in operating revenues annually in the M-KMA alone (R. McManus Consulting Ltd., Salmo Consulting Inc., 2004).