UNCONVENTIONAL WASTEWATER MANAGEMENT: A COMPARATIVE REVIEW AND ANALYSIS OF HYDRAULIC FRACTURING WASTEWATER MANAGEMENT PRACTICES ACROSS FOUR NORTH AMERICAN BASINS

Final Report For the Canadian Water Network

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DISCLAIMER

All statements contained herein are the responsibility of the authors and do no necessarily reflect the views of the Canadian Water Network.

EXECUTIVE SUMMARY

This objective of this study was to: examine wastewater handling, treatment, and disposal practises[1] as they apply to the hydraulic fracturing industry; identify knowledge gaps; and suggest research approaches to address the gaps. Despite the high level of concern by stakeholders, to date there has been no comprehensive, comparative examination of *wastewater management* practices involving handling, treatment, and disposal. This is at least in part because plays and formations vary greatly in: geological and hydrological structure, estimated reserves, mix of reserves (oil, gas, condensates), length of time active recovery has been under way, breadth of collected data, proximity to major populations, regulatory regimes, number of political jurisdictions responsible for regulation, and options available for wastewater management under the existing jurisdictional policies – which make a comparative review difficult.

Without the ability to go back in time to collect baseline data and retroactively establish regulations to the beginning of each formation's development, our comparison allows us to, in effect, compose a microcosm of the issues associated with handling, treatment, and disposal of hydraulic fracturing wastewater. This methodology allows a "before" and "after" picture to be developed. It is important to note that this study is not intended to provide a complete history of all issues involved in the three subject areas explored. Rather, the intent was to compile sufficient information to identify knowledge gaps and research approaches, recognizing that this study involved extensive research and the compilation of considerable details in each area.

The methodology for the study involved establishing three teams of researchers, each devoted to a specific task area representing a key issue in wastewater management. The three task areas were: *water treatment and disposal practises; regulatory policy regimes and voids within and across jurisdictions; and stakeholder concerns*. This study focused on four formations that enabled a comparison of jurisdictions with extensive experience in hydraulic fracturing wastewater management to those with less. The selections were the Duvernay and Montney formations in Canada, and the Barnett and Marcellus formations in the United States.

The research presented and the identification of knowledge gaps was the result of extensive literature reviews from numerous sources, interviews and briefings with subject matter experts, exchanges of information among team members, and feedback from advisory panels. In February 2015 a draft of the final report was circulated to an advisory group consisting of representatives from industry, government, and academia, four of which responded with detailed suggestions for technical corrections and revisions. This was combined with feedback provided by the CWN advisory and technical review committees and used to influence the final selection of knowledge gaps and approaches and to ensure technical accuracy.

The study culminates in the identification of knowledge gaps and approaches to filling those gaps within the three task areas. Following is a summary of the knowledge gaps by task area:

[1] Although not specifically referred to in the original terms of reference for this study, the practice of water reuse is also investigated.

Water treatment and disposal practices: Inconsistencies in reporting can result in missing information for individual wells in the three disposal well databases reviewed (FracFocus, geoSCOUT, and AccuMap). We observed gaps pertaining to: the fate of wastewater, the source of water used, water injection and production, and chemical analysis. The most prominent knowledge gap is that the fate of hydraulic fracturing wastewater is absent. In other words, it is not clear what portion of a well's wastewater is reused/recycled, treated, surface discharged, or deep-well injected. This lack of information prohibits any direct analysis of wastewater management practices for the hydraulic fracturing operations based on the available information in databases. We also found that the databases examined may not serve the information needs of stakeholders external to the regulatory and industry communities, while acknowledging that the databases were not designed specifically for that purpose.

Regulatory policy regimes and voids within and across jurisdictions: Our research indicates that there are significant differences in how disposal wells are classified and regulated across jurisdictions. The adequacy of the regulations for disposal wells in the U.S. was identified as a knowledge gap, and the degrees to which the current British Columbia and Alberta disposal well regulations (including the permitting process) are sufficient to protect the environment over the long term remains unknown. Our research also leads to the conclusion that significant knowledge gaps exist in the areas of regulatory outcomes, compliance and Best Management Practices, and terminology, particularly in how those factors incite and contribute to environmentally sustainable practices. We also found that First Nations have not imposed regulations for wastewater handling, treatment, and disposal on their lands, and a knowledge gap lies in the ability of assess the capacity of First Nations communities to regulate hydraulic fracturing activity.

Stakeholder concerns: We found that social acceptance of hydraulic fracturing is essential; yet it varies extensively across time and place. A comprehensive understanding of operator and regulator approaches for gaining and retaining social acceptance remains elusive, thus presenting a knowledge gap. As our research indicates, conventional understandings of risk management may not be adequate for dealing with grand challenges such as hydraulic fracturing, and organizational practices, which may have gone unnoticed or unchallenged in the past, may no longer apply, particularly in the context of the changing role of social media.

ABBREVIATIONS

AER - Alberta Energy Regulator
AESRD - Alberta Environment and Sustainable Resource Development
AWSS - aboveground walled storage systems
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 litres.
BC - British Columbia
BMP - best management practices
CAPP - Canadian Association of Petroleum Producers
CEM - cumulative effects management
CR - corporate responsibility
CSA - Canadian Standards Association
CSR - corporate social responsibility
CSUR - Canadian Society for Unconventional Resources
DEC - New York State Department of Environmental Conservation
DEP - Pennsylvania Department of Environmental Protection
DMR - New York Division of Mineral Resources
DOW - dangerous oilfield waste
DRBC - Delaware River Basin Commission
EA - environmental assessment
EPA - U.S. Environmental Protection Agency
ERCB - Energy Resources Conservation Board (now the AER)
FPIC - free prior and informed consent
FRPA - British Columbia Forest and Range Practices Act
IADC - International Association of Drilling Contractors
IEA - International Energy Agency
IMP - integrity management program
IOGCC - Interstate Oil and Gas Compact Commission
MEM - British Columbia Ministry of Energy and Mines
MNGD - British Columbia Ministry of Natural Gas Development
MOE - British Columbia Ministry of Environment
NORM - naturally occurring radioactive material
NPDES - National Pollutant Discharge Elimination System program (U.S.)
NRDC - Natural Resources Defense Council (U.S.)
NRPI - National Pollution Release Inventory (Canada)
NYDEC - New York Department of Environmental Conservation
OGC - British Columbia Oil and Gas Commission
OGWR - British Columbia Oil and Gas Waste Regulation
OOGM - Pennsylvania Office of Oil and Gas Management
PA DEP - Pennsylvania Department of Environmental Protection
PBR - play-based regulation pilot program (Duvernay)
PEST - Political, Economic, Social and Technological analysis
PLNGFR - British Columbia Pipeline and Liquefied Natural Gas Facility Regulation
PNGA - British Columbia Petroleum and Natural Gas Act
RCRA - Resource and Conservation Recovery Act (U.S.)

REDA - Alberta Responsible Energy Development Act
RRC - Texas Railroad Commission
RSA - Revised Statutes of Alberta
SDWA - Safe Drinking Water Act (U.S.)
SGEIS - New York Supplemental Generic Environmental Impact Statement
SLO - social license to operate
SRBC - Susquehanna River Basin Commission
STRONGER - State Review of Oil and Natural Gas Environmental Regulations
SWOT - Strengths, Weaknesses, Opportunities, Threats analysis
TAC - Texas Administrative Code
TCEQ - Texas Commission on Environmental Quality
Tcf - trillion cubic feet; a unit used to estimate gas and coalbed methane production volumes. According to the U.S. Department of Energy 1 tcf is the approximate volume of gas used by twelve million American households in one year.
TDS - total dissolved solids
UIC - Underground Injection Control
WLAP - British Columbia Ministry of Water, Lands and Air Pollution

GLOSSARY

AccuMap - Industry data management software of gas well logs and production histories.

Actor - For the purposes of our report, a regulator, regulatory agency, or decision-maker with the legal authority to make and enforce regulations.

Aquifer - A geological formation; group of geological formations; or a part of one or more geological formations that is groundwater bearing and capable of storing, transmitting and yielding groundwater. Aquifers are also used for deep injection or wastewater.

Barnett - shale formation located in northeastern Texas, by Dallas-Fort Worth

Basin - A geological area defined by its sedimentary, stratigraphic, or permeability characteristics. In the context of this report, a basin may include multiple shale gas plays.

Berm - An embankment or ridge constructed to prevent the movement of liquids, sludge, solids, or other materials.

Best Practices/Best Management Practices (BMPs) - Management practices or techniques recognized to be the most effective and practical means to develop the resource, while minimizing adverse environmental effects. BMPs may be regulation-based, but are frequently considered to be steps taken beyond existing requirements. As a result, they are usually non-binding and may not be observed by all industry operators.

Brine - Water that has a large quantity of salt, especially sodium chloride, dissolved in it; salt water and certain produced water are considered brines. Oil and gas regulations in Texas refer to wastewater as “brine.”

Brine (Ohio) - “Brine” refers to all saline geological formation water resulting, obtained, or produced in connection with the exploration, drilling, or production of oil and gas (Division of Mineral Resources Management – Oil and Gas, Ohio Administrative Code, Chapter 1501:9, January 2012).

Brine pit (Texas) - Pit used for storage of brine which is used to displace hydrocarbons from an underground hydrocarbon storage facility (Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule 3.8(a)2).

CAS Number - A unique identifier for chemical substances. Chemical Abstracts Service (CAS) is a division of the American Chemical Society that is responsible for the administration, quality assurance and maintenance of the CAS registry. A CAS Number itself has no inherent chemical significance, but provides an unambiguous way to identify a chemical substance or molecular structure when there are many possible systematic, generic, proprietary or trivial names. Laws in both Canada and the US may protect a CAS from disclosure where the chemical is determined to be proprietary and subject to exemption.

Characteristic Waste - Waste that is considered hazardous under RCRA (USA) because it exhibits any of four different properties: ignitability, corrosivity, reactivity, and toxicity. CEPA (Canada) has similar criteria for categorization as per Schedule 1 of CEPA, 1999, and hazardous waste regulations falling under CEPA.

Class II wells - Wells used for the injection or disposal of produced water or brine equivalent

Condensate - A low-density mixture of hydrocarbon liquids that are present as gaseous components in raw natural gas. The Duvernay, AB is particularly rich in condensate liquids held in conjunction with its gas deposits.

Conventional resources – gas and oil reserves drilled using standard vertical drilling techniques

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-vertical 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 extending in different directions, and at different depths.

Disposal Well (Injection Well) [Canada] - A well, commonly completed in a depleted hydrocarbon reservoir or saline aquifer, into which waste fluids can be injected for disposal. Disposal wells require regulatory approvals and permits, which are at the discretion of provincial regulatory agencies.

Disposal Well (Injection Well) [United States] - A Class II Well permitted under the SDWA, which is employed for the injection of produced water and certain other exploration and production wastes into an underground formation.

Duvernay - shale formation which spans east-central Alberta, south of the Montney

Flowback Water - The fluids returning to the surface of a well after hydraulic fracturing is complete. Flowback water is considered wastewater in the context of this report.

Formation - A geological unit composed throughout substantially the same kind of rock; lithologic unit. Each different formation is given a name, frequently as a result of the study of the formation outcrop at the surface and sometimes based on fossils found in the formation, and is sometimes based on electric or other bore-hole log characteristics (State Review of Oil and Natural Gas Environmental Regulations, Inc.).

Formation Water - The original water in place in a formation/reservoir at the time production commences.

FracFocus –publically accessible play-based geographic database

Frack fluid – the term for the composite fluid injected into a well

Fracking – common term for hydraulic fracturing

Freeboard - The distance measured vertically downwards from the top of the structure to the top of the liquid stored in the vessel as applied here to storage tanks, pits, berms, and impoundments.

Gas-in-place – the amount of gas estimated to be in a formation

geoSCOUT – industry data management software of gas well logs and production histories

Groundwater - Water naturally occurring below the surface of the ground.

Hazardous Waste - A waste with properties that make it dangerous or capable of having a harmful effect on human health and the environment. Under the RCRA (USA) and CEPA (Canada), hazardous wastes are specifically defined as wastes that meet a particular listing description or that exhibit a characteristic of hazardous waste.

Hydraulic Fracturing (also Fracking; Hydraulic Stimulation) - A method of stimulating production by increasing the permeability of the producing formation. Under hydraulic pressure, a fluid is pumped down the well and out into the formation. The volumetric pressure under which the fluid enters the formation causes parts of the bedrock to fracture and shatter. Chemicals and propping agents are used to keep the fissures open and facilitate hydrocarbon flow to the surface.

Imbibition - displacement of non-wetting fluid with wetting fluid in a porous medium

In-place Resource (Resource Potential) - The quantity of oil or gas remaining in known accumulations plus those quantities already produced from known accumulations plus those quantities in accumulations yet to be discovered.

Land Disposal (USA) - For purposes of RCRA Subtitle C Regulation, placement in or on the land, except in a corrective action unit, and includes, but is not limited to, placement in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, underground mine or cave, or placement in a concrete vault or bunker intended for disposal purposes.

Landfarming (Texas) - A waste management practice in which oil and gas wastes are mixed with or applied to the land surface in such a manner that the waste will not migrate off the landfarmed area (Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule 3.8(a)25).

Landfill (USA) - For purposes of RCRA Subtitle C, a disposal unit where non-liquid hazardous waste is placed in or on the land.

Liner - Continuous layer of natural or synthetic materials, beneath and on the sides of a surface impoundment, landfill, or landfill cell, which restricts the downward or lateral escape of waste, waste constituents, or leachate.

Loading Criteria - A numeric level, normally expressed in kilograms per hectare (Canada) or pounds per acre (USA), below which a specific chemical compound may be applied to the soil.

Manifest - a shipping document that travels with the waste from the point of generation, transportation, and disposal or treatment

Marcellus - shale formation that spans Ohio, Pennsylvania, New York, Virginia, West Virginia, and part of Maryland

Monitoring Well - A well that is used or intended to be used for the purpose of monitoring, observing, testing, measuring or assessing the level, quantity or quality of groundwater, or subsurface conditions, including geophysical conditions.

Montney - shale formation that spans northeastern British Columbia and northwestern to west-central Alberta

Non-commercial Fluid Recycling (Texas) - The recycling of fluid produced from an oil or gas well, including produced formation fluid, workover fluid, and completion fluid, including fluids produced from the hydraulic fracturing process on an existing commission-designated lease or drilling unit associated with a commission-issued drilling permit under section 3.9 of the TAC [relating to Disposal Wells] or a non-commercial injection well operated pursuant to a permit issued under section 3.46 of the TAC [relating to Fluid Injection into Productive Reservoirs], where the operator of the lease, or drilling unit, or non-commercial disposal or injection well treats or contracts with a person for the treatment of the fluid, and may accept such fluid from other leases and/or operators (Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule 3.8(a)41).

Non-hazardous wastes - boiler blowdown water, tank wash water, rig wash, spent glycols, drilling waste leachate, and other related fluids to oil and gas exploration and production that are not specifically flowback or produced water

Non-special wastes - former term used in British Columbia regulations for non-hazardous wastes.

Oil and Gas Wastes (Texas) - Materials to be disposed of or reclaimed which have been generated in connection with activities associated with the exploration, development, and production of oil or gas or geothermal resources, as those activities are defined in the Texas Administrative Code, and materials to be disposed of or reclaimed which have been generated in connection with activities associated with the solution mining of brine. The term "oil and gas wastes" includes, but is not limited to, saltwater, other mineralized water, sludge, spent drilling fluids, cuttings, waste oil, spent completion fluids, and other liquid, semiliquid, or solid waste material (Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule 3.8(a)26).

Oil field fluids (Texas) - Fluids to be used or reused in connection with activities associated with the exploration, development, and production of oil or gas or geothermal resources, fluids to be used or reused in connection with activities associated with the solution mining of brine, and mixed brine. The term "oil field fluids" includes, but is not limited to, drilling fluids, completion fluids, surfactants, and chemicals used to detoxify oil and gas wastes (Texas Administrative Code, Title 16, Part 1, Chapter 3, Rule 3.8(a)27).

Operator - The person or company,either proprietor, contractor, or lessee, actually operating a well, lease, or disposal facility, or transporting waste between production and disposal sites.

Pipeline - piping through which petroleum or natural gas; water produced in relation to the production of petroleum or natural gas or conveyed to or from a facility for disposal into a pool or storage reservoir.

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 that is water released at the same time as the resource. Produced water is typically very salty, or briny, and contains chemicals, trace and aromatic hydrocarbons, and naturally occurring radioactive materials (NORM). Produced water is considered wastewater in the context of this report.

Proppant - Sand or ceramic beads suspended in drilling fluid during hydraulic fracturing to keep ("prop") open the cracks in the rock when fluid is withdrawn and a well is put into production.

Proven Reserve - The quantity of oil or gas that is proven to be technically and economically feasible to recover.

Recycle - To process and/or re-use oil and gas wastes as a product for which there is a legitimate commercial use and the actual use of the recyclable product. Recycling activities are subject to permitting, and do not include injection for disposal.

Reuse - efforts made by industry operators to minimize freshwater use by using wastewater for subsequent hydraulic fracturing jobs with little to no pre-treatment

Salinity - The quantitative level of salts in an aqueous medium.

Shut-in period - the time period between creating a fracture and beginning production for a hydraulically fractured well. Also referred to as soaking time.

Social license to operate - A relational and iterative process between a company and community that can substantially impact the success of a unique development project.

Spillage - Means petroleum, natural gas, oil, solids or other substances escaping, leaking or spilling from a pipeline, well, shot hole, flow line, or facility, or any source apparently associated with any of those substances.

Stimulation - Also called treatment or completion in the literature. For clarity, treatment is used in this report only in the context of processing wastewater resulting from hydraulic fracturing.

Stakeholders - As per Freeman's definition, "any group or individual who can affect, or is affected by, the achievement of a corporation's purpose" (Freeman, 1984, p. vi); in the case of unconventional shale development, concerned stakeholders may include operators, regulators, communities, environmentalists, and others.

Transporter - A person, or company, engaged in the off-site transportation of waste.

Treatment - Any method, technique, or process designed to physically, chemically, or biologically change the nature of a hazardous waste.

Unconventional resources – gas reserves requiring the use of emerging technologies such as horizontal drilling and hydraulic fracturing

Underground injection wells - collective term used in U.S. for disposal wells

Wastewater – water contaminated by industrial handling and requiring disposal or treatment

Wastewater management - wastewater handling, treatment, reuse, and disposal practices, collectively

TABLE OF CONTENTS

CHAPTER 1: REPORT OVERVIEW AND SUMMARY OF FINDINGS

1.1 Project Objective and Research Methodology

This objective of this study was to: examine wastewater handling, treatment, and disposal practises[2] as they apply to the hydraulic fracturing industry; identify knowledge gaps; and suggest research approaches to address the gaps. Hydraulic fracturing wastewater is an emerging priority in the energy industry and in public policy. A recent national report by the Council of Canadian Academics indicated proper wastewater management as a key issue associated with hydraulic fracturing (CCA, 2014), while other similar reports (The Royal Society and The Royal Academy of Engineering, 2012; Cook et al., 2013; Ewen et al., 2013) have come to similar conclusions.

The methodology for the study involved establishing three teams of researchers, each devoted to a specific task area representing a key issue in wastewater management. The three task areas were: *water treatment and disposal practises; regulatory policy regimes and voids within and across jurisdictions; and stakeholder concerns*. Without the ability to go back in time to collect baseline data and retroactively establish regulations to the beginning of each formation's development, our comparison allows us to, in effect, compose a microcosm of the issues associated with handling, treatment, and disposal of hydraulic fracturing wastewater. This methodology allows a "before" and "after" picture to be developed. Understanding how these issues could unfold in shale formations slated for future development is of utmost importance for the protection of the environment and for setting an appropriate legal and regulatory context to ensure the balance between oil and gas extraction and environmental protection. It is important to note that this study is not intended to provide a complete history of all issues involved in the three subject areas explored. Rather, the intent was to compile sufficient information to identify knowledge gaps and research approaches, recognizing that this study involved extensive research and the compilation of considerable details in each area.

An established professor with expertise in the task area being examined led each research team and employed students through a variety of mechanisms[3] to assist with the research and to ensure the project contributed to the development of highly qualified personnel. The Principal Investigator oversaw the work of each team and was responsible for compiling the final report. The first team meeting was held in April 2014 and numerous additional meetings and conference calls were held during the project's duration. Team members also attended and presented the project at several conferences, including the Petroleum Technology Alliance of Canada Conference on hydraulic fracturing held in Calgary in May, 2014 and the American Chemical Society Conference held in Denver in March, 2015.

Shortly after the first team meeting, a meeting/videoconference was held with representatives from academia, industry and government (including the regulatory agencies) to discuss the conceptual framework and approach to the project. Based on their feedback, adjustments were

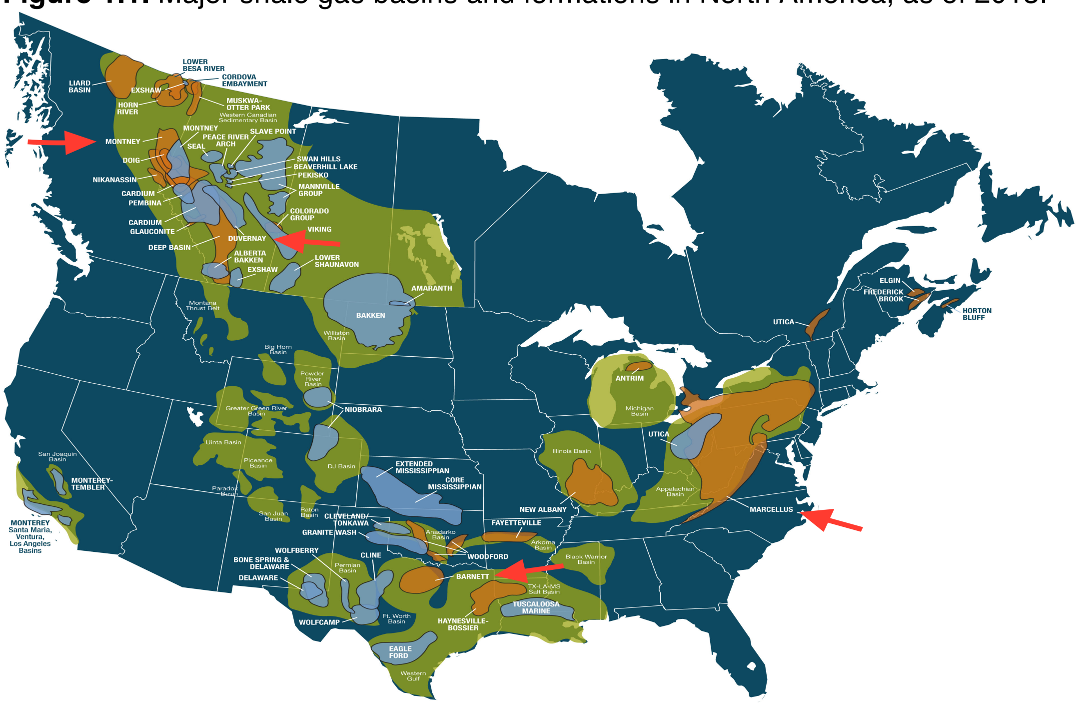
[2] Although not specifically referred to in the original terms of reference for this study, the practise of water reuse is also investigated.
[3] See the list of contributors on page i for details.

made and the research teams honed their frame works to ensure their efforts would result in the identification of specific research gaps. The teams then began an extensive review process, which included literature reviews and individual interviews with selected stakeholders and industry experts. In February 2015 a draft of the final report was circulated to an advisory group consisting of representatives from industry, government, and academia, four of which responded with detailed suggestions for technical corrections and revisions. This was combined with feedback provided by the CWN advisory and technical review committees and used to influence the final selection of knowledge gaps and approaches and to ensure technical accuracy.

1.2 Overview of Hydraulic Fracturing Wastewater Management

Hydraulic fracturing has long been employed in the oil and gas industry (Montgomery & Smith, 2010; Freeman, Moridis, Ilk, & Blasingame, 2013; Kargbo, Wilhelm, & Campbell, 2010). However, the recent combination of hydraulic fracturing and innovative horizontal drilling techniques has unlocked vast potential for shale gas and tight oil reserve extraction across North America - resulting in a transformed industry. There are now over 30 large, commercially relevant shale formations across North America, many of which contain multiple plays[4]. These formations cross provincial and state jurisdictions (Wozniak, Hayashi, Bentley, Grasby, & Eckfeldt, 2008) (see Figure 1.1) creating a complex legal and regulatory framework for water extraction, treatment, and disposal.

Figure 1.1. Major shale gas basins and formations in North America, as of 2013.



Note: Adapted from: PacWest Consulting (2013) *http://pacwestcp.com/2012/07/pacwest-publishes-updated-shaleunconventional-play-maps/* Basins are indicated in green, formations in orange, and our four focus formations with red arrows. The blue areas indicate formations with oil/liquid reserves.

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[4] Readers may refer to the glossary for the definition of terms such as 'formation' and 'play' used in this report.

The development of unconventional resources often takes place in locations not historically accustomed to oil and gas extraction, let alone on the scale involved with hydraulic fracturing. For some counties in the United States (U.S.), where hydraulic fracturing has been taking place the for the longest period, the number of residents living within a mile of a well has increased dramatically since 2000, from a small fraction to an overwhelming majority (Gold & McGinty, 2013). These changes will likely become widespread with the number of hydraulically fractured wells predicted to increase over the coming years. With such potential growth, it has become evident that a region's historical experience with conventional oil and gas policy approaches may not be adequate in dealing with the emerging context. At worst, past experiences may even inhibit the ability of producers and regulators to successfully deal with unconventional development.

Despite the high level of concern by stakeholders, to date there has been no comprehensive, comparative examination of *wastewater management* practices involving handling, treatment, and disposal. This is at least in part because each plays and formations vary greatly in: geological and hydrological structure, estimated reserves, mix of reserves (oil, gas, condensates), length of time active recovery has been under way, breadth of collected data, proximity to major populations, regulatory regimes, number of political jurisdictions responsible for regulation, and options available for wastewater management under the existing jurisdictional policies – which make a comparative review difficult. A few recent studies have examined the full water life-cycle of selected U.S. formations and provide an indication of what the future of wastewater management may look like for Canadian formations (Nicot et al., 2014; Clark et al., 2013). To date, this study provides the most comprehensive picture of wastewater management that could be relevant practices regardless of a formation's stage of development and applicable regulatory framework.

This study focused on four formations that which allows us to directly compare those with extensive experience in hydraulic fracturing wastewater management with less developed but strategically important formations. The selections were the Duvernay and Montney formations in Canada, and the Barnett and Marcellus formations in the United States. These were chosen amongst numerous choices because each is at different stages of production and represents different jurisdictional situations (see section 1.4 below).

1.3 Introduction to The Three Task Areas

Following this introduction, chapters 2, 3 and 4 are devoted to examining the task areas of: *water treatment and disposal practises; regulatory policy regimes and voids within and across jurisdictions; and stakeholder concerns* as encountered across the four formations selected. The chapters employ consistent definitions for commonly used terms in hydraulic fracturing chapters as defined in the glossary. As described above, the three chapters provided detailed examinations of issues but were not designed to be completely comprehensive. Issues that bear additional examination include: the ecological footprint of transportation, the potential for spills from leaky wells, pipelines or transport trucks, and the CO_2 footprint of disposal practices. While each of these issues is indeed relevant we deemed them to be out of the scope for our study due to resource limitations.

We expressly avoid the use of the term *fracking* throughout the report, except in quotes and in the keyword searches. Although it is prevalent in popular media, industry and some academics avoid the term as its popular meaning has become pejorative. Indeed, the imbalance in the use of the term may contribute in part to the lack of publicly available data, or at least data lost in translation; a concerned citizen may be unable to find objective literature due to the plethora of better search terms other than *fracking* that could/should be used.

1.3.1 Chapter 2 - Wastewater handling, treatment, and disposal practices

Chapter 2 examines the current hydraulic fracturing wastewater management practices used by operators in our four focus formations. Throughout Canada and the U.S., oil and gas well logs and production histories including data pertaining to wastewater reduction must be submitted to the oil and gas provincial or state regulator, which then makes them available. Selected data are obtained by 'data vendors' which then offer paid subscription services for GIS based product(s), such as geoScout and AccuMap (the most common). In addition, some jurisdictions now legally require fluids and non-proprietary proppants used in a well treatment to be uploaded to open access FracFocus websites. Although data on the quantities, types, and disposal locations of wastes generated by a particular well are typically available in one of these databases, often the data is not searchable and is included in attachments or appendices to the electronic well records rendering it difficult to access (Zhao, Givens, & Curtis, 2007).

Furthermore, a comprehensive picture of a single play's wastewater is often unobtainable because each database does not capture all the data relevant to a wastewater management study. As part of our review, it was necessary to manually extract and compile information from a variety of sources in order to create a sample database of the four selected formations. This enabled us to effectively compare the physical differences among the formations, which in turn provides a scientific background for identifying at least some of the differences among the formations regarding regulatory frameworks and public concern.

1.3.2 Chapter 3 - Regulatory and policy regimes and voids within and across jurisdictions

Chapter 3 undertakes a comparative analysis of the relevant policy and regulatory regimes concerning hydraulic fracturing wastewater management across our four formations. In particular, we summarize the existing and past relevant regulations and legislation in an attempt to track and compare the history and development of regulations over time. The research was guided by the following questions:

- How do wastewater handling, transport, treatment, and disposal standards differ between and within the formations?
- What are the primary influences on policy and regulations developed and in use today, and have these influences changed over time?
- What are the observed gaps in regulations observed between and within jurisdictions?

To answer these questions, we used a variety of resources including government websites, court documents, legal databases, and online versions of current legislation and regulations, as well as an extensive literature review of peer-reviewed articles, conference and symposia proceedings, and scholarly books. Wherever possible and practical, findings were discussed with regulators or subject matter experts.

1.3.3 Chapter 4 - Stakeholder Concerns

Chapter 4 compares stakeholder concerns in each of the four focus formations. One of the challenges of hydraulic fracturing has been the pace and scale of activity. In the wake of this activity, there has been a proliferation of stakeholder concerns, and a corresponding array of seemingly irreconcilable press reports and other information. As a result, within some areas operators and regulators have become increasingly concerned with their *social license to operate* (or, SLO). This portion of the study looks at the extent to which SLO is an explicit concern across the four formations, whether on the part of operators, regulators, or both; what kinds of efforts (if any) have been undertaken to secure, enhance, or restore SLO; and whether there is evidence that these efforts have made a difference in the SLO within a particular formation.

To answer these questions, we conducted a series of keyword searches of daily print newspapers in each of the four focus regions, and tabulated how many times SLO was discussed in conjunction with hydraulic fracturing concerns (both general and specific to wastewater). These searches were not intended to be comprehensive, but rather to serve as indicative proxies for the types and levels of stakeholder concerns across formations and time. Additionally, we reviewed the results of the Government of Alberta's recently completed Water Conversations (summer 2013), which included a discussion of hydraulic fracturing and water use.

1.4 Levels of Knowledge Across the Four Formations

1.4.1 Explanation of how the four formations were selected

With some active or planned plays in North America having little or no existing regulatory infrastructure for oil and gas recovery, or a regulatory infrastructure suited only for conventional resource development, comparing the oversights and foresights of jurisdictions on the leading edge of these developments provides insight for newly developing formations in Canada and elsewhere. Specifically, we wanted to compare jurisdictions that are all of relative importance to their respective provincial or state economy, but differ from each other in terms of length/breadth of unconventional resource development, and in terms of jurisdictional issues. Furthermore, we wanted to compare jurisdictions with extensive and/or increasing experience in wastewater management; as can be seen in Table 1.1, each of the formations chosen currently produce (or, in the future, will be producing) significant volumes of both unconventional shale gas and wastewater.

Table 1.1. Comparison of focus shale formations.

Formation	Regional Extent	Original Gas in Place Volume (Tcf)	Technically Recoverable Gas Base (Tcf)*	Approximate Wastewater Volumes (based on water use)
Montney	130,000 km^2 (BC & AB)	271 (BC) 178 (AB)	271	10,000-25,000 m^3/well
Duvernay	7,500 km^2 (wet gas window)	443	75-225	50,000 m^3/well (slickwater)
Barnett	13,000 km^2	225-750	75	10,600 m^3/well
Marcellus	167,300 km^2	1500	400-489	11,500-26,500 m^3/well

•

Typically, the amount of natural gas able to be extracted from a reservoir for commercial processing is only 10-30% of the total in place gas volume. For example, of the geophysically assessed volume of 1500 Tcf natural gas that is trapped in the Marcellus shale, only 400-489 Tcf (~26-32%) is considered technically recoverable.

Adapted from: Johnson & Johnson (2012); National Energy Board (2013); Nicot & Scanlon (2012); Pennsylvania State's Marcellus Center for Outreach and Research (2013); Precht & Dempster (2012); Smith Low (2012); US Energy Information Agency (2012); United States Geological Survey (2011).

In particular, the Barnett was chosen as it was the first unconventional shale gas formation in the U.S. to undergo significant development, meaning that it presents the largest picture temporally-speaking, which through hindsight and analysis allows for perhaps the most in-depth understanding of some of these issues. Furthermore, this formation is located in north-eastern Texas near the Dallas-Fort Worth area, and thus development has encountered many difficulties due to its proximity to highly urbanized areas. The city of Denton, Texas, for example, has just banned the hydraulic fracturing process through a referendum that resulted from residents opposing drilling that was occurring only 300 feet from a neighbourhood (Krauss, 2014).

The Marcellus was chosen as it is a more recently developed formation, with hydraulic fracturing carried out since 2004. However, the Marcellus adds much to the picture, as the scale and pace of activity are already exceeding anything seen in the Barnett. Furthermore, the formation spans six states (Ohio, Pennsylvania, New York, Virginia, West Virginia, and Maryland), some jurisdictions which are both much less accustomed to gas development and are much more heavily populated than other plays, with activities directly occurring in urban areas and near watersheds that provide the domestic water supply. With a greater number of affected stakeholders and hydraulic fracturing related activities that cross state lines, the result has been significant controversy and contention among the parties involved, providing complex issues for operators and regulators alike.

For a Canadian context, the two formations currently active were included in the study, the Montney and the Duvernay. The Montney, shared between northeastern British Columbia and north-central Alberta, is one of the largest unconventional shale gas formations in the world, making it potentially open to as much activity as seen in the Barnett and Marcellus formations.

The Duvernay in east-central Alberta, on the other hand, is comparable to the Barnett in that it falls within a single province. While this region does not have as extensive a history as the U.S. formations, the Duvernay is the site of many potential changes to unconventional resource development regulations and policy, and thus is may become a significant influence on decision-makers in other Canadian jurisdictions in the near future.

1.4.2 Brief comparison of production, regulatory environments, and stakeholder concerns across the formations

The four focus formations are thus quite different in their respective extent of development, accessibility to or preference in wastewater treatment/disposal methods, geology and subsequent water needs, inter-jurisdictional matters, key stakeholder concerns, etc. However, there are a number of similarities across all four formations. In terms of analyzing wastewater management practices, there is difficulty in quantifying both the volumes and fate of wastewater across all the focus formations. This is partly due to incomplete or inconsistent database reports which indicates that accurate reporting is a persistent challenge (as it is in any industry), and that databases designed for one purpose (such as the requirements of a regulator) do not necessary serve other purposes (such as satisfying the public's database interests) very well. In terms of legislation and regulation, there seems to be homogeneity across the jurisdictions in regulatory criteria, being either highly specific or rather broad with a focus on pollution prevention, and a reliance on industry to use best management practices. From the perspective of stakeholders, concerns across the four regions seemed to peak in 2011, possibly due to the release of the film *Gasland* in 2010, and its number of nominations and awards from 2010 to 2011. Furthermore, certain issues seemed to be mentioned more times than others across all the focus regions, such as the potential impacts of hydraulic fracturing on health, or hydraulic fracturing wastewater treatment.

1.5 Summary of Findings: Knowledge Gaps and Approaches to Filling Gaps

This section provides, for each chapter, a brief summary of the identified research gaps and approaches to filling them. Readers are encouraged to refer to the appropriate chapter sections in order to gain a complete understanding of how the knowledge gaps were identified and the approaches and cost ranges related to addressing those gaps.

1.5.1 Chapter 2 Knowledge Gap - Disposal Well Databases

While inconsistencies in reporting mean that some information is missing for individual wells in one or more of the databases (which does not necessarily constitute a knowledge gap in itself), we observed gaps pertaining to: the fate of wastewater, the source of water used, water injection and production, and chemical analysis. The most prominent knowledge gap related to the database analysis conducted in this section is that the fate of hydraulic fracturing wastewater cannot be found in the three databases. In other words, it is not clear what portion of a well's wastewater is reused/recycled, treated, surface discharged, or deep-well injected. This lack of information prohibits any direct analysis of wastewater management practices for the hydraulic fracturing operations based on the available information in databases.

1.5.2 Chapter 2 Approaches, Strengths and Weaknesses - Disposal Well Databases

Critical to addressing these gaps is identifying information that is required by various stakeholders, such as industry, the public, regulators, academics, and policymakers. Numerous databases, including those mentioned above, contain information about water in hydraulic fracturing. However, there appears to be a consensus that more information about the water cycle in hydraulic fracturing should be made publicly available. We therefore suggest the following two research approaches:

The first **approach** would be to hold consultations with stakeholders to assess which information they would find useful in a publicly available format. Feedback could be gathered using many mechanisms to accurately sample various demographics; for example: email, social messaging, town hall information meetings, and surveys or information requests by post could be employed. Ideally the development of the consultation mechanism would involve experts from industry, academia, government, and members of the public.

The **strength** of this approach is that it would provide comprehensive feedback and verification of the gaps in current databases as observed by this study. It would also provide concrete evidence from stakeholders regarding what data/information they are looking for, and how it might be provided in a useful way. The **weakness** is that it may raise undue expectations on the part of stakeholders, and result in pressure to make significant alterations to current databases that may be serving the needs of the data base owners adequately.

A second **approach** would be to develop a prototype open information portal to disseminate hydraulic fracturing information to stakeholders based on the findings of this study and other studies examining stakeholder information needs. The prototype would then be released in a publicly accessible format with the capacity to provide feedback from users.

The **strength** of this approach is that a prototype already exists and it could rapidly advance the body of knowledge regarding what stakeholders are looking for. The **weakness** is that stakeholders may react in a less positive fashion toward the database if they feel they were not consulted on its design or results in undue costs.

1.5.3 Chapter 3 Knowledge Gap - Disposal Well Classification

Our research indicates that the topic of disposal well classification presents an important knowledge gap and that there are significant differences in how disposal wells are classified and regulated. The adequacy of the regulations for disposal wells in the U.S. has also been questioned. Similarly, the degrees to which the current British Columbia and Alberta disposal well regulations (including the permitting process) are sufficient to protect the environment over the long term are unknown.

1.5.4 Chapter 3 Approaches, Strengths and Weaknesses - Disposal Well Classification

One **approach** would be to use case studies and detailed examinations of disposal well regulations to assess whether increased consistency in classification across jurisdictions would be likely to lead to improved environmental protection and regulatory efficacy. The **strength** of this approach is that it is based on existing sources and therefore would be a cost effective means of conducting research. The **weakness** of this approach is that it would, by definition, be limited to existing findings and would not provide a mechanism for direct engagement.

A second **approach** would be to bring regulators from the jurisdictions studied together to discuss the disparate classifications of disposal wells and evaluate the potential to reach a higher level of consistency. This would involve a conference, or a series of conferences and workshops supported by other engagement mechanisms such as videoconferences and exchange/review of documents. The **strength** of this approach is that by directly engaging regulators, an exchange of current and future plans for this topic could take place. It would therefore be considered a more proactive approach than the first suggestion. As well, it may be supported by industry in that greater consistency across jurisdictions would be expected to result in improved efficiency in well construction and disposal practices. The **weakness** would be the potential difficulty of convincing regulators that it is worth their time, and the obviously greater expense considering the time, travel and facility arrangements involved.

1.5.5 Chapter 3 Knowledge Gap - Regulatory Outcomes, Compliance and Best Management Practices, and Terminology

This study and others cited in this study have identified which waste water practices and infrastructure requirements are regulated, how they are regulated, and the level of detail imposed within the regulations. It is acknowledged that assessing whether regulations are enforced, identifying the compliance rate of industry operators, and defining a regulator's capacity to enforce are as important as the regulation itself (e.g. Richardson et al., 2014). This observation, supported by our research, leads to the conclusion that significant knowledge gaps exist in the areas of regulatory outcomes, compliance and Best Management Practices, and terminology.

1.5.6 Chapter 3 Approaches, Strengths and Weaknesses - Regulatory Outcomes, Compliance and Best Management Practices, and Terminology

The single, recommended **approach** to addressing the above four gaps is to create a multi-disciplinary research team with sufficient expertise to provide background knowledge in the areas of: regulatory development, implementation and enforcement, behavioral science, and organizational theory. The team would then determine whether a series of case studies, conferences, interviews, or other methods would be the most effective paths to pursue. Creating the team, then relying on the members establishing the specific approach could be perceived as counterintuitive. But the recommendation is based on the observation that the four gap areas are extremely complex, and in this case it may make sense for the approach to be based on expert assessment.

The **strength** of this approach is that it could provide groundbreaking research, which could then be applied to other industries beyond addition to hydraulic fracturing. The **weakness** would be the potential expense – although as recommended in other gaps areas, adopting a phased approach that would begin with a pilot project covering perhaps two jurisdictions could mitigate this. Another weakness would be the 'leap of faith' required in establishing a team charged with examining specifically identified gaps but without a mandated approach to addressing them.

1.5.7 Chapter 3 Knowledge Gap - First Nations Regulatory Capacity

The final knowledge gap in this chapter involves the engagement of First Nations, which is a critical consideration in the development of hydraulic fracturing projects. Our research indicates that First Nations have not imposed regulations for wastewater handling, treatment, and disposal on their lands. However, federal and provincial governments are obliged to consult with First Nations under the Canadian Constitution. In some cases, First Nations have established formal organizations to negotiate their own development rights in the face of widespread concern about the impacts of shale gas development.

1.5.8 Chapter 3 Approaches, Strengths and Weaknesses - First Nations Regulatory Capacity

Because no literature on this topic was found in this study, the single research **approach** recommended to addressing this gap is a consultation exercise with First Nations groups involved in hydraulic fracturing. The consultations would result in information on the current, and potential future, ability of First Nations communities to develop and deploy wastewater treatment regulations. If it appears that indigenous capacity could not be developed, other alternatives for a more empowered approach by First Nations could be explored. The **strength** of this approach is that it would gain first hand knowledge and indications of the relative desire and ability of First Nations communities to regulate. The **weakness** is that there is likely to be considerable disparity in regulatory ability among First Nations communities, and the development of a single applicable path forward may prove an elusive goal. There also may be disparity between the regulations in effect for non-First Nations jurisdictions and First Nations jurisdictions, in which case consistency of standards and practices becomes important.

1.5.9 Chapter 4 Knowledge Gap - Stakeholder Concerns

This knowledge gap is based on the findings from the research undertaken for this report that social acceptance of hydraulic fracturing is essential; yet it varies extensively across time and place. A comprehensive understanding of operator and regulator approaches for gaining and retaining social acceptance remains elusive. All organizations depend on social acceptance for their survival and success. SLO is the latest articulation of this principle and our analysis indicates decreased levels of trust in industry and government, both in terms of procedures and outcomes. As our research indicates, conventional understandings of risk management may not be adequate for dealing with grand challenges such as hydraulic fracturing, and organizational practices, which may have gone unnoticed or unchallenged in the past, may no longer apply, particularly in the context of the changing role of social media.

1.5.10 Chapter 4 Approaches, Strengths and Weaknesses - Stakeholder Concerns

Given the broad scope of this knowledge gap, two possible approaches are proposed. Both would involve ambitious theoretical and empirical examinations of the impact of the industry-regulation concerns on organizational legitimacy in the hydraulic fracturing industry (and vice versa). They would address issues such as, trust in organizations, cultural theories of risk, and organizational values practices. They could also explore the relationship between sustainability frameworks by industry and SLO. For instance, one of the industry reviewers for this study emphasized the need to further explore the relationship between triple bottom line reporting, a particular approach to sustainability in which organizations report on their financial, environmental, and social costs and benefits. Interest in triple bottom line accounting has been growing among business, governments and nonprofits. But there are important questions to consider. For instance, does the use of triple bottom line accounting by industry result in increased stakeholder receptivity to hydraulic fracturing activities? Essential to both suggested approaches is contextualizing the research questions through the lenses of technology, relationships, time and culture.

The **first approach** would be to undertake a meta-analysis, which comprises statistical methods for contrasting and combining results from different studies to identify patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies. Sources would include any published studies of statistical relationships of interest. The **strength** of this approach is that by using existing sources of information a research team could be quickly assembled and begin work. An obvious **weakness** is that by relying on existing information, personal contact with and insight from stakeholders would not be obtained. A **second weakness** is that this approach might not capture the rapid pace of innovation in the industry.

The **second approach** would involve new primary research, including nationwide interviews and focus groups with stakeholders from industry, government (policy makers and regulatory bodies), communities, environmental groups, and media representatives. The **strength** of this approach is that it is extremely comprehensive, and would draw on a wide variety of existing knowledge supplemented by insight and shared experience from stakeholders which could be applied at the local level, while acknowledging that there is no single recipe for social acceptance and that solutions must be developed organically. A **second strength** is that it is scalable. One tactic could involve a more fine-grained study of regional discourses, for instance, differences between Pittsburgh and Dimock, Pennsylvania, between Denton and Fort Worth, Texas, or between Alberta and New Brunswick. Specific projects under this approach could be focused on a subset of the shale plays examined in this study, with subsequent projects building on the results of earlier efforts. As a result, the cost of implementing the approach would also be scalable. A **third strength** is that an independent, multi-academic institution research team could conduct it. This would potentially avoid the any perceived bias that sometimes occurs when consultations are conducted by government or industry.

One **weakness** of the approach is that it could ultimately result in complex, multi-disciplinary project, which would take considerable time, resources and commitment to undertake. However, as noted above, developing a pilot project that would address the issues in a specific, constrained geographic space could mitigate this. Lessons learned from the pilot could then be applied to a broader agenda. Another **weakness** could be the receptivity by industry to participate. Review comments provided by one industry association demonstrated a degree of skepticism as to whether the findings would be useful.

CHAPTER 2: WATER TREATMENT AND DISPOSAL PRACTICES

2.1 Introduction

The amount of water used in the hydraulic fracturing and well completion processes varies significantly depending on the properties of the formation being fractured. However in many cases horizontally drilled, hydraulically fractured wells produce significant volumes of wastewater. How that wastewater is managed varies greatly among formations, jurisdictions, and operators, and at specific wells. The amount of a wastewater derived from a well and the chemistry of that wastewater depends on factors including the geology, fracture characteristics, and geochemistry of the shale reservoir, the type of fracture fluid and source of water used for that particular well, and the well construction. The available options for treatment or disposal are dependent on the amount and chemical makeup of the wastewater, local regulations, proximity/capacity of treatment/disposal facilities, infrastructure, development, schedule, cost, and other factors that may be considered by the operator. In this chapter, we will compare the known wastewater management practices and overall wastewater picture of our four focus formations by: 1) generally discussing hydraulic fracturing water usage and subsequent wastewater production and management (sections 2.2-2.3); 2) reviewing the data available in the literature for each formation individually (section 2.4); and 3) discussing the results (and limitations) of the analyses of three databases containing hydraulic fracturing wastewater information, to see what additional data can be accessed for each formation (section 2.5). Finally, we will identify the knowledge gaps that remain after the database queries (section 2.6).

2.2 Water Usage in Hydraulic Fracturing

Before discussing how the wastewater produced from hydraulically fractured wells is managed, it is useful to first note where the water initially comes from, particularly to get a sense of how *much* water is being managed in the life-cycle of a completed unconventional well. The water for a single well may be drawn from more than one source depending on the available resources, and thus may be a combination of fresh surface water, fresh groundwater, saline groundwater, or recycled/treated water. Overall, a substantial amount of water is used for hydraulic fracturing, with an estimated 97 billion gallons of water having been used in the U.S. alone between January 2011 and May 2013 on 39,294 shale gas wells (Freyman, 2014).[5] The amount of water used by a single hydraulically fractured well is dependent on various factors. First, there are generally four types of stimulations (also called *treatments* or *completions*) used to achieve the desired network of fractures, called *gel, slickwater*, *energized*, and, a hybrid of the latter two, *energized slickwater*; all stimulations consist of injecting pressurized fluid into a well for the purpose of propagating fractures in the shale rock, with the general makeup of that fluid characteristic of one of the three stimulations. Slickwater stimulations use large amounts of water and proppant (often silica sand or ceramics) and small amounts of various chemicals; energized stimulations use smaller amounts of water (compared to slickwater stimulations), large amounts of sand, and compressed gases (e.g. CO_2, N_2); and energized slickwater stimulations use large amounts of water and compressed gases (see Table 2.1). Johnson and Johnson (2012) note that less than 30%

[5] This number comes from Freyman's analysis of data for 39,294 oil *and* shale gas wells, taken from *FracFocus.org*.

of the initial water used returns to the surface as wastewater with slickwater stimulations, while up to 70% of the initial water used returns to the surface with energized and energized slickwater stimulations (due to the compressed gases in those fluids)

Table 2.1. Average attributes of fracture stimulation methods, with data from plays in northeast British Columbia.

Hydraulic fracturing stimulation type	Water per stage (m^3)	Sand per stage (T)	Water/sand ratio (m^3/T)	Count of fractures
Slickwater	2101	178	14	8126
Energized*	168	98	2	7877
Energized slickwater**	791	130	10	594

*Data averaged from three sub-types of energized stimulation: CO_2, CO_2/N_2, and N_2.

**Data averaged from two sub-types of energized slickwater stimulation: CO_2 slickwater and nitrified slickwater.

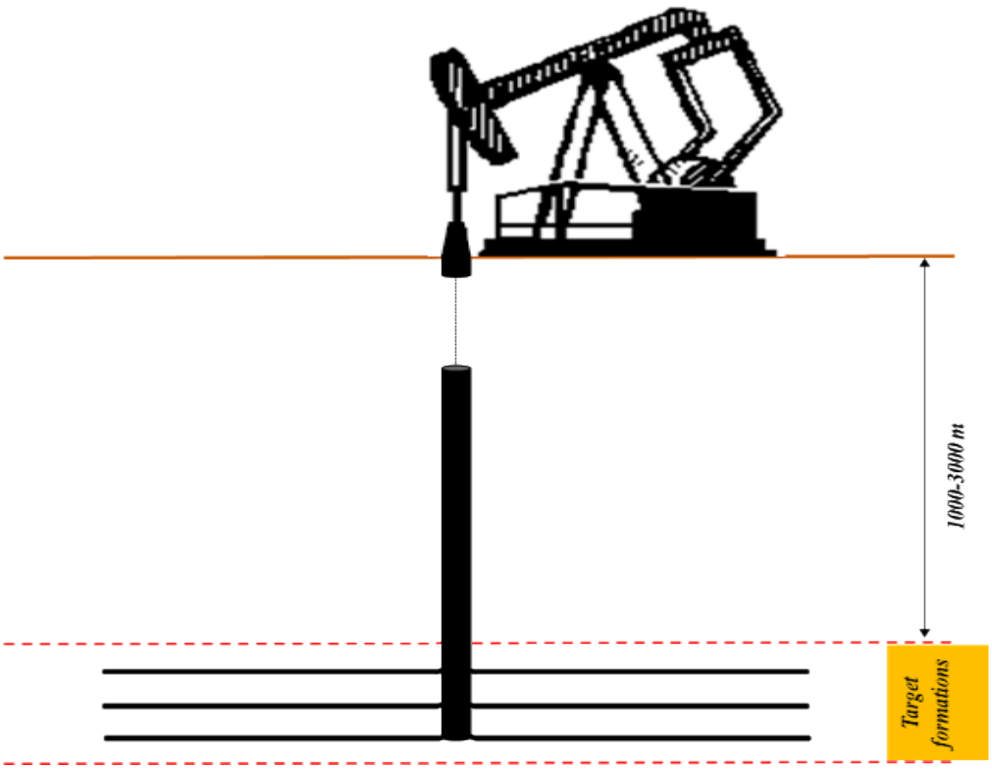
Adapted from: Johnson & Johnson (2012).

For the most part, the geology of the target reservoir determines the stimulation used, as each type of stimulation has a specific geological environment in which it will most successfully propagate fractures, due to the sensitivity of shale formations to specific fracturing fluid compositions. Specifically, slickwater stimulations are better suited for more brittle rock such as in the Barnett and do well at great depths; energized slickwater stimulations are better suited for semi-brittle rock such as in the Marcellus, although the majority of Marcellus wells are slickwater; and energized stimulations are better suited for less brittle rock such as in Haynesville and do not do well at great depths (Johnson & Johnson, 2012). Also, more saline fluid is better suited for formations with higher clay content to minimize clay swelling and formation damage, though higher salinity could decrease the *imbibition* rate and amount of hydrocarbon recovery (Wang, Butler, Liu, & Ahmed, 2011a and b). In the case of multi-lateral horizontal wells where a single well pad may produce oil or gas from a number of formations with different rock compositions (see Figure 2.1), the chemistry of the fracturing fluid must be chosen to minimize damage across all the affected formations (Zhang, Wang, & Butler, 2013). In addition to the specific geology, cost influences the type of stimulation chosen; slickwater stimulations are the most economical, and thus will likely be chosen if appropriate for the geological environment in question. The exact makeup of the fluid may be proprietary information, and thus the exact chemicals and amounts used can vary greatly among operators; while only up to a dozen chemicals are likely combined for a particular fracturing fluid, there are at least 750 chemicals from which this dozen can be chosen (CCA, 2014).[6] To give a general sense of the mass of chemicals used in slickwater fractures, as slickwater is the most common type of stimulation used, in 20,000 m^3 slickwater fluid, typically "there is approximately one and

[6] This figure comes out of the study done by the U.S. House of Representatives Committee of Energy and Commerce in 2011, which documented all of the chemicals used by over 2,500 service companies in North America between 2005 and 2009.

a half million kilograms of proppant, 100 cubic metres of acid, 1,000 kilograms of friction reducer, 900 kilograms of disinfectant and 0.3 cubic meters of corrosion inhibitor" (CCA, 2014, p. 54).[7]

Figure 2.1. Schematic view of multi-lateral horizontal wells within a target formation..



The overall water use for an individual well is dependent on the number and length of the stages of the well, and the number of times that well is stimulated (i.e. on the number of *completions*) (Johnson & Johnson, 2012). Due to the high expense of the hydraulic fracturing process, the production of a single well is usually optimized by initiating hydraulic fracturing as close as possible to the end of the well then moving closer to the wellhead and stimulating/completing successive sections, one at a time. Each stage produces wastewater. As an example of water volume used for hydraulic fracturing, a well in the Montney requires between 200 m^3 and 4,600 m^3 water for a single stage, while a single well in the formation may need 800 m^3 to 13,000 m^3 water total for hydraulic fracturing, depending in part on the number of stages (Johnson & Johnson, 2012).

Lastly, water is used during the initial drilling process, prior to hydraulic fracturing. Generally referred to as *drilling mud*, this water is used to cool down and assist the drill bit when the well is first being drilled, and, compared to the amounts of water used in the hydraulic fracturing process, is a relatively small amount of water. However, some of this water does return to the

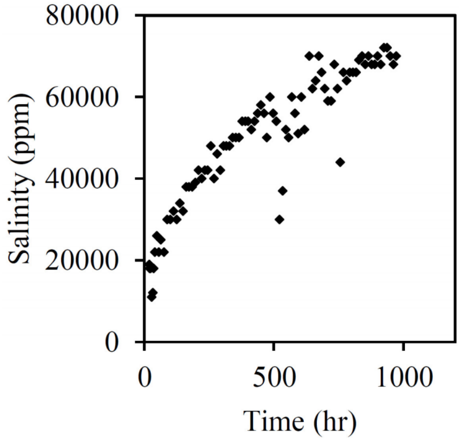
[7] These figures are metric conversions of the imperial figures given in King (2012), for a typical four million gallon slickwater stimulation.

surface (often referred to as *drilling fluid*) and must be handled, and thus for our purposes is considered wastewater. The amount of water actually used for drilling is often not explicitly recorded or reported and so it is difficult to differentiate from the overall wastewater reporting (Lutz et al., 2013)

2.3 Wastewater from Hydraulic Fracturing

After stimulation, wells may be immediately flowed or left for a time known as the *shut-in period* (also referred to as "soaking time"; King, 2012). This period allows water to imbibe into the shale rock, which subsequently expels gas (and oil, if present) from the shale matrix into the fractures, and increases the gas production rate (King, 2012; Lan, Ghanbari, Dehghanpour, & Hawkes, 2014). After the shut-in period the wells are put into production. At this time, a portion of the water used for the hydraulic fracturing process returns to the surface, with the amount and chemical composition depending on the type of stimulation, original source of water (fresh, saline, or recycled), geology, and what stage the well is at. This water is called flowback, and in Canada "is a potentially hazardous waste because it typically contains hydrocarbons including variable amounts of benzene and other aromatics, fracturing chemicals, and potentially hazardous constituents leached from the shale," such as salts, metals, metalloids, and naturally occurring radioactive materials (NORMs) (CCA, 2014, p. xiv). As mentioned in the previous section, the general makeup of the fluid used for hydraulic fracturing is characteristic of one of the three common types of stimulations. While not all of these chemicals necessarily return to the surface, a portion of the original chemicals will return with flowback water. Furthermore, with subsequent stages and time, the chemistry of the flowback water from a particular well will change, with higher/lower concentrations of certain stimulation chemicals and new chemicals produced from inter-well reactions between, for example, the stimulation chemicals, the formation, and the formation fluids (Bearinger, 2014; Zolfaghari Sharak, Noel, Dehghanpour, & Bearinger, 2014; Zolfaghari Sharak, Ghanbari, Dehghanpour, & Bearinger, 2014). In general, the initial volumes of flowback water have lower salinity than later flowback water (see Figure 2.2). Depending on the geology of the reservoir, the wastewater being produced may be hyper-saline, resulting in the precipitation of salts that could impede the production of the well. Thus, wells with such salty conditions (*e.g.* in the Bakken) might require daily flushing with fresh water (called *maintenance water*) over the entire production life-cycle of the well (up to 30 years; Kiger, 2013). The water needed (and wastewater produced) per well may be more than three to four times that of the water initially used for the hydraulic fracturing process (Kiger, 2013).

Figure 2.2. A typical flowback water salinity profile during the flowback process for a well completed in the Horn River Basin, British Columbia.



Source: Zolfaghari Sharak et al. (2014b).

Aside from flowback water from the hydraulic fracturing process, water also returns to the surface during the production phase of a well (i.e. after the fracturing is complete) at the same time as the shale gas or oil, called *produced water*. This water may include traces of *maintenance water* (discussed in the previous section), and water naturally present in the targeted reservoir (called *formation water* or *in situ brine*). Similar to the flowback water, produced water will likely contain some of the chemicals originally present in the stimulation fluid, as well as potentially hazardous contaminants leached from the reservoir itself and new chemicals produced from inter-well reactions (Lutz, Lewis & Doyle, 2013). Although often considered to be different types of water by industry and/or regulators, ultimately all flowback and produced waters are recognized by regulators and industry as wastewater, and ultimately require treatment or disposal. Furthermore, as previously mentioned, some of the water used for initial drilling (*drilling fluid*) must be handled, and thus for our purposes is also considered wastewater, though it is often not included in wastewater reporting (Lutz et al., 2013). In the remainder of this chapter and report, *wastewater* will thus refer to all types inclusively.

2.3.1 Wastewater Management

Due to the variability in the amount and chemical composition of wastewater between wells, as well as factors including the variability in a region's geology, available facilities, and regulations, not all wastewater management practices are equally appropriate for individual shale plays in North America. Additionally, each wastewater facility may be unable to accept all of the hydraulic fracturing wastewater from its respective region; because these facilities continuously receive wastewater from different companies, well-pads, and often other industries, the volumes as well as concentrations and ratios of contaminants may vary over large ranges, affecting their ability to process more wastewater during particular periods. Furthermore, the dependency of the chemistry of wastewater on time also factors into the development of appropriate wastewater management practices. For instance, if the concentration of a specific contaminant changes during the flowback process, a particular wastewater treatment method initially may be effective to treat the flowback water, but insufficient at later times. As such, a variety of wastewater management practices are used throughout the shale plays in North America. In general, the practices can be divided into four categories: surface disposal, reusing/recycling, treatment, and deep-well injection. Before any of these practices are employed, the wastewater must be handled to some degree, i.e. stored and/or transported. While handling is a necessary part of wastewater management, the exact methods vary greatly between operators, and information regarding such is either not well documented or publicly accessible. Lined ponds at the drilling site, storage tanks, C-rings, and movement via pipelines are prevalent methods of temporary storage of wastewater if needed, and trucks remain the primary method of transportation for the entire hydraulic fracturing process in general, including wastewater handling.

2.3.1.1 Surface disposal

Due to the potential toxicity of the wastewater, existing guidelines in Canada and the U.S. either strictly regulate (e.g. in the Marcellus; see section 3.6.2.4) or completely prohibit the discharge of wastewater directly to surface water. Likewise, while some jurisdictions in the U.S. allow surface disposal of produced brines by spreading on roads (*e.g.*, the New York State Department of Environmental Conservation and Pennsylvania Department of Environmental Protection allow for the road spreading of produced wastewater, but not flowback, from conventional, low volume hydraulic fracturing as late as 2014), this practice is not legal for wastewater from any of our four focus plays. As such, this category of wastewater management is not discussed at length in our report. Some wastewater may be released through accidental spills and discharges; however, disposal via these accidental methods are not well documented in the literature, and thus are not considered under the heading of wastewater management in this report. Regulators treat these intentional or unintentional fluid spill offences seriously, document them, and take compliance actions as needed.

2.3.1.2 Reusing/recycling

With the high volumes of water needed for hydraulic fracturing activities, sourcing water may prove to be a problem in the future, particularly when there are competing water users in the same area and/or a scarcity of water. As Freyman (2014) discusses, almost half of the wells hydraulically fractured in the U.S., British Columbia, and Alberta between 2011 and 2013 were in regions with high to extreme water stress, with over 55% of those wells being in areas experiencing drought.[8] Therefore, *reusing* and/or *recycling*[9] wastewater for use in subsequent hydraulic fracturing stages is a useful and economic practice to mitigate water sourcing, transport, and wastewater disposal issues, as well as cost, particularly if the turnover can be done on-site.

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[8] Freyman's study consists of 1,341 wells in British Columbia and Alberta and 39,294 in the U.S., with data for the British Columbia wells dating to December 2011-July 2013; for the Alberta wells dating to December 2012-July 2013; and for the U.S. wells dating to January 2011-May 2013. For the Canadian wells, 8% were found to be in areas of high to extreme water stress; for the U.S. wells, 47% were (Freyman, 2014). *Water stress* is defined by Freyman as a metric that indicates the level of competition for water in a certain area, comparing the total annual water withdrawals to the amount of water available.

[9] As noted in Chapter 3, there is some debate as to what *reuse* and *recycle* mean exactly. For our purposes, *reuse* is assumed to mean that little or no treatment is applied to wastewater before using again in subsequent fracturing stages, and *recycle* is assumed to mean some form of treatment is necessary before using again (treatment which produces some amount of concentrated waste for disposal) (Nicot et al., 2014a). However, it should be noted that when these terms are used in the literature, they may be used with different definitions, and thus, for example, Chesapeake's claim of 100% *reuse* is stated here as 100% *reuse/recycle.*

There is increasing interest toward reusing/recycling wastewater, and many different techniques have been developed to separate the water from the wastewater (e.g. evaporation/distillation, chemical precipitation, chemical conditioning, blending, filtering, gravity settling, flocculation/coagulation, reverse osmosis, electro-coagulation; Johnson, 2012), resulting in water that can again be used in subsequent hydraulic fracturing stages, and a smaller amount of concentrated waste or sludge to be treated/disposed. In some cases, wastewater could be directly reused with little to no treatment in the same well, or in a well in a different formation, depending on the wastewater chemistry (particularly the salinity) and its compatibility with the formation in question. Some operators report that they reuse/recycle nearly all of their produced water in certain areas (e.g. Apache in the Permian Basin and Chesapeake in the Marcellus; see Freyman, 2014; Driver & Wade, 2013; EPA, 2011). However, it is often not possible to reuse or recycle wastewater, depending on the salinity and overall chemistry of the wastewater (e.g. water up to 25,000 ppm can be reused, above 25,000 ppm can often be reused with the addition of particular friction reducers; Johnson, 2012), the volume of the wastewater to be handled, the development stage of a well, and the operator (Broomfield, 2012). Furthermore, a play's production/season timeline could impact the amount and source of water consumption; in the times of water shortage and drought, water is primarily allocated to municipalities and agricultural activities, and seasonal or temporary water withdrawal permits may force operators to employ different recycling/withdrawal plans at different times (Precht & Dempster, 2012). Furthermore, as recycling (and possibly reusing) requires some form of treatment, which adds to the overall cost of development, employing such a practice may in the end come down to economics; "[m]ost operators, especially in drier regions, don't recycle water because of the availability of deep well injection sites where hydraulic fracturing wastewater can be disposed of at almost no cost (excluding trucking costs)" (Freyman, 2014, p. 41). Therefore, it is estimated that the highest formation-wide reuse/recycling rate is about 56% (in the Marcellus; Lutz et al., 2013; Freyman, 2014), compared to only 5% of water used for hydraulic fracturing in the Barnett in 2011 was reused/recycled water (Nicot et al., 2012).

2.3.1.3 Wastewater treatment

Before recycling wastewater for reuse in subsequent hydraulic fracturing stages, recycling for use by another user (e.g. another industry), or some forms of disposal (e.g. discharge into surface water), wastewater may require treatment to reduce the salinity and/or remove some or all of the chemicals present from the stimulation fluid, inter-well reactions, and chemical mixing with formation brines. Also, as some locations are not suited for deep-well injection (e.g. if the geology and/or regulations do not allow for the injection of large quantities of water; if disposal wells are not at a convenient distance), treatment may be the only option for wastewater management. For such treatment, there are three general types of treatment facilities, one or more of which may be used to treat the wastewater of a single well: a standard municipal sewage plant, an off-site industrial treatment plant (i.e. a facility specifically devoted to industrial wastewater), or on-site equipment. Note that after all types of treatment, there will typically be a smaller amount of sludge or solid waste leftover that must be disposed of itself. This waste is either treated until it is considered non-hazardous, or directly shipped to a hazardous waste landfill. This report does not address disposal of that resulting solid waste.

For plays near urbanized areas, wastewater treatment may occur at a municipal sewage plant. However, treatment in a municipal sewage plant is not allowed in many jurisdictions and has increasingly fallen out of favour because of incomplete treatment. Just as some hydraulic fracturing equipment can be made less effective by processing wastewater with a high level of total dissolved solids (TDS), a municipal sewage plant's biological wastewater treatment process may be less effective when dealing with high TDS wastewater, particularly in large amounts such as would come from a hydraulically fractured well (NYSDEC, 2011). More specifically, municipal wastewater facilities usually do not encounter the type of chemistry resulting from the mix of injected hydraulic fracturing fluids, dissolved salts/shale constituents, in situ formation brines, and/or ion exchange with or leaching from clay minerals, which may be present in wastewater from a hydraulically fractured well. Also, as municipal sewage plants generally discharge their treated water into surface water bodies, and as such facilities may not be equipped to remove certain chemicals that are not permitted in a municipal sewage plant's discharge (e.g. barium, strontium, bromides, NORMs) and/or may be located by surface water bodies with already high ambient levels of TDS, a municipal sewage plant may be unable to accept wastewater from hydraulic fracturing (NYSDEC, 2011; Howarth, Ingraffea & Engelder, 2011). As such, if a municipal sewage plant can handle the large volume of wastewater from a hydraulically fractured well, is allowed to accept it under the governing regulations and is the only available option, wastewater may need to be pre-treated before it is sent to the plant (Broomfield, 2012). Such pre-treatment would presumably happen on-site (discussed below).

Commercial industrial wastewater treatment facilities are an increasingly popular option for certain operators, whether operated directly or by a third-party operator. These facilities are typically in centralized locations, and have cutting-edge technologies created especially to treat high TDS waters such as the wastewater from hydraulically fractured wells. An example of this is Encana's Neptune Water Treatment Facility, currently being constructed in Wyoming for produced water from Encana's Fort Union wells. The facility will use filters, chemical treatment, and a reverse osmosis membrane to reduce high TDS levels to drinking water levels (i.e. less than 250 ppm; Encana, 2013). While a portion will be reused in field operations, the majority of the facility's treated water (80-90%) will be piped to the Boysen reservoir in central Wyoming (Stastny, 2014). Facilities such as these, however, are a relatively new concept, and thus are few and/or still in development (roughly just over a dozen exist in North America; Easton, 2013). Furthermore, these facilities may be available only for the companies that build them, and thus are not a widely used option.

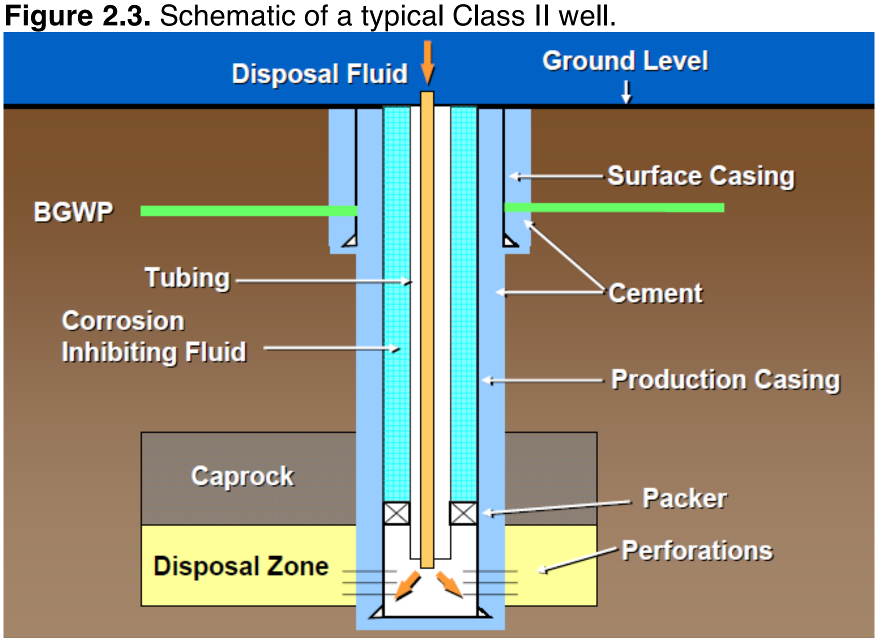
On-site or mobile wastewater treatment facilities are another primary option for wastewater treatment, in which treatment equipment is at or near the well-pad. A similar suite of processes such as those mentioned in the previous section on recycling are employed when wastewater is treated on-site before sending for disposal or reuse elsewhere. Treatment decisions are based on the needs of the operator, the requirements of the end user or wastewater receiver, and the available technology. Typically, on-site treatment is used to reduce the TDS of the wastewater. With evaporation, the resulting treated water is usually pure enough to allow it to be discharged to surface waters (Yoxtheimer, 2012). Chemical precipitation could also expedite the removal of ions and suspended particles from wastewater (Yoxtheimer, 2012). As with the exact type of treatment equipment used, the availability of on-site treatment equipment is dependent on the region and operator.

2.3.1.4 Deep-well injection

Although there is an increasing interest towards reusing/recycling wastewater from hydraulic fracturing, the high costs of treatment and/or the isolated location of a hydraulically fractured well may make deep-well injection the most attractive method of wastewater disposal. This method involves permanent disposal via injection into a formation, typically in the same region as the hydraulically fractured well. Yet not all formations are appropriate for deep-well injection (e.g. the Marcellus), as the respective formation must be able to accommodate large volumes of fluid (typically, this means a depleted oil/gas reservoir, or a saline aquifer), and must be at an adequate distance from non-saline aquifers and oil/gas wells (CCA, 2014). Therefore disposal wells may be the best or only option even if far from the shale gas wells (as is the case in the Marcellus), and extensive transport to the disposal wells via tanker trucks may be an operator's only choice. In the U.S., there are approximately 150,000 active disposal wells (AWWA, 2013); in British Columbia and Alberta, there are 11,497 wells (see section 2.5.3.2).

Deep-well injection is highly regulated, and typically requires a specific type of well, a *Class II well*, which is usually owned and operated by a disposal service company or operator-owned (Freyman, 2014). This type of well must protect the non-saline groundwater zone it passes through and the disposal zone with cement, casing, tubing and isolation packer (see Figure 2.3). Regulations vary by jurisdiction; for example, in Alberta hydraulic fracturing flowback wastewater is considered oilfield waste that must be disposed of in a Class Ia or Ib well.

Figure 2.3. Schematic of a typical Class II well.



Source: Parks (2005).

2.3.2 Well/Site Abandonment and Residual Treatment Water

This report defines as wastewater those fluids which must be handled, treated or disposed of at the surface. However fracturing fluid lost to the reservoir could also be considered as part of the total pool of wastewater associated with fracturing operations. Chemical analysis of fracturing fluid could help to identify the fate of the remaining fracturing fluids in the reservoir and its possible impacts on nearby shallow aquifers and water bodies. Depending on the hydraulic properties of the fractured reservoirs, up to 95% of the injected hydraulic fracturing fluid may not return to the surface as flowback (King, 2012; Ghanbari, Abbasi, Dehghanpour, & Bearinger, 2013; Fan, Thompson, & Robinson, 2010). There is public concern that these remaining fracturing fluids may have the potential to cause environmental problems after a well or drilling site is abandoned; several previous studies have addressed potential environmental impacts associated with well/site abandonment (e.g. Broomfield, 2012; Goldman et al., 2013; Myers, 2012; Rozell & Reaven, 2012). For example, it has been proposed that hydraulic fracturing fluids could migrate along abandoned wells, through natural fractures and other naturally occurring pathways, or along the outside of active wells with faulty cement jobs (e.g. Goldman et al., 2013; Myers, 2012; Rozell & Reaven, 2012). As early as 1987, the U.S. Environmental Protection Agency (EPA) expressed that fracturing activities near Jackson County in West Virginia had contaminated the drinking water wells from fracturing fluid migrating from nearby abandoned wells to a drinking water aquifer (EPA, 1987). However, controversy has since surrounded the content and interpretation of this report (e.g. Urbina, 2011; *The New York Times*, n.d.).

Although hydraulic fracturing activities have raised concerns about groundwater contamination, several scientists believe that upward migration of fracturing fluid from the zone of hydraulic fracturing is too slow or not plausible to be a concern for contamination of shallow aquifers (e.g., CCA, 2014) . Flewelling and Sharma (2014), stated that hydraulic gradient and permeability of the bedrock control the upward migration of hydraulic fracturing fluid and that, where there is an upward gradient, it would take millions of years for fracturing fluid to migrate to near the surface. Engelder, Cathles, and Bryndzia (2014), argue that capillary and osmotic forces propel any residual fracturing fluid into the rock matrix, where it will permanently remain and never reach shallow water tables. Controversy about the fate of hydraulic fracturing fluids in the vicinity of the well bore is still ongoing, however. This topic is dealt with specifically in a parallel CWN sponsored study and will not be further considered.

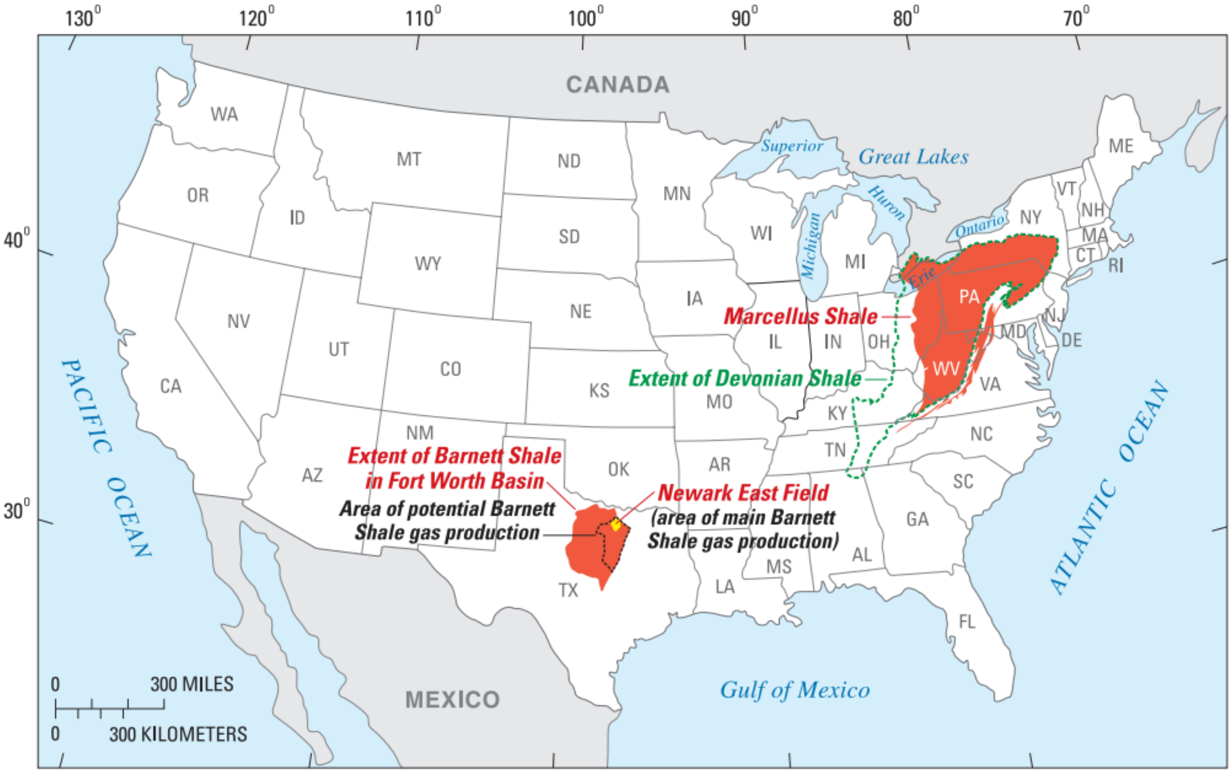
2.4 Wastewater Production and Treatment Practices in the Focus Formations

As mentioned in the above sections, the amount of wastewater produced and how it is managed is highly variable from well to well and formation to formation. In this section, we will discuss the general trends in wastewater production and management in each of our four focus formations. If practices specific to our focus formations are noted in the literature, they will be mentioned below. Generally, lined ponds at the drilling site, storage tanks, and C-rings are the most common method of temporary storage of wastewater if needed, and trucks are the primary method of wastewater transportation.

2.4.1 Marcellus

The Marcellus shale formation is mainly located across Pennsylvania, West Virginia, and New York (see Figure 2.4). In terms of both gas-in-place and area, the Marcellus is the largest shale gas deposit in the U.S., accounting for 29-55% of the U.S.'s reserves (Lutz et al., 2013). Since 2010, the Marcellus has been the biggest producer of shale gas in U.S. covering about 10% of the total natural gas domestic needs (Lutz et al., 2013).

Figure 2.4. The Marcellus and Barnett shale formations.



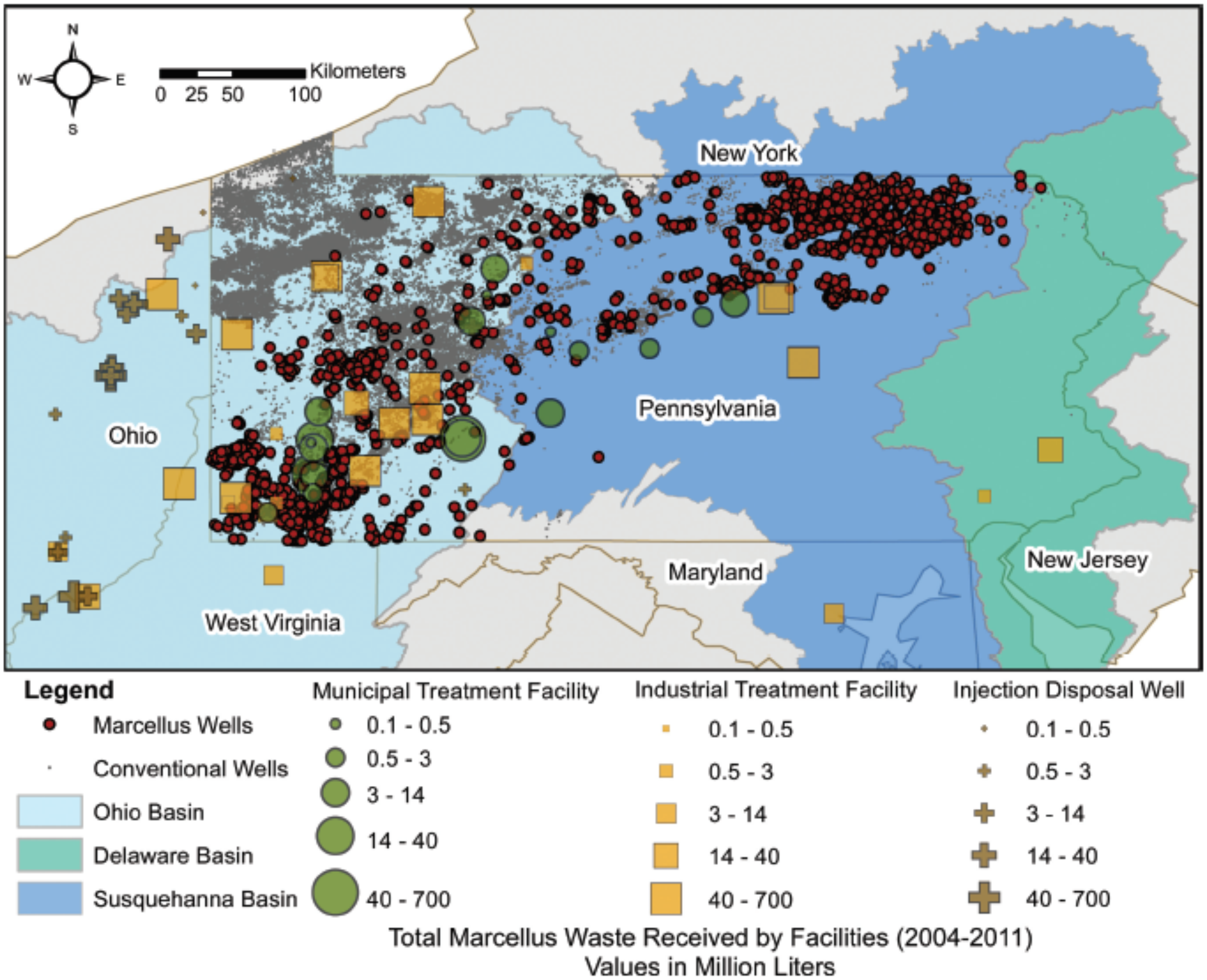
Source: Bruner & Smosna (2011).

With such a vast size and degree of development, it follows that the Marcellus is one of the largest water users among all the shale formations in North America, and subsequently one of the largest producers of cumulative wastewater from hydraulic fracturing activities.[10] A variety of different stimulation methods (slickwater, energized, and energized slickwater) are used for hydraulic fracturing in the Marcellus, and so a well in the region may require anywhere between 2,000 – 12,000 m^3 of water for its hydraulic fracturing operations (Fontaine, Johnson, & Schoen, 2008; Patel, Robart, Ruegamer, & Yang, 2014; Arthur, Uretsky, & Wilson, 2010). In a study quantifying the wastewater produced from 2,189 active wells in the Marcellus from 2004 to 2011, due to the exponential increase in the amount of new hydraulically fractured wells being drilled in the area, Lutz, Lewis, and Doyle (2013) showed that the cumulative volume of wastewater generated was also increasing exponentially, with the amount generated in 2011 (3,144,300 m^3) approximately 1,000,000 m^3 more than the total generated in 2010; Lutz et al. (2013) predicted that, in 2014, the cumulative total would be 5,370,000 m^3/yr. According to data

[10] According to Freyman (2014), the Marcellus is the second top user of water in the U.S., with the Eagle Ford formation using the greatest amount of water.

from studies dated from 2011-2013, the approximate volume of wastewater produced per well in the Marcellus is 11,500-26,500 m^3 (see Table 1.1).[11]

Figure 2.5. Map of wells, disposal facilities, and wastewater management in the Marcellus, from 2004-2011.



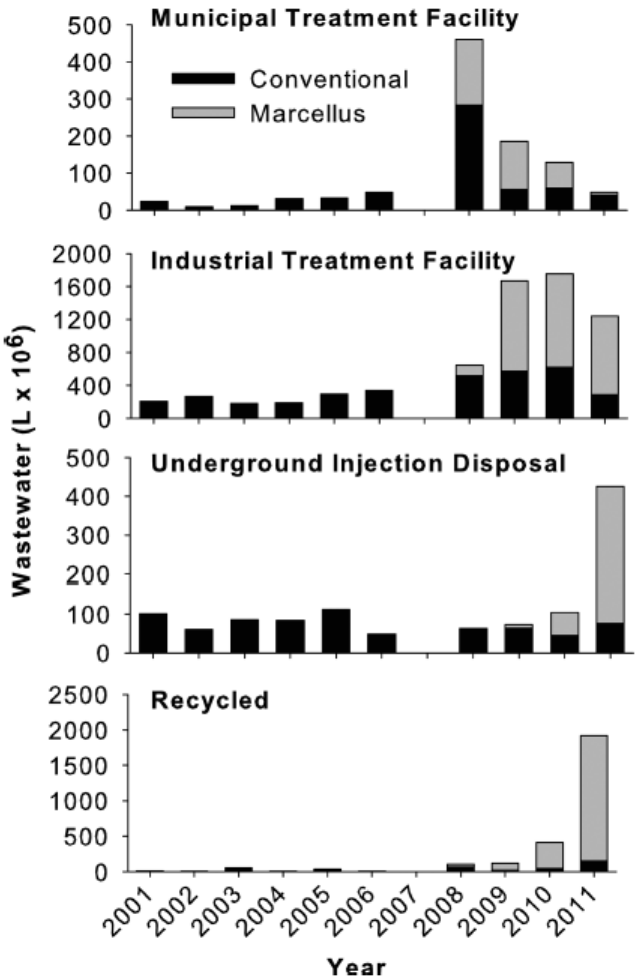
Source: Lutz et al. (2013).

[11] Lutz et al. (2013) estimated that each hydraulically fractured well in the Marcellus produced on average 5,211 m^3 wastewater. From this total, 654 m^3 was wastewater from drilling, 1,683 m^3 was technically classified as flowback, and 2,874 m^3 was technically classified as produced water or brine, generated during the first four years of the well (Lutz et al., 2013, p. 652).

With an increase in generated wastewater comes the increased problem of how to manage that wastewater.[12] As previously mentioned, most of the geology of the Marcellus is not conducive to deep-well injection. Furthermore, disposal wells in the formation are located almost solely in Ohio, whereas the majority of the hydraulically fractured wells are located in northeast and southwest Pennsylvania (see Figure 2.5). As such, municipal treatment facilities, which are spaced more evenly throughout the formation, received the majority of hydraulic fracturing wastewater from the Marcellus at the beginning of shale gas development. However, following the imposition of stricter discharge limits, it soon became clear that such facilities were not equipped to deal with the high volumes and elevated TDS levels of the wastewater. Wastewater processing by municipal facilities quickly declined after 2008, and essentially stopped in 2011 following a request from the Pennsylvania Department of Environmental Protection to cease processing and discharge of wastewater from shale gas operations. Between 2008 and 2011, more wastewater was thus processed in industrial waste facilities, which are mostly located in western Pennsylvania (see Figure 2.5). However, when more stringent regulations on TDS levels of effluent (<500 mg/L TDS) were passed in Pennsylvania in 2011 (discussed in Chapter 3, section 3.6.3), industrial facilities also became unable to handle the high TDS levels of hydraulic fracturing wastewater. As such, the amount of wastewater dealt with via municipal treatment facilities has decreased since 2008, and via industrial treatment facilities since 2011; at the same time, reusing/recycling and deep-well injection increased dramatically (Lutz et al., 2013; see Figure 2.6).

[12] The use of ponds for temporary wastewater storage in the Marcellus is not clear in the literature. For example, Easton (2013) stated that during the previous two years, Pennsylvania had "completely eliminated the use of surface ponds for wastewater storage"; there was no indication in the article as to what handling method had been used since. Then in Phillips (2014), it was noted that the number of ponds in Pennsylvania had increased from eleven in 2005 to over five hundred in eight years. However, this data came from aerial images, and it is not known which are used to hold fresh versus wastewater, or which are currently used.

Figure 2.6. Wastewater management practices used for conventional and unconventional wells in the Marcellus, from 2001-2011.



Note: The incompatibility of treatment of unconventional flowback wastewater in municipal treatment facilities is evidenced by the dramatic decline in treatment at these facilities from 2008 to 2011.
Source: Lutz et al. (2013).

Today, deep-well injection and, to a lesser extent, reusing/recycling (via centralized industrial or on-site/mobile wastewater treatment facilities) remain the main wastewater management practices in Marcellus. While some Marcellus operators claim 100% reusing/recycling (e.g. Chesapeake, as mentioned above in section 2.3.1.2), the amount of wastewater reused/recycled is highly variable across operators, and may only be feasible as long as “the number of new wells being constructed outnumbers those in production (such that demand for recycled wastewater is high)” (Lutz et al., 2013, p. 655). A more realistic rate of wastewater reusing/recycling for the region may be around 56% (Lutz et al., 2013).[13] As for deep-well injection, the geology of Pennsylvania and West Virginia does not allow for underground disposal. As such, wastewater

[13] This figure is from 2011 data.

from hydraulically fractured wells in these states is usually transported via truck to Ohio, where there are 184 injection wells (Lutz et al., 2013).

2.4.2 Barnett

The Barnett shale formation is located entirely in the state of Texas, near the Dallas-Fort Worth region (see Figure 2.4). Of our four focus formations, its shale gas resources have been developed the longest and, until it was replaced by the Marcellus in 2010, it was the most productive shale gas field in North America.

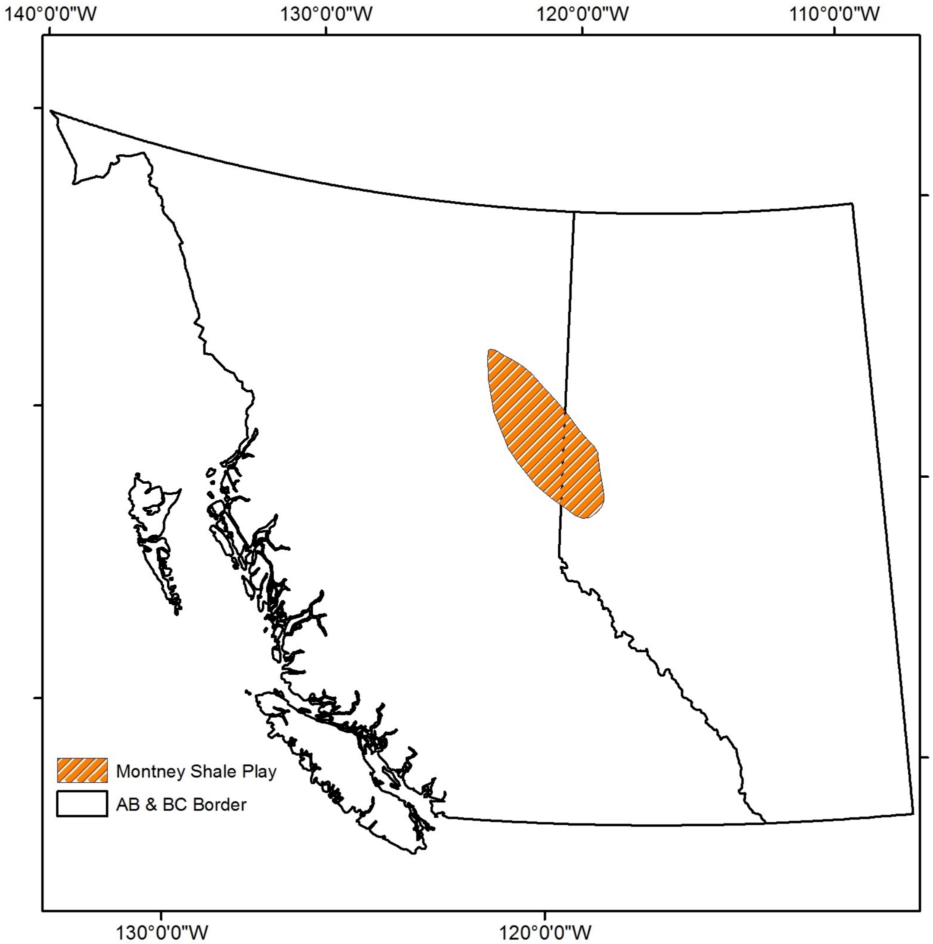
In water-sensitive shale formations, water absorption and clay swelling can cause wellbore collapse [136]. In the past, there were fears that the Barnett would be water-sensitive, and so low-water fracture fluid was used for roughly the first twenty years of shale gas development; however, since studies indicated that the shale is not water-sensitive, slickwater fracturing, which has the highest water consumption rate, has been widely used in this formation (e.g. Martin & Weiss; Kuuskraa, 2010). Each well in the Barnett typically uses between 3,000 to 14,000 m^3 of water for its hydraulic fracturing operations (Nicot, 2009). According to data from studies dated from 2011-2013, the approximate volume of wastewater produced per well in the Barnett is 10,600 m^3 (see Table 1.1).

In the Barnett formation, nearly half of the produced wastewater from hydraulic fracturing operations is initially stored in surface ponds (Easton, 2013). From there, the majority is disposed of via deep-well injection, as this is the most economical and convenient option for the majority of the state. There are centralized industrial wastewater facilities in the region, such as Aqua-Pure's plant which treats hydraulic fracturing wastewater to be recycled for future fracturing operations (Aqua-Pure, n.d.). Because of the dry climate and limited water resources, there is a constant threat of drought in the region, which would potentially increase the demand for recycling, at least in theory (Horner, 2006); however, as previously mentioned, of the water used for hydraulic fracturing in the Barnett in 2011, only about 5% came from reuse or recycling, suggesting that the practice is still rather uncommon (Nicot et al., 2012).

2.4.3 Montney

The Montney formation extends along the Alberta-British Columbia border (see Figure 2.7). This formation consists primarily of fine siltstones and is not a true shale. Development initially commenced with limited vertical wells in 2001, switching to horizontal wells with large fracture stimulations in 2005 and has since quickly grown. The majority of the initial gas-in-place is located in British Columbia, and so the majority of gas produced from this formation comes from the wells which lie on the British Columbia side of the border; in fact, about 85% of the new wells being drilled in British Columbia lie within the Montney Formation. According to the National Energy Board, it is estimated that gas from the Montney alone could meet Canada's needs for 145 years (Government of Alberta, 2013, p. 6).

Figure 2.7. The Montney shale formation.



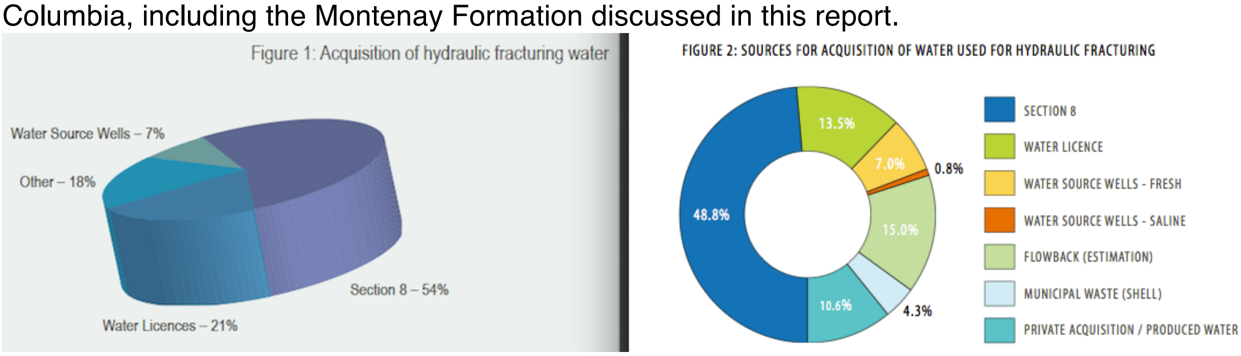
Of the shale formations being developed in northeast British Columbia, where the majority of shale development occurs in Canada, the Montney uses the least amount of water, due to energized fracture fluid being the most common type of stimulation used in the region's wells. Johnson and Johnson (2012) analyzed data from hydraulically fractured wells in northeast British Columbia wells up to 2010, for wells fractured via energized fracture fluid, the average water use per well is 1,900 m^3, or 250 m^3 per stage; for wells using a slickwater or energized slickwater fracture fluid (the common types of stimulation for the few wells in the northern part of the formation), the average water use per well is 7,800 m^3, or 1,000 m^3 per stage (Johnson & Johnson, 2012). Water use in at least the British Columbia portion of the formation seems to have dramatically increased since then. In 2013, an average of 8,356 m^3 per well was used in the Heritage Basin region of the Montney formation, and 10,907 m^3 per well in the north area of the formation, with a total of 3,869,942 m^3 of cumulative water use across the formation (BCOGC, 2013).[14] Our investigation of the FracFocus database (see Section 2.5.3.1) indicated that the average cumulative water consumption for the hydraulically fractured wells up to March 2014 in Alberta and British Columbia are 3,990 and 10,430 m^3/well, respectively. According to data

[14] For 2012, an average of 6,684 m^3/well was used in the Heritage Basin, 10,053 m^3/well in the north area, and 2,737,412 m^3 total was use (BCOGC, 2013).

from studies dated from 2011-2013, the approximate volume of wastewater produced per well in the Montney is 10,000-25,000 m^3 (see Table 1.1).

In British Columbia, the wastewater produced from oil and gas exploration/extraction is either disposed of in approved disposal wells or is treated in water treatment facilities for reuse (BCOGC, 2014); in Alberta, as discussed in the following section, hydraulic fracturing wastewater cannot be treated in municipal treatment facilities, and must be disposed of in approved disposal wells (Rokosh et al., 2012). Though the number of companies who are interested in recycling hydraulic fracturing wastewater is increasing, the volumes of water reused or recycled are uncertain. According to the 2012 annual report on water use from the British Columbia Oil and Gas Commission, 18% of water used for hydraulic fracturing consisted of "other sources, including increased use of flowback and produced water recycling" (BCOGC, 2012, p. 10); according to the 2013 report, an estimated 15% came from reused flowback water, and recycled produced water was grouped together with water from private acquisition, collectively making up 10.6% of the water used that year (BCOGC, 2013; see Figure 2.8). With the difference in categories over the two reports, it is difficult to determine whether there has been any recent increase in the use of either reused or recycled water in hydraulic fracturing operations.

Figure 2.8. Hydraulic fracturing water source graphics from BC Oil and Gas Commission's 2012 and 2013 annual water use reports. Includes all water use for hydraulic fracturing in British Columbia, including the Montenay Formation discussed in this report.

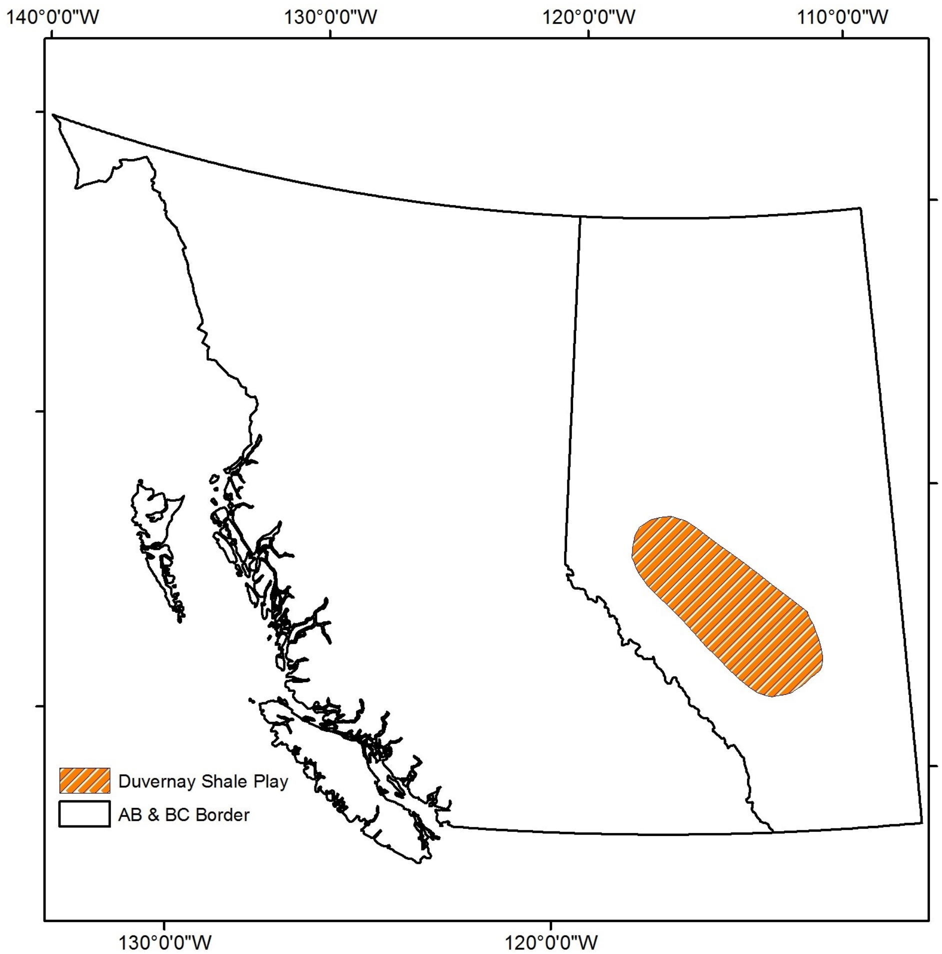


Note: 2012 pictured on the left, 2013 on the right.
Sources: BCOGC (2012 and 2013).

2.4.4 Duvernay

The Duvernay shale formation is located entirely in the province of Alberta (see Figure 2.9). While the amount of produced natural gas from the Duvernay shale is much less than that of Montney, the region's wet gas has made it an active liquid-rich shale play in the province (Rokosh et al., 2012).

Figure 2.9. The Duvernay shale formation.



A variety of stimulation methods (slickwater, energized, and energized slickwater) are used for hydraulic fracturing in the Duvernay (Packers Plus, 2014; Wasylishen & Fulton, 2012). Some companies that are active in the Duvernay formation have been trying to reduce their freshwater usage by using alternative water sources such as municipal wastewater, nitrogen foams, and recycled hydraulic fracturing wastewater (e.g. Encana, 2013; Canyon, 2011). While this may alter the water chemistry and amount of water used in hydraulic fracturing (and thus the chemistry and amount of resulting wastewater), it is unknown to what extent such sourcing practices occur across the play. According to data from studies dated from 2011-2013, the approximate volume of wastewater produced per well in the Duvernay is 50,000 m^3 (see Table 1.1).

The wastewater handling, treatment, and disposal practices for the Duvernay Formation are not well documented. For the province in general, produced wastewater is not allowed to be treated in municipal wastewater treatment plants (Rokosh et al., 2012). Moreover, if it is not suitable for reuse/recycling or treatment, the wastewater must be disposed of in approved disposal wells (Rokosh et al., 2012).

2.5 Database Analyses

From the data and literature discussed above, a number of general knowledge gaps regarding wastewater management practices for our four focus formations remain, such as: What portion of hydraulic fracturing water is disposed to the surface (whether it be recycled/reused, treated, or deep-well injected)? How does this vary among and within formations? What is the potential impact of the time-dependency and extreme variability of wastewater chemistry on wastewater management? What are the wastewater management practices for the Duvernay shale formation, in particular? In order to identify whether these knowledge gaps were specific to the literature reviewed and not necessarily the available data, we studied hydraulic fracturing data located in three different databases, namely FracFocus, geoSCOUT, and AccuMap. Note again that all three of these databases display publicly-available data, and any one database may not contain all of the available reported data. Due to time constraints, we focused on the Duvernay and Montney Formations in Canada for our database analyses. In the sections which follow, we will provide a brief overview of the databases, including a discussion of the particular and shared limitations of the databases, and the previous studies which have used these databases as sources of data. Next, we will identify the knowledge gaps that remain even when armed with these tools. Finally, in light of these limitations, we will discuss the particular database queries we ran for the two focus formations, and any remaining knowledge gaps.

2.5.1 Database overview

Several oil and gas databases contain information about hydraulically fractured wells. FracFocus.org and FracFocus.ca contain information about American and Canadian wells, respectively, that are easily accessible to the public. FracFocus was not intended to be a water or risk management tool; however, play-scale water use data can be extracted by tabulating data from individual wells in the database. In addition to this, we gained access to two of the most widely-used industry databases, geoSCOUT (geoLOGIC systems ltd.) and AccuMap (IHS Inc.), that contain more detailed information than is available in FracFocus, but data that are also available from the regulators to the public. Table 2.2 compares the features available among the three databases, focusing on the accessible data in each.

Table 2.2. Comparison of accessible data in FracFocus, geoSCOUT, and AccuMap databases.

	FracFocus	geoSCOUT	AccuMap
Database coverage	Canada - FracFocus.ca U.S. - FracFocus.org	Canada only	Canada (AB, BC, MB, SK, NT, NU, YT), U.S. (MT, ND, WY) NOTE: Limited according to software license purchased.
Fracture date	last fracture date fracture start/end date	—	—
Start date of production	—	✔	✔
Location of well	province/state longitude and latitude NOTE: Does not specify basin/play.	province/state longitude and latitude	province/state longitude and latitude
Well condition or mode (active/suspended/ abandoned)	—	✔	✔
Operator name	✔	✔	✔
Source of water used	—	—	—
Production type (oil or gas)	✔	✔	✔
Depth of well	✔	✔	✔
Number of stages	✔		✔
Water consumption/production	cumulative water injected	cumulative water production	monthly water production
Hydraulic fracturing fluid composition	component type (carrier fluid, proppant, or additive) trade name of component supplier of component purpose of additive ingredient/family name of component Chemical Abstract Service (CAS) # conc. in component (% by mass) conc. in HF fluid (% by mass)	—	—
Fluid analysis	—	—	gas analysis oil analysis water analysis NOTE: Not consistent for all wells, particularly for water analyses.
Wastewater treatment/disposal practice	—	—	—

2.5.1.1 FracFocus

In 2011, FracFocus.org was launched as a hydraulic fracturing chemical inventory in the U.S., run by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission. On this website, hydraulic fracturing companies can voluntarily report the chemicals used in their hydraulic fracturing operations, as well as other general information specific to each well; at the time of writing, nearly 86,000 well sites were registered on the website. The BC Oil and Gas Commission then developed FracFocus.ca for hydraulic fracturing operations in Canada; since January 1, 2012, companies in British Columbia are required to report the chemicals used in their hydraulic fracturing operations, from December 31, 2012, companies in Alberta have also been required to report to the website (ERCB, 2012b), and the National Energy Board has requested that companies regulated by the Canada Oil and Gas Operations Act also release information about the fracturing fluids on FracFocus.ca (CIT). As seen in our following discussion, there are nearly 5,000 well sites registered on the Canadian website.

For both the U.S. and Canadian versions of the website, all data reported is collected in a single PDF file for each well. This provides an accessibility issue, as readers are limited to open a single PDF file at a time, and cannot simultaneously compare wells. Konschnik, Holden, and Shasteen (2013) noted this problem in their analysis of the database as a regulatory compliance tool, as well as other issues. For instance, the authors also discussed the inconsistencies in the reporting of the same chemicals across PDFs in the database (i.e. different names are used for a single chemical), and how the limited search functions make identifying such inconsistencies a time-consuming task. Their report indicated that 29% of the Chemical Abstracts Service (CAS) numbers reported to FracFocus.org in July 2012 did not exist in the CAS database of over 71 million numbers to identify unique substances. Furthermore, in its current form, it is not possible to search the database for multiple wells across a formation in order to gain a holistic view about the hydraulic fracturing operations in a region; as Konschinik et al. (2013) said, "the limited search function sharply limits the utility of having a centralized data cache" (p. 2). However FracFocus is not designed to act as a hydraulic fracturing management tool.

Aside from the difficulties in searching the well information contained in the PDF files, the FracFocus database provides limited data on the hydraulic fracturing fluid itself, as well as more general information for some wells. Information about the source of water used for hydraulic fracturing (e.g. surface water, groundwater, saline water, or reused/recycled water), the service provider names, basin or play names, wastewater treatment and disposal practices, or well condition (active or abandoned) are not included in the PDFs. Also, as the exact chemical content of fracturing fluids used is considered proprietary information, many specific chemical constituents are not made publicly available. Neither information about flowback volume and its chemistry, nor any information on the amount of wastewater that is reused, recycled, or disposed of per well (i.e. information which is vital from the perspective of wastewater management) are included in the FracFocus database. Moreover, data regarding fracturing stages, license number, region, and operator name are missing for some wells.

2.5.1.2 geoSCOUT

geoSCOUT was initially introduced to the market in 1993, replacing the earlier geoMATE, and these platforms were the first software specifically designed to manage oil and gas geological data (geoLOGIC, n.d.). geoSCOUT is not a public database, but rather is software purchased and primarily used by oil and gas companies as a decision-support tool (geoLOGIC, 2014). In particular, geoSCOUT is a mapping, data management, and analysis software that integrate both public and proprietary oil and gas well data for the Canadian basins.

As with FracFocus, there are limitations to what can be done with geoSCOUT software. Firstly, the software covers information about oil and gas wells only within Canada, limiting the regional extent of any inquiry or study using the software. Also, fluid analysis, particularly flowback water chemistry, is not included in the database; such data is vital from the perspective of wastewater management. Moreover, no information about the source of water used for hydraulic fracturing or the fate of the produced water is available in the database. Furthermore, similar to FracFocus, there are different and inconsistent styles of reporting data to the geoSCOUT database. For instance, the well-mode tag is not consistent across the database and, in our analysis, we identified eighteen different well-mode tags for disposal wells alone (e.g. *WTR Disp*, *LicDisp well*, *Water Disposal*, *Salt disp well*, *drlgdisp well*). With such limitations, the needs of comprehensive searches and comparisons such as ours are not always met by geoSCOUT.

2.5.1.3 AccuMap

AccuMap is a mapping, data management, and analysis software from IHS that contains data for both Canadian and U.S. basins (IHS, 2014). It includes data for approximately 4 million wells in U.S. and 2.5 million wells in Canada. Similar to geoSCOUT, AccuMap is not a public database, but is a software/database subscription that must be purchased. In addition, AccuMap does not verify data accuracy or validity.

The requirement for and resulting costs of software licensing could be a drawback to using AccuMap for a comprehensive study. As full licenses for oil and gas software packages such as AccuMap and geoSCOUT cost tens of thousands dollars per year, universities, small companies, and individual laboratories may have only limited access to the database due to budgetary constraints. For example, in this study, we had access for the Canadian regions we were studying, but for the U.S., we had access only for Montana, North Dakota, and Wyoming. In addition to this regional limitation, the database did not include all the data we were interested in. For example, as with FracFocus and geoSCOUT, AccuMap does not include information about the source of water used for hydraulic fracturing. Although it is possible to filter a map being studied based on the well-mode, there is no filtering option for wastewater disposal wells. Furthermore, the available data are not consistent for wells having the same well-mode label (e.g. gas well). For instance, not all wells have water analysis data; some wells do not report flow rate data if the flow rate was not stabilized during the production; some wells do not have water composition data or report it with differing sampling times; and reported dates are often in different formats (e.g. dd/mm/yyyy vs. mm/dd/yyyy). In order to be able to compare the flowback water chemistry of different wells, the sampling time, and/or produced water volume, the way in which these categories are reported would have to be consistent. Furthermore, there may be an inconsistency in how the identification of wells are reported within the database, as only 4,118 out of the 4,917 wells in the FracFocus.ca database were matched in the AccuMap database. Lastly, just as with FracFocus and geoSCOUT, information on the amount of wastewater that is reused, recycled, or disposed of per well is not available.

2.5.1.4 Previous studies

Perhaps the most comprehensive study based on the FracFocus database was done by Freyman (2014), which was mentioned briefly in our discussion on reusing/recycling. Freyman used FracFocus to analyze the water consumption of 39,294 wells hydraulically fractured in the U.S. between January 2011 and May 2013, and 1,341 wells hydraulically fractured in British Columbia and Alberta, between December 2011 or December 2012 (respectively, due to the provinces' differing start times of reporting on FracFocus.ca) and July 2013. By combining the well data from FracFocus with the water stress indicator maps from the World Resources Institute, Freyman identified a relationship between the cumulative water usage of a developed shale formation and the region's water stress. For the U.S. wells, 47% were found to be in areas of high to extreme water stress; for the Canadian wells, 8% were, with Alberta experiencing much greater stress than British Columbia (Freyman, 2014; also see Romanowska, 2013). At the time of the study, few operators within Alberta and British Columbia were reporting on FracFocus, and "[d]ue to water volume reporting inconsistencies, water use trends could not be analyzed for the Canadian data" (Freyman, 2014, p. 76), illustrating the limitations of the FracFocus database.

To our knowledge, Johnson and Johnson (2012), referred to in the previous section on water usage, is probably the most comprehensive study that uses the geoSCOUT and AccuMap databases. In this study, well information from the OGC Integrated Resource Information System (IRIS) database was combined with data from AccuMap and geoSCOUT to investigate the relationship between water consumption and the stimulation method. Specifically, data dating from 2005 to 2010 for 496 hydraulically fractured wells in northeast British Columbia (primarily those in the Montney and the Horn River Basin) were analyzed, with the results indicating, among other things, that the higher the volume of water consumption, the higher the volume of flowback water produced (Johnson & Johnson, 2012). Also, the study shows that the amount of water used varied widely between the basins studied; as the variability in water consumption was largely based on the geology (i.e., as previously mentioned, the stimulation type chosen is primarily chosen according to the geology), the authors concluded that "water demand can be anticipated regionally through basin geology, treatment style for fracture stimulation and local trends in the completions per well" (Johnson & Johnson, 2012, p. 61). It should be noted that the IRIS database was the primary database used in this study, and any database limitations noted by Johnson and Johnson had to do with IRIS alone. However, this and previous studies, as well as our own database review, show that the best method of collecting data for hydraulic fracturing processes is to combine information from all available sources in order to benefit from the particular strengths of each database. This is far from ideal, in terms of the cost, time and complexity required to answer basic descriptive questions, let alone issues such as wastewater chemistry and risk issues across a play.

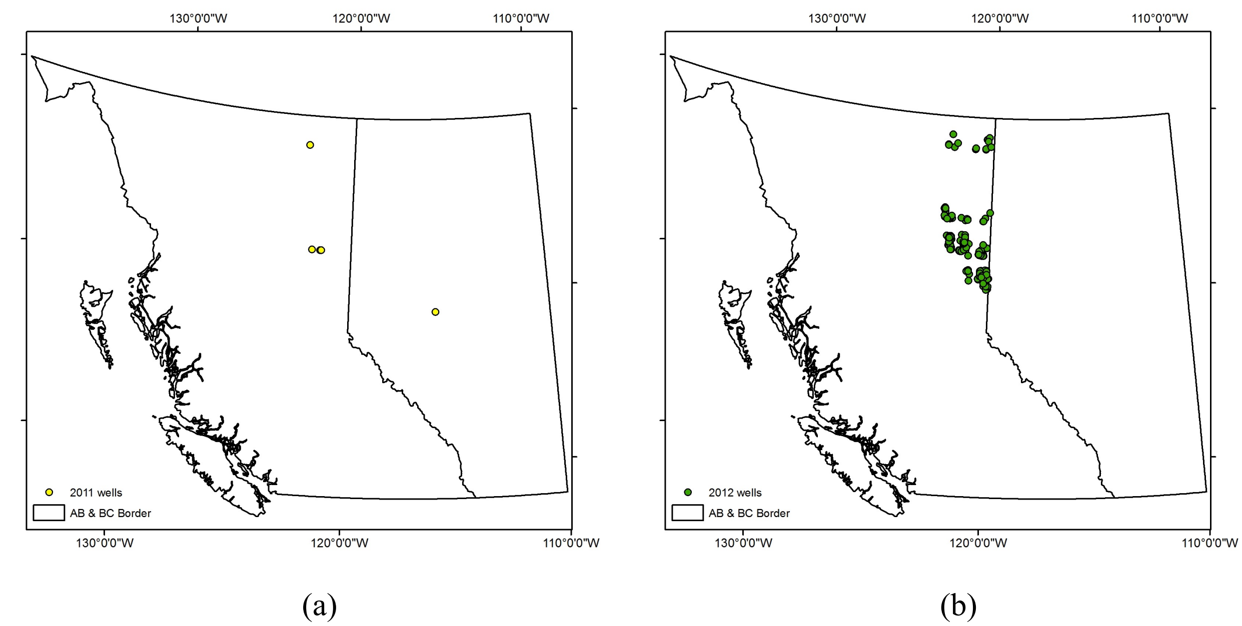
2.5.3 Database queries

Using the FracFocus, geoSCOUT, and AccuMap databases, we ran the queries for the following parameters: 1) water consumption; 2) geographical distribution of water disposal wells; and 3) geographical distribution of wastewater treatment facilities. As previously mentioned, due to time constraints and the complexity of cross-referencing these databases, we focused on the Montney and Duvernay formations in Canada for our database analyses.

2.5.3.1 Water use in the Montney and Duvernay

To study the water use in the Montney and Duvernay plays, we used the FracFocus database. According to data in the FracFocus.ca database, there were 4,917 oil and gas wells that were hydraulically fractured between November 2011 and March 2014 in Alberta and British Columbia Of these, 4,078 wells are located in Alberta, 837 are located in British Columbia, and the locations of the remaining two wells are not specified. Figure 2.10 shows the geographical distribution of the wells reported to the FracFocus database by year; as can be seen, the number of new hydraulically fractured wells has been increasing in recent years. With just a couple months of data captured for 2011,[15] only 11 wells were reported (Figure 2.10a). However, in 2012, 423 wells were reported (all of which were in British Columbia; Figure 2.10b); in 2013, there were an additional 3,862 (Figure 2.10c); and, in the first three months of data captured for 2014, there were another 609 (Figure 2.10d).

Figure 2.10. Geographical distribution of hydraulically fractured wells recorded in the FracFocus database by year: (a) 2011, (b) 2012, (c) 2013, and (d) 2014 (January-March).



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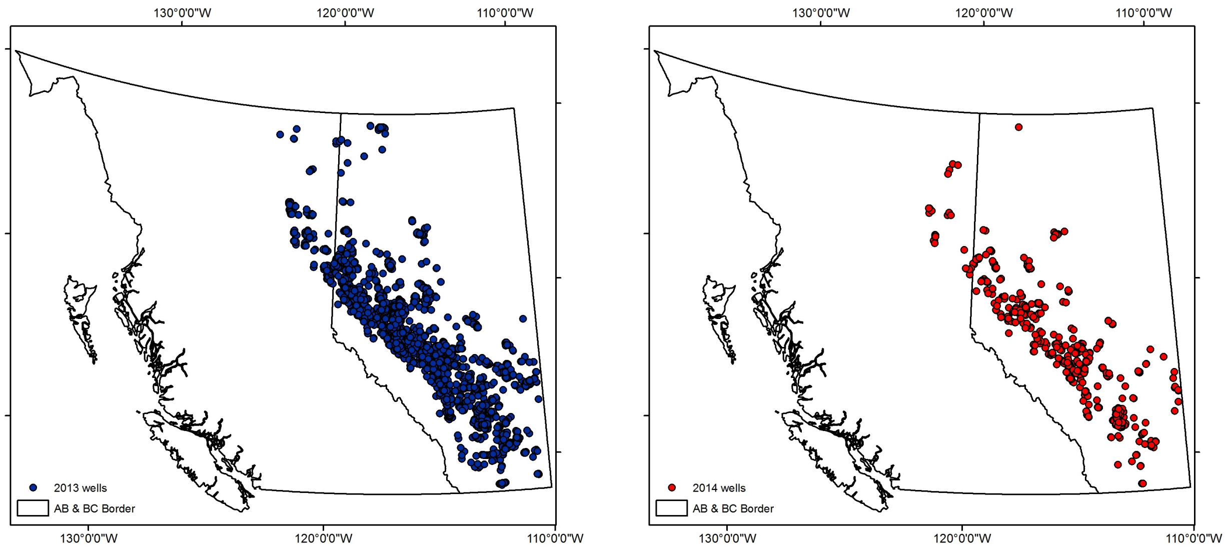
[15] Though companies operating in British Columbia and Alberta were not required to report to FracFocus.ca until 2012 (January for British Columbia and December for Alberta; see section 2.5.1.1), data for a few wells (eleven) falls prior to this start date.



©

(d)

In addition to the increasing number of hydraulically fractured wells, the average number of stages per well has also increased with time. For the British Columbia and Alberta wells, the number of hydraulic fracturing stages vary between one and fifty-eight per well, with the majority of wells having less than twenty. Figure 2.11 shows the distribution of wells with respect to the number of fracturing stages, and Figure 2.12 shows the average number of fracturing stages by year. Given that the data for 2014 only covers three months (January-March), it is likely that the average number of stages for the entire year will be higher.

Figure 2.11. Number of wells versus hydraulic fracturing stages per well, for wells completed in Alberta and British Columbia between November 2011 and March 2014.

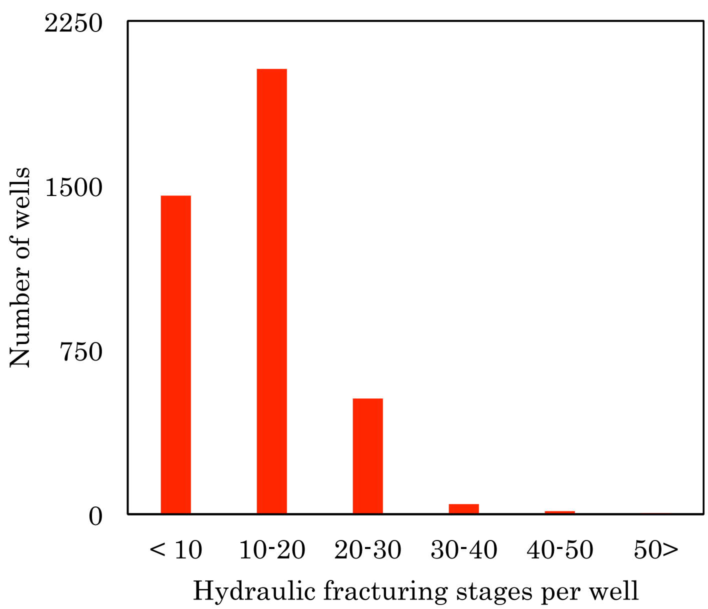
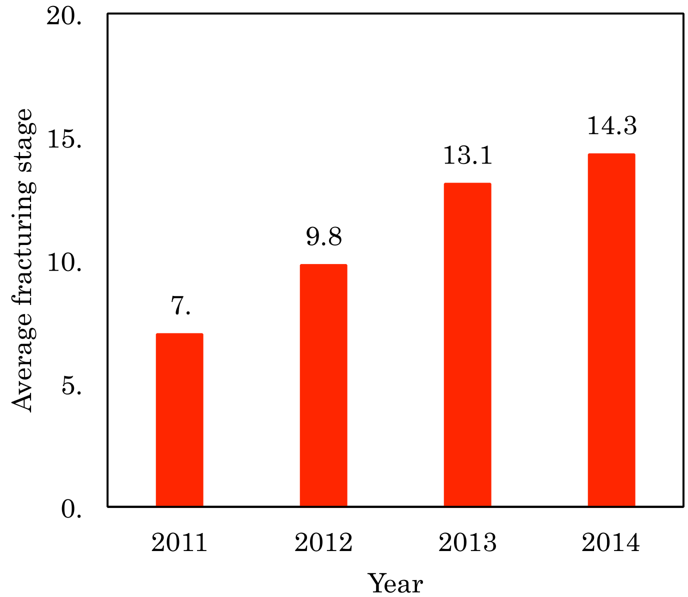


Figure 2.12. Average number of fracturing stages per well by year, for wells completed in Alberta and British Columbia between November 2011 and March 2014.



As can be expected, the growing number of fractured wells combined with a tendency toward more fracture stages per well increases both the average cumulative water consumption in an area, and the average water consumption per well (see Figure 2.13). For each particular well, the amount of cumulative injected water depends on the variety of parameters, such as lithology of the reservoir (and subsequent choice of stimulation method), number of fracture stages, accessibility to water resources, and jurisdictional restrictions.

Figure 2.13. Cumulative injected water by year, for wells completed in Alberta and British Columbia between November 2011 and March 2014.

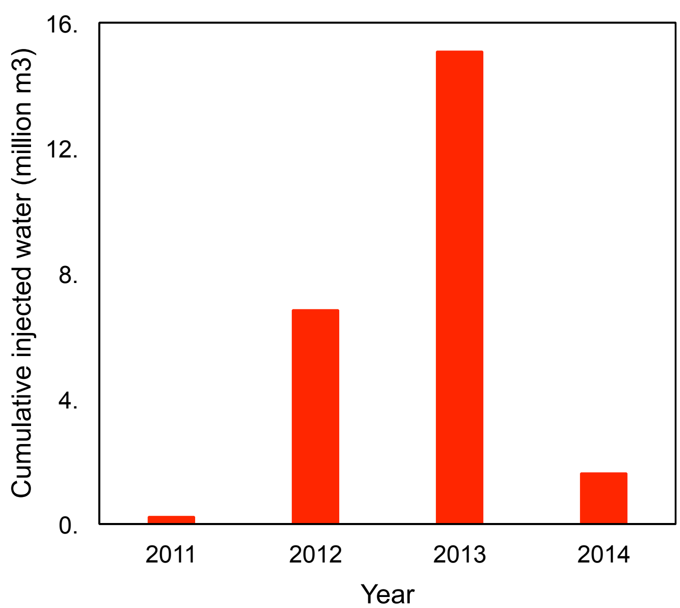


Figure 2.14 shows the compiled distribution of total water injected in each of the hydraulically fractured wells in Alberta and British Columbia between November 2011 and March 2014; Figure 2.15 then splits the same data into four clusters according to cumulative injected water value, for clearer visual representation of geographical trends.

Figure 2.14. Distribution map for cumulative injected water (in m^3) per well, for wells fractured in Alberta and British Columbia between November 2011 and March 2014.

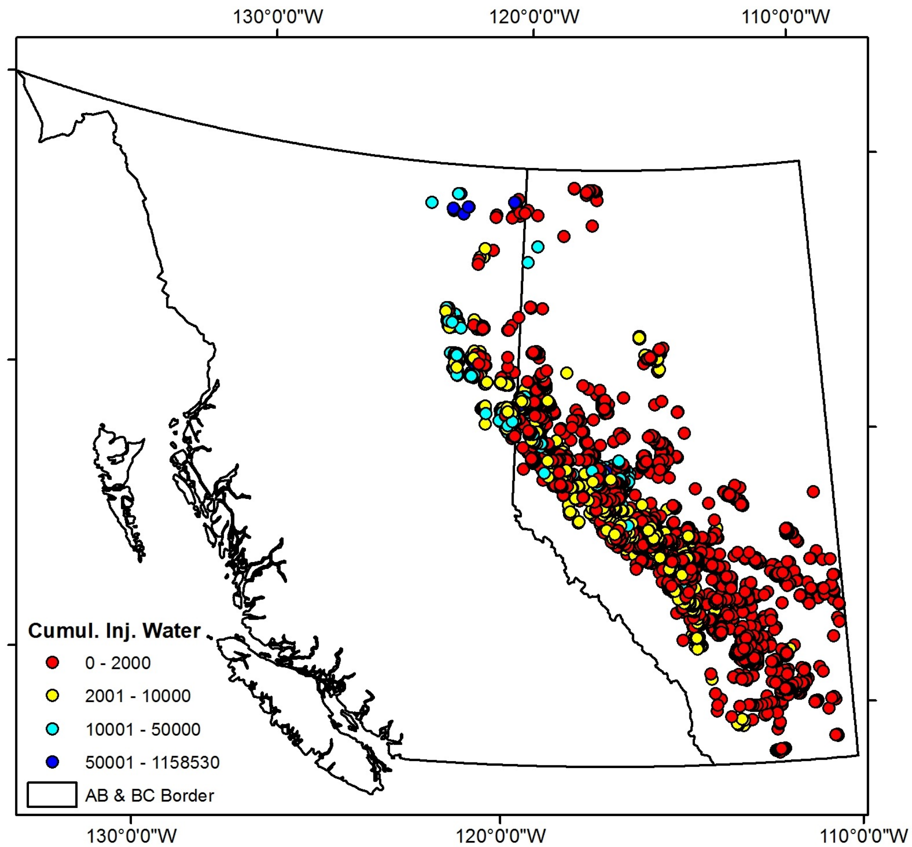
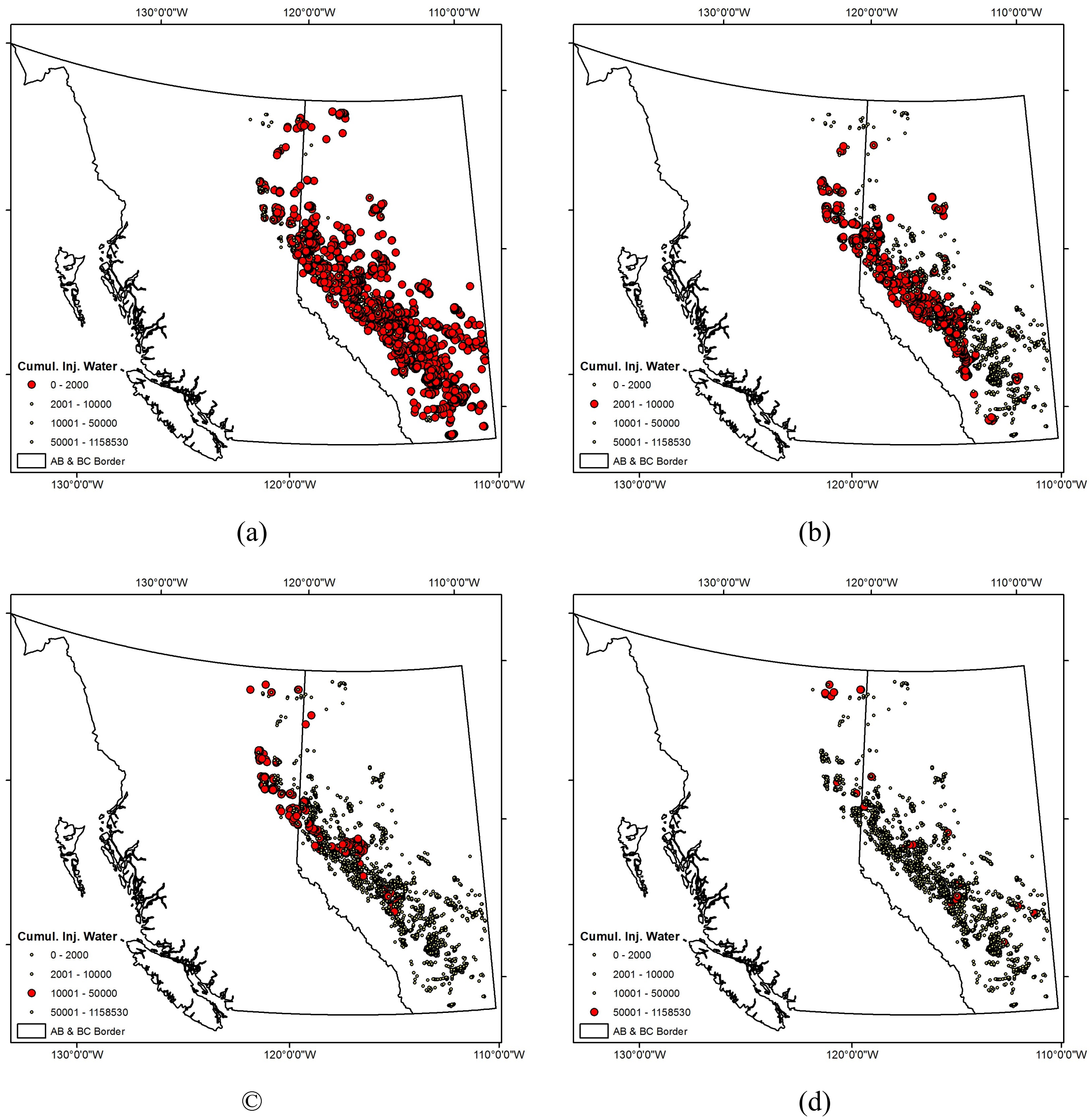


Figure 2.15. Distribution maps of well-clusters for cumulative injected water (in m^3) per well, for wells fractured in Alberta and British Columbia between November 2011 and March 2014: (a) 1-2,000 m^3; (b) 2,001-10,000 m^3; (c) 10,001-50,000 m^3; and (d) > 50,000 m^3.



As can be seen in the two figures, most wells in Alberta and British Columbia typically use 10,000 m^3 of water or less in total, with an average of 3,990 m^3/well for Alberta, and an average of 10,430 m^3/well for British Columbia. However, the total amount is quite variable, as the maximum reported cumulative injected water for a single well in this timeframe was 1,158,530 m^3 , which is almost certainly an example of an erroneously large water volume reported to the database. The majority of the wells with the highest volumes of cumulative injected water (Figure 2.15d) are located in the Horn River Basin, where slickwater is the most common stimulation technique (Johnson & Johnson, 2012). Most relevant for our purposes, the majority of the wells in the 10,001-50,000 m^3 range (Figure 2.15c) are located in the Montney and Duvernay shale formations.

There are 1,009 hydraulically fractured wells in the Montney formation; of these, 269 wells are located in Alberta. Figure 2.16 shows the compiled distribution of total water injected in each of the hydraulically fractured wells in the Montney between November 2011 and March 2014; Figure 2.17 then splits the same data into four clusters according to cumulative injected water value, for clearer visual representation of geographical trends within the Montney.

Figure 2.16. Distribution map for cumulative injected water (m^3) per well, for wells fractured in the Montney shale formation between November 2011 and March 2014.

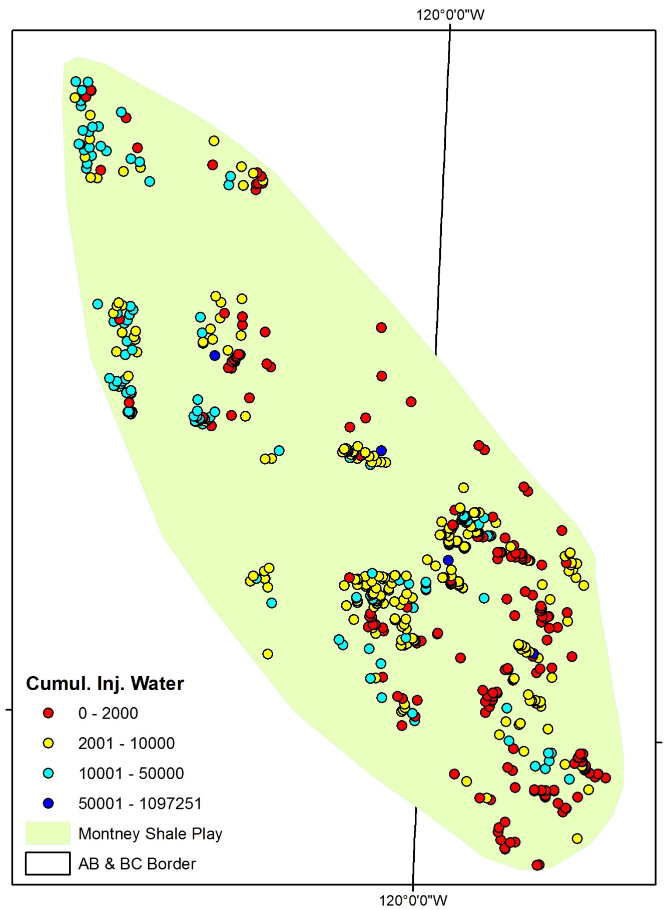
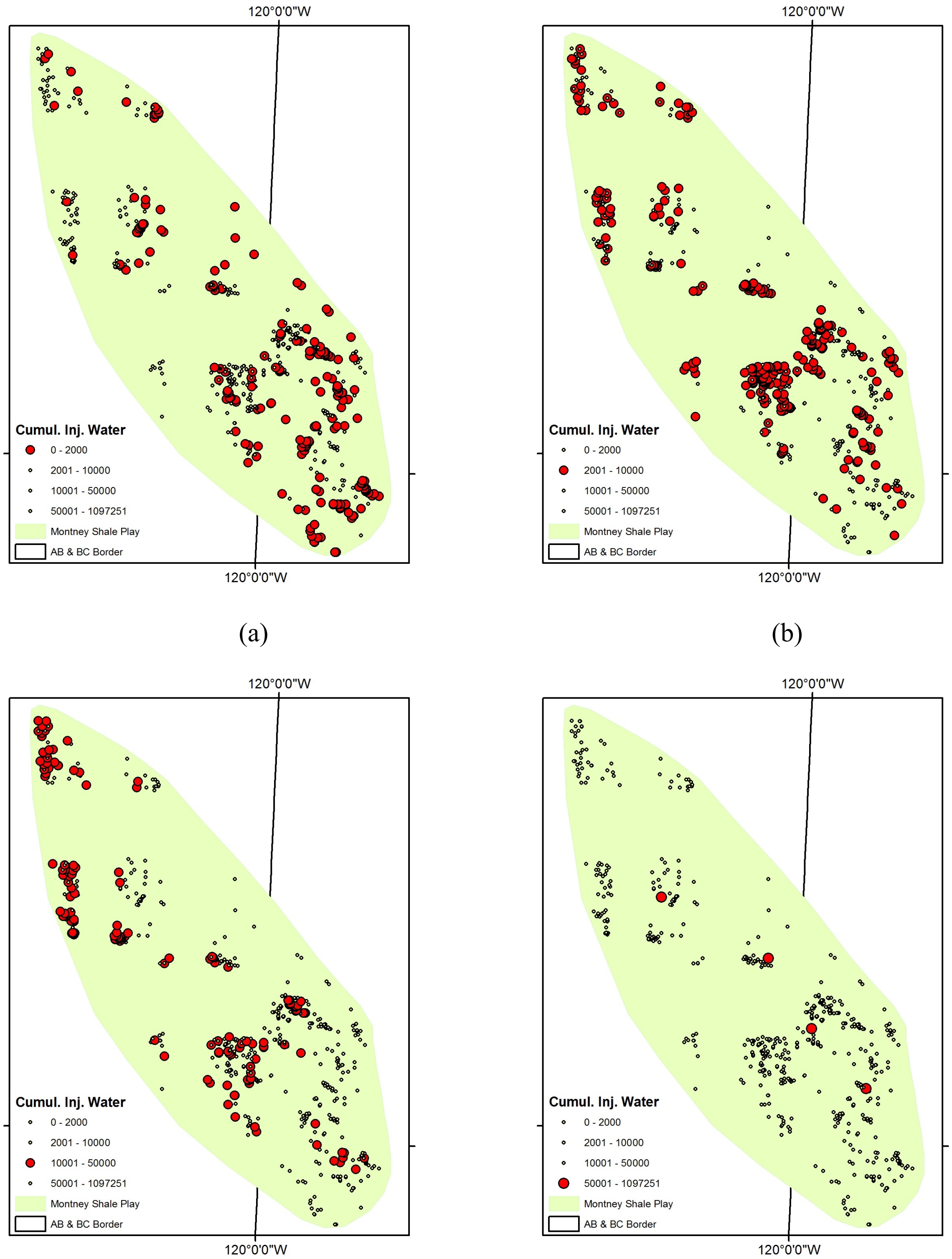


Figure 2.17. Distribution maps of well-clusters for cumulative injected water (in m^3) per well, for wells fractured in the Montney formation between November 2011 and March 2014: (a) 1-2,000 m^3; (b) 2,001-10,000 m^3; (c) 10,001-50,000 m^3; and (d) > 50,000 m^3.



As the above figures show, the wells are mostly concentrated in small regions and are not evenly distributed throughout the formation. The different clusters of cumulative injected water, however, are more uniformly distributed throughout the region, though the majority of the wells in the 10,001-50,000 m^3 range (Figure 2.17c) are located on the British Columbia side of the border.

There are 1,923 hydraulically fractured wells in the Duvernay Formation. Figure 2.18 shows the compiled distribution of total water injected in each of the hydraulically fractured wells in the Duvernay between November 2011 and March 2014; Figure 2.19 then splits the same data into four clusters according to cumulative injected water value, for clearer visual representation of geographical trends within the Duvernay.

Figure 2.18. Distribution map for cumulative injected water (m^3) per well, for wells fractured in the Duvernay shale formation between November 2011 and March 2014.

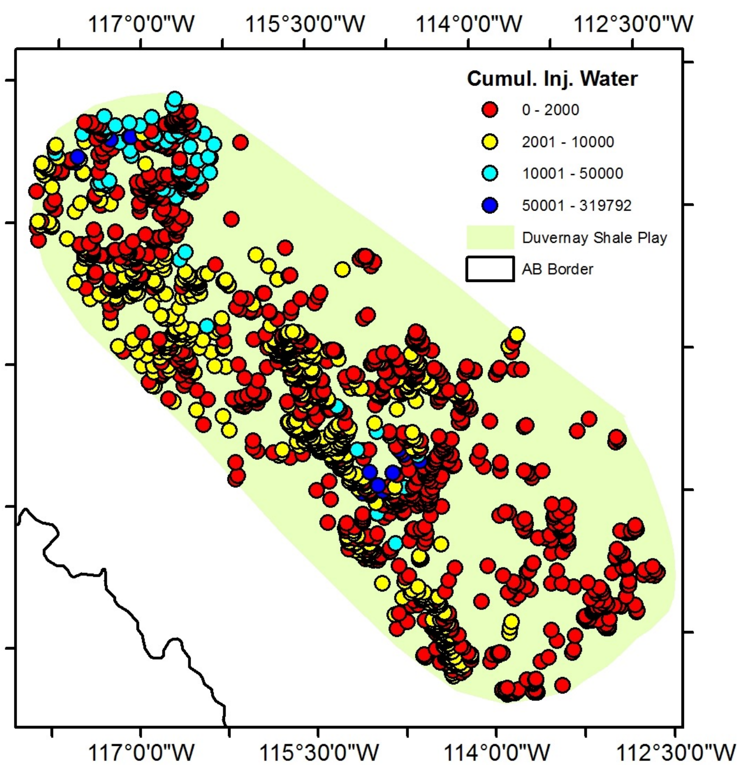
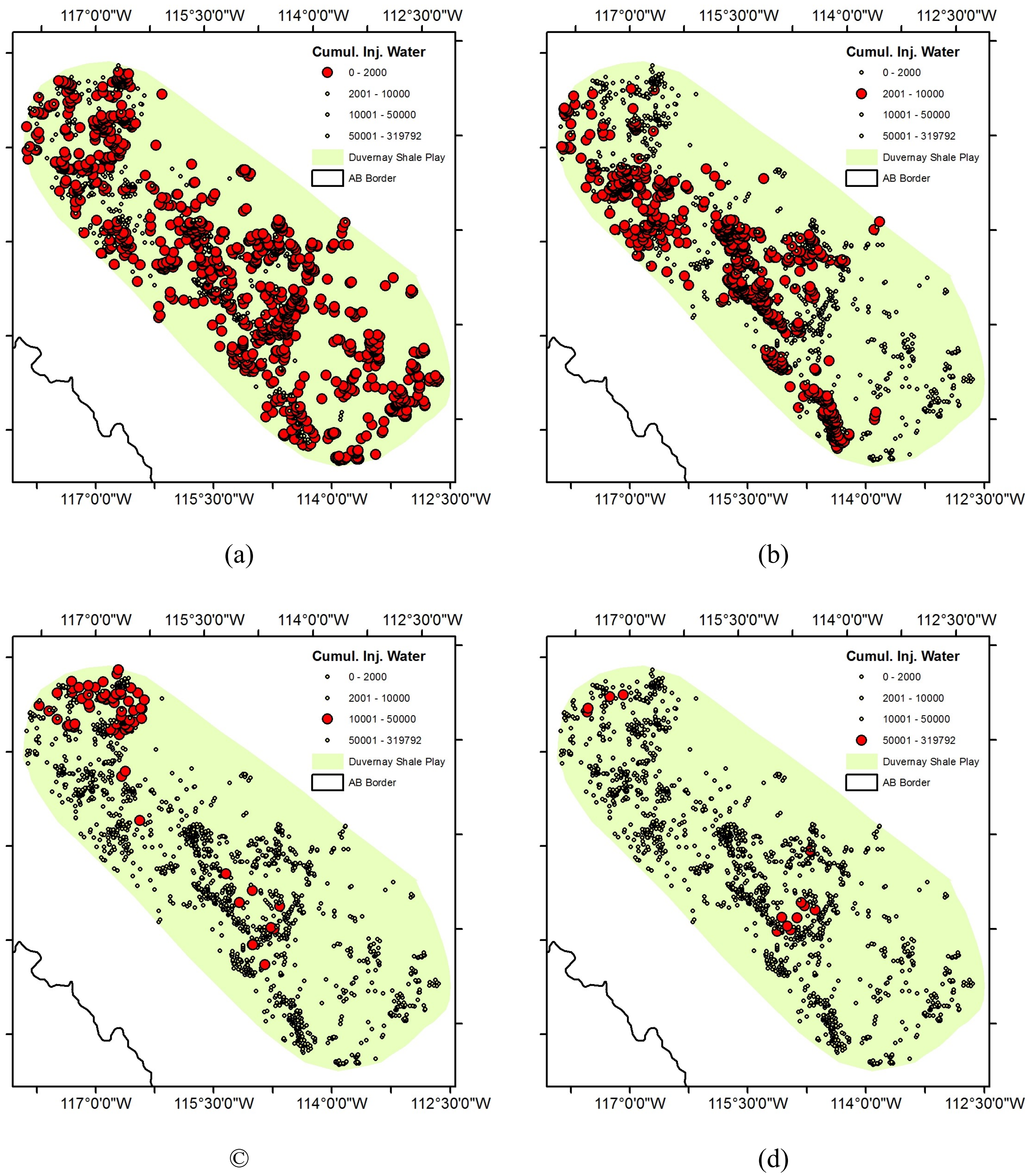


Figure 2.19. Distribution maps of well-clusters for cumulative injected water (in m^3) per well, for wells fractured in the Duvernay formation between November 2011 and March 2014: (a) 1-2,000 m^3; (b) 2,001-10,000 m^3; (c) 10,001-50,000 m^3; and (d) > 50,000 m^3.



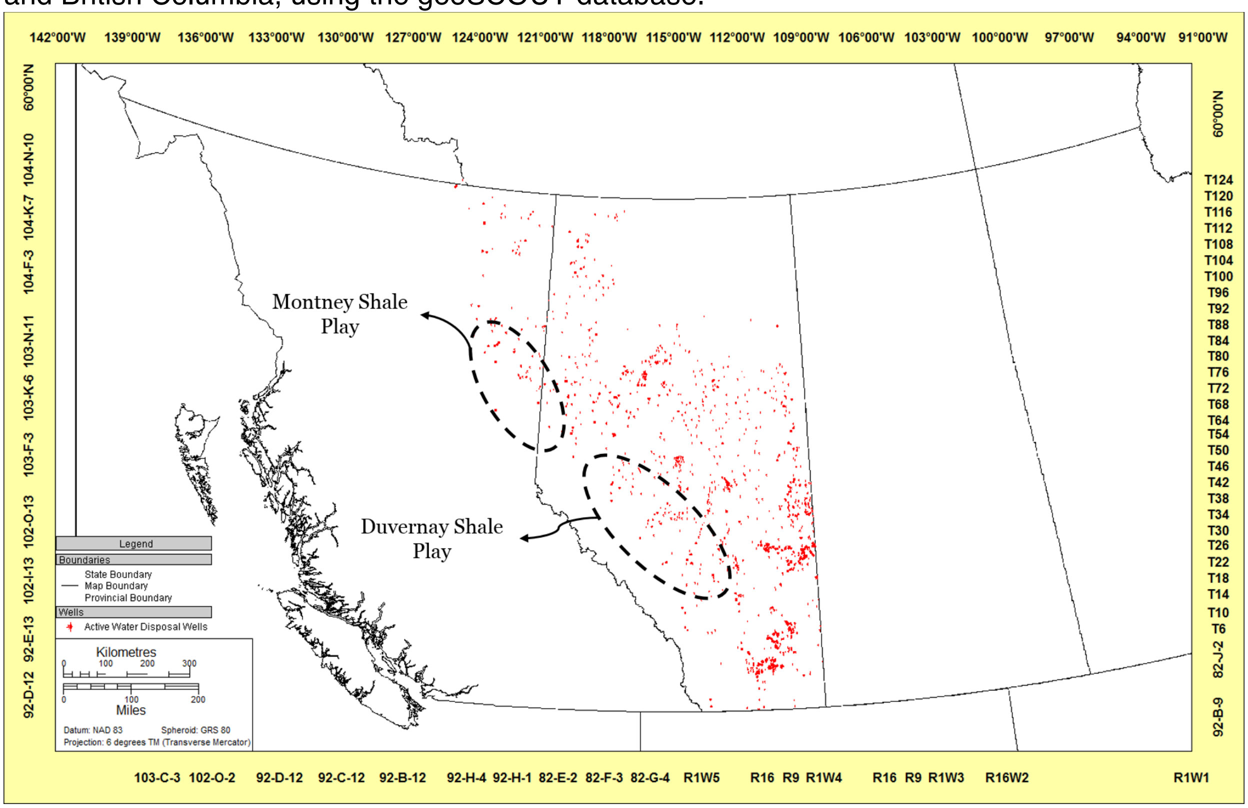
The hydraulically fractured wells in Duvernay are, for the most part, evenly distributed throughout the formation, and the majority of the wells typically use 10,000 m^3 of water or less in total. The wells with the higher amounts of cumulative injected water (Figure 2.19c-d) are concentrated in the central and northwestern parts of the region, indicating higher overall water consumption in those areas.

2.5.3.2 Geographical distribution of wastewater disposal wells in the Montney and Duvernay

To study the geographical distribution of wastewater disposal wells in our focus formations, we used the geoSCOUT database. Each type of well (e.g. oil, gas, disposal) has a different type of well-mode tag in geoSCOUT. As an illustration of the difficulty of extracting play-wide data from the databases, we identified eighteen different notations of the disposal well-mode tag alone (such as *WTR Disp*, *LicDisp well*, *Water Disposal*, *Salt disp well*, *drlgdisp well*, *cmpldisp well*, *cmglDisp Well*). According to geoSCOUT, there are a total of 13,361 disposal wells in Alberta and British Columbia combined; of these, 11,497 are active, and the remainder are either abandoned (1,145 wells) or suspended (719 wells).

The active disposal well list (11,497 wells) was filtered for the following well-mode tags to only consider the active water disposal wells: *Cased Disp Well*, *Cased Waste Disp*, *Salt WTR Disp*, *Water Disposal*, *WTR Disp*, and *WTR Disposal*. Through this screening, the number of active water disposal wells was narrowed down to 2,509 wells. The geographical distribution of these wells can be seen in Figure 2.20.

Figure 2.20. Geographical distribution map for the active wastewater disposal wells in Alberta and British Columbia, using the geoSCOUT database.

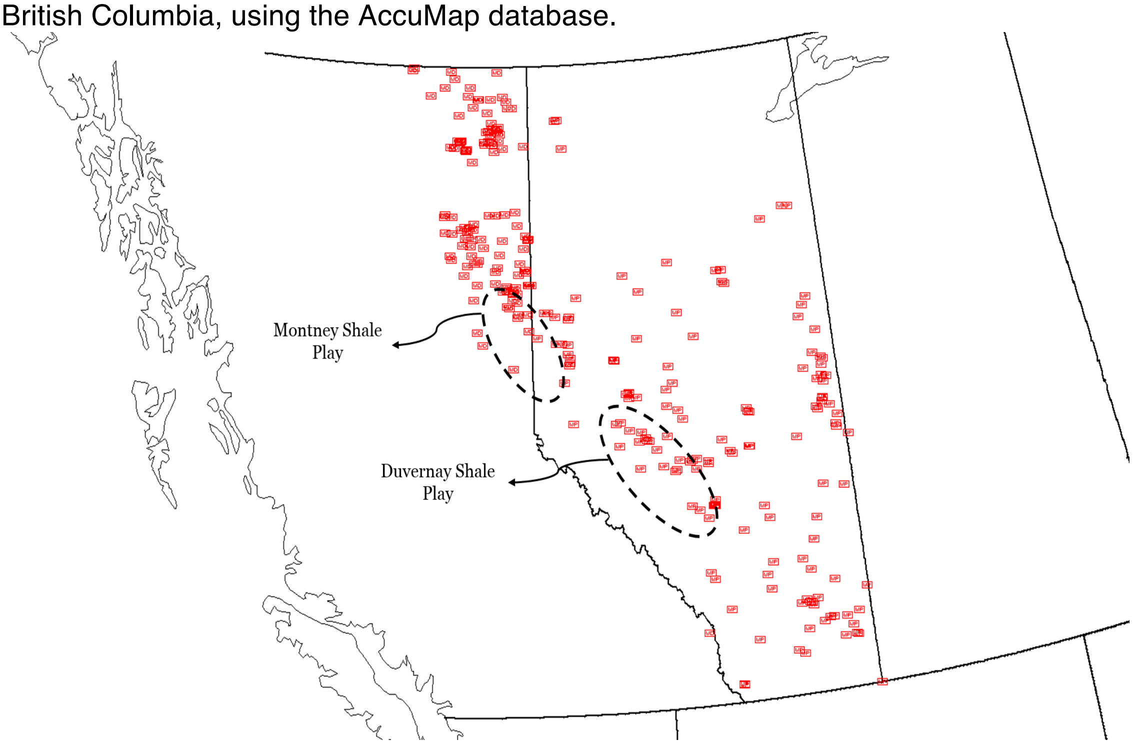


Comparing the location of the active wastewater disposal wells (Figure 2.20) with the location of the hydraulically fractured wells in the Montney (Figure 2.16) and Duvernay (Figure 2.18) shale formations, it can be seen that the active wastewater disposal wells are generally located relatively far from the regions with a high concentration of hydraulically fractured wells. Therefore, there is likely significant trucking traffic of wastewaters from the concentrated oil and gas well regions to the water disposal wells. Disposal wells in the Barnett formation, in comparison, tend to be within the same region, injected into the underlying Ellenberger Formation (Nicot et al., 2014b). The situation in the Montney and Duvernay is perhaps between practices in the Barnett and Marcellus; although deep well injection has handled the majority of wastewaters in the Montney and Duvernay, there has been a significant shift towards recycling and reuse in recent years.

2.5.3.3 Geographical distribution of wastewater treatment/disposal facilities in the Montney and Duvernay

As previously discussed, hydraulic fracturing wastewater often must be treated or diluted with freshwater before recycling, and sometimes treated before disposal. Having a better knowledge of the location of wastewater treatment facilities is therefore important in selecting the best treatment/disposal method for a particular well or play. Of the three databases we analyzed, only the AccuMap database contains information about wastewater facilities, and it does not clearly indicate whether each facility is necessarily a treatment versus a disposal facility. There are two sets of data (or layers) for wastewater facilities in AccuMap, labeled either as *waste plant* (WP) or *water disposal* facilities (WD). When data is screened using these two options, all WPs appear to be located in Alberta, and all WDs are located in British Columbia, indicating that there is likely a difference in terminology between the two provinces (see Figure 2.21).

Figure 2.21. Geographical distribution map of wastewater treatment facilities in Alberta and British Columbia, using the AccuMap database.



Although the number of fractured wells is higher in Alberta (Figure 2.14), the wastewater facilities are more concentrated in British Columbia (Figure 2.21). However it is not clear what portion of the facilities in either province accept wastewater from hydraulic fracturing operations, that is, which are municipal wastewater treatment facilities versus industrial wastewater disposal facilities that accept hydraulic fracturing wastewater.

2.6 Conclusion

In this chapter, we outlined the sources of hydraulic fracturing wastewaters, methods of treating, reusing, or disposing of them, and how these factors vary across the four unconventional shale formations studied here. Generally, wastewaters are operationally defined in this report as drilling fluids plus flowback, produced, and maintenance waters. Flowback and produced waters that return to the surface following reservoir stimulation comprise the greatest volume of wastewater, and are the focus of the report. The chemistry of these waters varies greatly as a function of the formation or play that is hydraulically fractured, operational parameters such as shut-in time, and the time after well flowback begins. The variation in wastewaters necessarily leads to a wide range of techniques in handling the water when it returns to the surface. In the formations studied, we note that in the Marcellus formation there has been a shift from treatment in conventional wastewater treatment plants, towards a combination of on-site treatment, reuse/recycling and deep well injection in Ohio. In the Barnett, deep well injection remains dominant, despite the play being located in a water-short region. The Duvernay and Montney formations in Canada were initially dominated by deep well injection of wastewaters, but a shift towards recycling and reuse is being observed. As will be further discussed in the following chapters, these shifts in the handling of wastewater are driven not only by physical supply issues, but by differences in jurisdictional regulations and public environmental concerns across the plays.

To bolster the literature review conducted for the first part of the chapter, we additionally explored three hydraulic fracturing databases: FracFocus, geoSCOUT, and AccuMap. Working with these databases clarified and confirmed a general observation formed during the literature review: that extracting broad trends in water sourcing or wastewater disposal practices across a region, jurisdiction, or play is difficult at present. To extract even broad generalizations about water use in the Montney and Duvernay, the two formations studied in our databases exercise, extensive cross-referencing of the databases was necessary. While water use and wastewater data may be good for an individual well, modes of reporting or nomenclature among wells are often inconsistent, resulting in datasets from which trends are difficult to extract. Indeed, achieving a regional or formation-wide picture of the hydraulic fracturing water cycle (or even just the wastewater disposal portion of that cycle) using these databases would be very difficult at best. However, studying databases like these is a useful way to identify current gaps in well information reporting procedures. A better consensus on information - important not only to operators, but to governments and regulators as well - could be strengthened by such studies. Ultimately, a better understanding of the water cycle and increases in water use efficiency at the regional scale will be facilitated by easier access to hydraulic fracturing wastewater datasets from regulators (a process that is underway in many places), research studies of these data, consultations with expert practitioners in industry, and development of new, more comprehensive public hydraulic fracturing data portals that address the information needs of various stakeholders.

2.7 Knowledge Gaps and Research Approaches

2.7.1 Overview of Knowledge Gap – Disposal Well Databases

While inconsistencies in reporting mean that some information is missing for individual wells in one or more of the databases (which does not necessarily constitute a knowledge gap in itself), we observed gaps pertaining to: the fate of wastewater, the source of water used, water injection and production, and chemical analysis.

The most prominent knowledge gap related to the database analysis conducted in this section is that the fate of hydraulic fracturing wastewater cannot be found in the three databases. In other words, it is not clear what portion of a well's wastewater is reused/recycled, treated, surface discharged, or deep-well injected. This lack of information prohibits any direct analysis of wastewater management practices for the hydraulic fracturing operations based on the available information in databases.

With respect to the source of water used: AccuMap provides a distribution of water sources in Alberta (not for any other region), but does not provide well-specific water source data. There is no information about water sources in the FracFocus or geoSCOUT databases. This knowledge gap impacts the usefulness of the data in: understanding more clearly the water cycle (or mass balance) in a region; understanding the evolution of the chemistry of flowback (e.g. if the fracturing fluid used is already somewhat saline, the resulting flowback will start more saline than a well that uses fresh surface water, but will likely evolve to the same TDS of the deep brine); assessing environmental impacts of hydraulic fracturing operations; and related decision/policy making.

For water injection and production, none of the three databases provide a complete view of the amount of injected *and* resulting wastewater. For instance, only the produced water volume is available in the geoSCOUT and AccuMap databases, but there is no information about the total amount of injected water. As of 2015 these data are readily available for hydraulically fractured wells in British Columbia (via the BC Oil and Gas Commission), but are not for many other jurisdictions. In contrast, only the total amount of injected water is available in the FracFocus database. As the two amounts are obviously related, such data would be useful for forecasting wastewater management needs.

Regarding chemical analysis, although the chemicals used in hydraulic fracturing fluid can be found in the FracFocus database, these data are often incomplete due to the proprietary nature of hydraulic fracturing fluid compositions. Additionally, chemical analyses of the resulting wastewater are not found in the studied databases. In AccuMap, only the ion concentrations of the produced water are accessible, and not the concentrations of chemical compounds. Knowing the chemical compound composition of the flowback water improves the understanding of the nature of the produced wastewater, which offers a better foundation for analyzing appropriate wastewater management practices, including treatment, reuse/recycling, handling, disposal, and risk analysis. Furthermore, the ion concentrations available in AccuMap are reported inconsistently across the database (e.g. different sampling times), impeding comparative study of wastewater from wells across a region or play.

2.7.2 Approaches, Strengths and Weaknesses – Disposal Well Databases

Critical to addressing these gaps is identifying information that is required by various stakeholders, such as industry, the public, regulators, academics, and policymakers. Numerous databases, including those mentioned above, contain information about water in hydraulic fracturing. However, there appears to be a consensus that more information about the water cycle in hydraulic fracturing should be made publicly available (see Chapter 4, section 4.3.6). We therefore suggest the following two research approaches:

The first **approach** would be to hold consultations with stakeholders to assess which information they would find useful in a publicly available format. Feedback could be gathered using many mechanisms to accurately sample various demographics; for example: email, social messaging, town hall information meetings, and surveys or information requests by post could be employed. Ideally the development of the consultation mechanism would involve experts from industry, academia, government, and members of the public. During the open survey of stakeholders, a trial-and-feedback approach would allow for discussion regarding the merits of building an information portal, as well as an assessment of which information industry and governmental agencies would release into the portal.

The **strength** of this approach is that it would provide comprehensive feedback and verification of the gaps in current databases as observed by this study. It would also provide concrete evidence from stakeholders regarding what data/information they are looking for, and how it might be provided in a useful way. The **weakness** is that it may raise undue expectations on the part of stakeholders, and result in pressure to make significant alterations to current databases that may be serving the needs of the data base owners adequately. The cost of this approach, depending on the scope of the consultations, could range from $200,000 to over $500,000..

A second **approach** would be to develop a prototype open information portal to disseminate hydraulic fracturing information to stakeholders based on the findings of this study and other studies examining stakeholder information needs. The prototype would then be released in a publicly accessible format with the capacity to provide feedback from users. FracFocus.org and FracFocus.ca are an example of existing information portals, but the limitations are well-described in this report and elsewhere. Another example, WellWiki.org, is a pioneering oil and gas information portal that contains information on approximately 1.5 million wells in Alberta, BC, Pennsylvania, West Virginia, New York, and Ohio, and by mid-2015 will cover wells in Colorado and Texas. The Wiki format allows feedback from any stakeholder, including the public, and may prove a useful template for piloting the studies on information consensus mentioned above. The WellWike.org prototype could possibly be used as the actual prototype for this approach.

The **strength** of this approach is that a prototype already exists and it could rapidly advance the body of knowledge regarding what stakeholders are looking for. The **weakness** is that stakeholders may react in a less positive fashion toward the database if they feel they were not consulted on its design. The **cost** of this approach, depending on the extent of modifications to the database required before its release, would range from $250,000 to $500,000.

CHAPTER 3: REGULATORY AND POLICY REGIMES, AND VOIDS WITHIN AND ACROSS JURISDICTIONS

3.1 Introduction

Wastewater management for oil and gas activities in North America has a lengthy history. Oil and gas resources have been commercially developed for the past century or more, at least to some degree, in Alberta, New York (ca. 1825), Ohio, Pennsylvania (ca. 1829), Texas, and West Virginia, and in British Columbia (ca.1950). The waste stream associated with extracting these resources is significant in volume and has had implications for the environment and human health, dating from the initiation of the industry (Clark and Veil, 2009; Lee and Neff, 2011; Spellman, 2013). Robust regulations are relied upon to prevent environmental degradation and risk to human health from inadequate handling, treatment, and disposal of wastewater for industrial processes. Additionally, regulations establish protocol for emergency response and remediation, liability where improper handling, treatment, or disposal has occurred, and room for amendments to address emerging issues. Because the total volume, total dissolved solids (TDS) and total suspended solids (TSS) levels of wastewater produced by hydraulic fracturing activities, in particular, are often much higher than from other oil and gas extraction methods given the chemical additives and volumes of sand or other proppants added to fracturing fluids (Gay et al., 2012), some regulations for effective waste management are unique to shale gas development. Furthermore, as the amount of cumulative wastewater from hydraulic fracturing is increasing exponentially with the steady appearance of new hydraulically fractured wells, and as the amount and chemical makeup of wastewater is often dependent on the physical context of the hydraulically fractured well in question, amending regulations for wastewater from hydraulic fracturing is a current, ongoing process, and varies according to geology and hydrology (STRONGER, 2014). As such, a temporal review of both general oil and gas waste regulations and those specific to shale gas development across jurisdictions illustrates how regulations have been amended (or not) to reflect changing development objectives, citizens' concerns, and environmental interests. The aim of the assessment carried out in this chapter is to present a summary of existing and past regulations and legislation pertaining to handling, treatment, and disposal of wastewater from hydraulic fracturing in our four selected shale gas formations; subsequently, this assessment also identifies the absence of regulations governing the aforementioned activities. Given the importance of transport in the life-cycle of wastewater, regulations specific to transport are also addressed throughout the chapter.

3.2 Overview of Shale Gas Formations and Jurisdictions

3.2.1 Focus formations

As described in Chapter 1, the four focus formations of this project were selected for being at different stages of production and having varying jurisdictional situations, in order to compose a microcosm of the industry's issues associated with wastewater. All four formations, however, have similar actual and/or potential production volumes. As each formation has (or will have) significant production volumes, each can be assumed both to be of relative importance to its respective state or provincial economy (or economies), *and* to have the largest actual or potential waste streams in comparison to other shale gas plays (see Table 3.1).

Table 3.1. Comparison of focus shale formations.

Formation	Regional Extent	Original Gas in Place Volume (Tcf)	Approximate Wastewater Volumes (based on average water use assuming no recycling)
Montney	130,000 km^2 (BC & AB)	271 (BC) 178 (AB)	10,000-25,000 m^3/well
Duvernay	7,500 km^2 (wet gas window)	443	50,000 m^3/well
Barnett	13,000 km^2	225-750	10,600 m^3/well
Marcellus	167,300 km^2	1500	11,500-26,500 m^3/well

* Typically, the amount of natural gas able to be extracted from a reservoir for commercial processing is only 10-30% of the total in place gas volume. For example, of the geophysically assessed volume of 1500 Tcf natural gas that is trapped in the Marcellus shale, only 400-489 Tcf (~26-32%) is considered technically recoverable.

Adapted from: Johnson & Johnson (2012) – Average use calculated for multi-stage wells; National Energy Board (2013); Nicot & Scanlon (2012); Pennsylvania State's Marcellus Center for Outreach and Research (2013); Precht & Dempster (2012); Smith Low (2012); US Energy Information Agency (2012); United States Geological Survey (2011).

The Montney formation is one of the largest unconventional shale gas resources in the world and alone holds the reserves equivalent to fuel all of Canada's consumptive needs for 145 years (NEB, 2013).[16] Similarly, according to geophysical assessment, the Barnett formation may contain the largest shale gas reserves onshore in the U.S. within a single jurisdiction, although it is less than half that of the Marcellus. In addition to containing significant volumes of natural gas, the Duvernay and Montney (and in the southwest of the Marcellus) formations produce wet gas, or gas returns containing a high percentage of condensate or gas liquids; because condensate is priced similarly to light oils in a weak natural gas market, these shale gas plays may be considered more economically viable than gas produced from dry formations. Finally, the Marcellus formation contains enormous amounts of natural gas, and has the added benefit of proximity to high-demand energy markets situated along the eastern U.S. seaboard.

With this high production linkage between the four formations, a comparative review of the different development and regulatory histories of the formations allows us to see what factors create each unique regulatory environment. Both the Montney and Duvernay formations, for example, are economically important to Canada and share similar compliance enforcement frameworks, legal frameworks, decision-making processes, and overarching federal laws and obligations to Aboriginal nations. To this point, the provinces have shared many similarities in their regulatory models, and British Columbia has borrowed many features of regulations and governance of the industry from Alberta. However, British Columbia was an early adopter of the goal oriented regulatory approach and is currently working on implementing concepts of "basin

[16] Calculated by assuming 2012 rates of Canadian energy consumption.

planning" or "area based management". Alberta is also currently implementing a first-of-its-kind pilot project in the Duvernay late in 2014 that will assess the effectiveness of play-based regulation, recognizing the variability between plays (Ernst and Young LLP. 2015). The Montney and Duvernay formations will be discussed comprehensively in Sections 3.4 and 3.5, respectively.

Whereas development of some shale formations, such as the Montney, tends to occur in more rural and remote areas, the most productive shale gas field in North America, the Marcellus, is under densely populated areas and watersheds crucial to the domestic water supply. Furthermore, in contrast to formations such as the Duvernay, which are solely within one jurisdiction, the Marcellus spans six states. The regulations of each of the six states in the Marcellus have evolved independently of one another, and complex jurisdictional issues have become apparent through the myriad of states, municipalities, watershed commissions, non-governmental organizations, industry operators, and private citizens that have (or have expressed) interest in the intersection of environmental preservation and resource development. Interests, and the agents expressing them, have initiated very successful trans-boundary coalitions and agencies that have produced regulations guiding handling, transport, and disposal of wastewater to supplement existing state regulations. Moreover, as seen in Chapter 2, states in the Marcellus such as Pennsylvania commonly transport wastewater to other nearby states such as Ohio for disposal[17] when economics, infrastructure or regulations make it impossible or impractical to treat or dispose of wastewater internally; this trans-boundary materials management has had both positive and negative ripple effects for the regulations of Marcellus states. A more comprehensive overview of the evolution of regulations in the Marcellus is found in Section 3.6.

Lastly, the Barnett has a longer than average development history with shale and other petroleum production, and thus has mature oil and gas regulations that have addressed and responded to wastewater management issues. Furthermore, due to the formation's proximity to highly urbanized and urbanizing areas in the Dallas-Fort Worth region, development in the Barnett has induced municipalities and landowners to legally challenge the supremacy of state regulations and laws with regard to local regulations stipulating set-backs, moratoria, and compensation for infrastructure wear caused by trucks transporting wastewater. Some of the first court cases regarding contamination issues suffered by residents in the Barnett to go to trial and set precedent for hydraulic fracturing case law have been in Dallas courts. In early 2014, a Dallas court awarded almost US$3 million to a family suffering from the effects of "cumulative environmental contamination and polluting events" related to air emissions in a 5 to 1 decision (*Parr et al. vs. Aruba Petroleum, Inc.*).[18] Precedent like *Parr et al.* is an important example of legal change affecting the future of industry behaviour and regulatory shifts that take environmental contamination and human health as their impetus. The Barnett will be discussed at greater length in Section 3.7.

[17] There is potential for pre-treatment in Ohio to filter out hydrocarbons and solids prior to injecting.
[18] For more information see: *Parr et al. v. Aruba Petroleum, Inc.*, Case No. CC-11-01650-E in the County Court at Law No. 5, Dallas County, Texas.

In selecting these four divergent formations for comparison, the assessment carried out in this chapter generates a more representative sample of the kinds of regulations and regulatory challenges that exist for active shale gas formations across North America.

3.2.2 Layers of jurisdictional framework

In North America, handling, transport, treatment, and disposal practices in the regulation of oil and gas wastewater is complex and multifaceted. Much of this complexity comes from shared jurisdiction over many aspects across provincial or state lines (for some development areas) and/or across provincial/state and federal levels. Federal acts provide parameters for managing hazardous waste, protecting groundwater, and other broader issues. As such, in Canada, onshore resource extraction is primarily delegated to provincial legislatures and, in the U.S., individual states hold jurisdiction over legislation and regulations pertaining to wastewater management. Most provinces and states have one or two regulatory agencies that establish and enforce regulations, as well as grant permits. At the federal level, in both Canada and the U.S., there is no legislation that explicitly deals with hydraulic fracturing fluids or produced water. In Canada, the National Energy Board (NEB) regulates oil and gas exploration and production activities under the *Canada Oil and Gas Operations Act* (*COGOA*). In all cases where a proposed work or activity requiring an Operations Authorization (OA) involves hydraulic fracturing (i.e. on federal lands), the NEB assesses future applications for drilling that involve hydraulic fracturing. The filing requirements include describing in detail the on-site storage capability for produced fluids including flowback fluids and formation fluids; and describing in detail the handling, treatment, disposal and waste management capabilities for the fracture fluids, flowback fluids and other used or un-used chemicals. The Filing Requirements apply to hydraulic fracturing operations in the Northwest Territories and Nunavut. In the U.S., no comprehensive set of national standards exists at this time for the disposal of wastewater discharged from natural gas extraction activities. Under the *Safe Drinking Water Act* (*SDWA*), the *Energy Policy Act of 2005* exempted hydraulic fracturing and disclosure of fracturing fluids from federal review except in cases where diesel fuel is in use (see Cahoy et al., 2013). However, the U.S. Environmental Protection Agency does have a number of initiatives and actions under several acts to address wastewater from hydraulic fracturing (U.S. EPA, 2015)

In the U.S., some regional commissions, watershed commissions, municipalities, and communities affected by activities related to shale gas development may also establish regulations. These regulations frequently address issues such as water quality and quantity, limitations on transport activities, prohibitions for certain disposal practices, storage set-backs from residential areas, and moratoria. The Susquehanna River Basin Commission (SRBC), for example, has been instrumental in increasing recycling practices in the Marcellus shale through regulations established for limiting consumptive water use within the basin. Traditionally, zoning decisions are delegated to municipalities, which gives them the authority to determine whether or not activities can take place in, or close to, city limits. Zoning authority has given many jurisdictions the right to enact a full or partial moratorium on hydraulic fracturing and its associated wastewater management practices. For example, within our focus regions, Youngtown, Ohio in 2013 and Denton, Texas in 2014 successfully lobbied to include fracturing moratoriums on the ballot in local elections (Youngtown citizens have voted down a ban in four elections since May 2013, while Denton citizens approved a ban in the November 2014 election;

Skolnick, 2014; Krauss, 2014). In Canada, commissions, municipalities, etc. must comply with provincial regulation.

Consultation with First Nations and recognition of Aboriginal rights and title in matters of development and associated regionally imposed regulations is also factor. In Canada, the Crown has a fiduciary duty to consult with First Nations regarding lands they hold title to as per section 35 of the Canadian *Constitution Act, 1982*. First Nations opposition to a variety of development projects occurring in their territories has recently had implications for the interpretation of Canadian law, and the obligations of industry and government towards Aboriginal title. Judicial decisions have served to enumerate and expand the rights held by First Nations. For the Canadian study areas, references to title do not apply. Title was ceded in the numbered treaties covering these areas. Even where title potentially exists, industry does not have obligations in relation to it.

Complex conflicts frequently arise when dealing with accidents and contamination occurring from the handling, transport, and disposal of wastewater. In these cases, disputes may be adjudicated by the court system. Decisions rendered by justices become precedent, and provide another level of legal and regulatory direction for industry operators. Precedent may also serve to establish hierarchies within regulations, and to establish which parties can be held liable for damages. Whereas many oil and gas companies have been the defendants in lawsuits and some have been charged, a recent court case in Alberta, in which the plaintiff argued that the Energy Resources Conservation Board (ERCB) (now the Alberta Energy Regulator, or AER) failed to protect her water supply, it was determined that the ERCB holds statutory immunity from being charged with negligence in a hydraulic fracturing suit (*Jessica Ernst vs. ERCB & Encana*[19]). The case has since been overturned on appeal, and as of February 9, 2015 Supreme Court of Canada *Justice Rosalie Abella, Justice Andromache Karakatsanis and Justice Suzanne Côté* will review Ernst's application for leave to decide if the court will hear her case. In short, a regulator in Alberta cannot be sued for private legal claims, unless there is bad faith or gross negligence. Legal decisions like these and others provide guidance for government agents, industry operators, policy-makers, members of the judiciary, and private citizens within the jurisdiction where the decision takes place, as well as cross-jurisdictionally. Particularly where cases are complex or there is no existing precedent, justices will turn to other states, provinces, and nations for legal decisions made under similar circumstances. However, because multi-stage hydraulic fracturing and directional drilling are relatively new technologies, there are few precedent-setting decisions; many related issues are currently before the courts. As use of these technologies and their associated waste stream sees exponential growth, court decisions related to handling, transport, treatment, and disposal of wastewater may influence the development of regulations.

Finally, there are industry initiatives that influence handling, transport, treatment, and disposal of wastewater. For example, in 2012, the Canadian Association of Petroleum Producers (CAPP) introduced guiding principles for hydraulic fracturing, and specific operating practices building on the aforementioned principles for industry. Among other requirements, these principles

[19] For more information see: *Jessica Ernst v. Energy Resources Conservation Board & Encana Corporation*. (November 13, 2013). Alberta Court of Appeal. Appeal Number: 1301-0346AC. Retrieved from: *http://www.ernstversusencana.ca/wp-content/uploads/2014/02/2014-02-03-Ernst-v-ERCB-Appeal-Factum.pdf*

strongly recommend CAPP members to recycle and treat flowback fluids and mitigate risks related to storage, transport, and disposal of wastewater. CAPP states that it is committed to "safeguard the quality and quantity of regional surface and groundwater resources, through sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse as much as practical" (CAPP, 2012). CAPP member companies are strongly encouraged to comply with CAPP Operational Requirements when sourcing, measuring, or reusing water, although the requirements are not legally binding. Best management practices (BMPs) are an important asset to wastewater management; however, they are only useful insofar as they are widely adopted and utilized by industry operators.

3.2.3 Changes in regulation over time

In general, regulation changes over time in response to technological advances, public pressure, scientific discovery, and societal values. In the regulations that govern oil and gas extraction specifically, environmental disasters, risks posed to human health and (worker) safety, and intensification of industrial activities themselves have also precipitated such changes. Indeed, the relationship of legislation and regulations to oil and gas wastewater management is influenced by the occurrence and severity of events such as water contamination. In particular, environmental movement and citizens' rights groups in both the U.S. and Canada have pressured governments to enact more stringent legislation to protect drinking water, species at risk, sensitive habitats, and, in Canada, First Nations' rights. Provinces, as well as the federal government, have enacted charters and rights in their laws, such as in Quebec: a person has a right to a clean environment, or to clean potable water or that projects must be evaluated in view of sustainable development principles. The history of regulatory change thus provides a chronology of problems and challenges posed by an industry, and a given jurisdiction's attempt to mitigate those challenges. By reviewing regulatory responses of one jurisdiction against another, it is possible to identify best practices and sometimes extrapolate them to other situations undergoing similar stresses. Furthermore, a time-tailored perspective of regulations identifies gaps in regulatory frameworks, and presents opportunities to foresee and troubleshoot emerging problems, and to proactively mitigate risk presented by given activities.

Apart from indirectly portraying the history of issues, tracking the changes leading up to existing regulations also provides a better understanding of how departmental and regulatory objectives can produce conflicts. Conflicts between objectives must be mitigated, and regardless of how subtle they may be, they require regulators to balance tradeoffs when implementing and enforcing regulations. The NEB defines this as "The public interest is inclusive of all Canadians and refers to a balance of economic, environmental and social considerations that changes as society's values and preferences evolve over time" (NEB, n.d.). All jurisdictions within the study area maintain objectives dedicated to both resource development and also environmental protection and conservation to some degree. Regional and state governments have implemented innovative policy responses over time, and modified them accordingly. One particularly effective regulatory response addressing the 1985 objectives according to current shale gas development realities has been the emphasis placed on recycling fluids by the Delaware and Susquehanna River Basin Commissions (DRBC and SRBC).

3.3 Methodology

3.3.1 Approach taken

The approach used for this assessment consisted of: summarizing the existing and past regulations and legislation pertaining to handling, transport, treatment, and disposal of wastewater across the four shale gas formations; examining the jurisdictional level at which an *actor*[20] imposes and enforces regulations; and attempting to track the history and development of regulations over time.

The research was guided by the following questions:

- How do wastewater handling, transport, treatment, and disposal standards differ between and within the formations?
- What are the primary influences on policy and regulations developed and in use today, and have these influences changed over time?
- What are the observed gaps in regulations observed between and within jurisdictions?

Data were obtained from government websites, court documents, legal databases, and online versions of current legislation and regulations for the different jurisdictions across each formation. Additionally, academic literature was used to supplement the findings and provide relevant research and commentary.

For the purposes of this assessment, this chapter emphasizes regulations and legislation in British Columbia and Alberta, given their importance to Canada. Developing detailed timelines for the U.S. formations was out of the scope of this assessment, and these formations are thus discussed only to the extent to which such discussions could inform the Canadian context.

3.3.2 Database structure

A Microsoft Access database of existing and past regulations was created as a companion to this chapter (Notte and Allen, 2015). Regulations for Alberta, British Columbia, Texas, Ohio, Pennsylvania, and West Virginia are categorized according to the following criteria:

- if the regulation is historical or in force
- the date of enactment or repeal
- the authorizing Act or piece of legislation
- the category within handling (including transport), storage, treatment, and/or disposal that it pertains to
- a description or summary of the regulation
- a web link to facilitate review of the original document

This structure enables the user to search according to criteria, and generate a report consisting of key elements of the regulations that are pertinent to the query. As there is a state-wide ban on hydraulic fracturing activities in New York, its regulations are in draft form only and are not included in the database.

[20] A regulator, regulatory agency, or decision-maker with the legal authority to make and enforce regulations.

3.3.3 Description of how the results are summarized

The summary for each formation (Sections 3.4-3.7) is organized into sub-sections: a) *Policy and regulatory context*, which describes how regulators provide oversight of shale gas development and how policy is created; b) *Legislation and regulation*, which provides an overview of key legislation and regulations according to the main categories (handling, transport, treatment, and disposal); c) *Discussion*, which focuses on the cross-jurisdictional (if applicable) and temporal aspects of the assessment; and d) *Summary of findings*.

3.4 Montney

The Montney formation crosses the border between British Columbia and Alberta, and both of these provinces contain a substantial marketable resource base. This section focuses primarily on regulatory and policy development in British Columbia. Alberta's regulations, policies, and the development of such will be addressed in Section 3.5, describing the Duvernay. The lack of cross-jurisdictional coordination between British Columbia and Alberta will be discussed in Section 3.8.

3.4.1 Policy and regulatory context

Natural gas activities in British Columbia 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 BC Oil and Gas Commission (OGC) (established in 1998) serves as the 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,* which, in turn, enables some specific authorities under the *Environmental Management Act* (MNGD, 2013), as well as a number of other provincial enactments. To a lesser extent, the Ministry of Energy and Mines (MEM) and the Ministry of Environment (MOE) provide jurisdiction over other environmental or industry matters that fall under the *Heritage Conservation Act*, *Water Act*, Hazardous Waste Regulation (under the *Environmental Management Act*), *Land Act*, and *Forest Act*. Also, as much of the activity in the Montney is executed on Crown land, it is also, and to a lesser extent, 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 from time to time.

Currently, all oil and gas exploration and production activities, including wastewater management, are subject to applications for permits. Permitting is a primary mechanism for enforcing the regulatory framework.

3.4.2 Legislation and regulation

British Columbia's *Petroleum and Natural Gas Act* (*PNGA*), the first to address oil and gas activities separate from coal exploration and mining, was drafted in 1944, and was accompanied by regulations. Apart from minor amendments, wastewater regulations remained relatively unchanged for forty years. The *Oil and Gas Activities Act*, enacted in 2010, governs hydrocarbon production and extractive activities in British Columbia, and is complemented by regulations that set out criteria for handling, transport, treatment and disposal of waste products. It amalgamated and updated the regulations governed by the *Oil and Gas Commission Act* (Bill 32-1998), the *Pipeline Act* (RSBC 1996), and some aspects of the *PNGA* (RSBC 1996 - Chapter 361). The *Water Act* will be replaced by the *Water Sustainability Act* (*WSA*) (Bill 18-2014) 2015/16. Notably, changes to the regulatory regime covered by the *WSA* will include regulation of groundwater use for the first time. The *PNGA* (1996) defines "water source well" as a hole in the ground drilled to obtain water for the purpose of injecting water into an underground formation in connection with the production of petroleum or natural gas (*PNGA* [RSBC 1996 - Chapter 361] part 1). Authority over oil and gas industry subsurface water source wells, water injection wells, and water disposal wells is currently legislated under the *OGGA* (2008) and associated Drilling and Production Regulation.

See Figure A.1 (in Appendix A) for a timeline of key legislation, regulation, and various directives in British Columbia; Table A.1 (in Appendix A) is a summary of the topics addressed in Figure A.1.

3.4.2.1 Handling and storage

Division 4(20) of the Drilling and Production Regulations 2010. B.C. Reg. 282/2010 subject to the *Oil and Gas Activities Act* stipulates that:

> *Before a well permit holder drills, completes, plugs or begins production from a well, the well permit holder must ensure that adequate provision is made for the management of any oil, gas, formation water, drilling fluid, completion fluid, chemical substances, and waste.*

Additionally, Section 51 of the Drilling and Production Regulation pertains to wastes including produced water and requires that:

> *(1) A well permit holder must ensure that formation water, oil, drilling fluid, completion fluid, waste, chemical substances or refuse from a well, tank or other facility do not do any of the following:*
>
> > *(a) create a hazard to public health or safety;*
> >
> > *(b) run into or contaminate any water supply well, usable aquifer or water body or remain in a place from which it might contaminate any water supply well, usable aquifer or water body;*
> >
> > *(c) run over, pollute or damage any land or public road;*
> >
> > *(d) pass into or, on ice, over any water body that is frequented by fish or wildlife or that flows into any such water body.*
>
> *(2) A well permit holder who deposits into an earthen pit drilling fluids that may be harmful to domestic livestock or big game must maintain the pit so as to prevent domestic livestock or big game from ingesting the fluids.*

(3) A well permit holder who uses an earthen pit to store liquid waste from a well drilling operation must ensure that the pit is

(a) not located within 100 m of the natural boundary of a water body,

(b) not located within 200 m of a water supply well,

(c) constructed of clay or other suitable impermeable material with the bottom of the pit above ground water level,

(d) located or ditched so that it will not collect natural run-off water,

(e) is filled to not more than one metre below the point of overflow at any given time, and

(f) is completely emptied and any excavation filled without unreasonable delay.

(4) Within 90 days of completing a drilling waste disposal, a well permit holder must submit to the commission a report of the drilling waste disposal.

Appropriate handling and storage of wastewater is necessary for moderating risk to human health and safety and the environment. Prior to drilling a well, industry operators must submit a Well Permit Application. Applicants must indicate if wastewater will be stored on site and what method of containment will be used. The OGC (2014c) notes that particularly where c-rings, open-top tanks, or earthen excavations and pits are used, approval is subject to an applicant implementing additional measures to prevent harm to wildlife that may arise from exposure to wastewater. Specifically, industry information letter OGC 09-07 stipulates that adequate fencing, skimming hydrocarbon sheens from liquids, and netting for open-top containment units be used where applicable. The scope of criteria for on-site wastewater handling is highly specific for engineering parameters and performance measures. For example, the standard OGC requirement for wastewater storage in pits includes double liners with leak detection between the liners. OGC 09-07 stipulates that synthetic liners must be a minimum of 30/1000 inch, and be capable of withstanding extreme temperature fluctuations or exposure to other environmental conditions. The same industry information letter provides detailed criteria for the operation and construction thresholds to which storage infrastructure must adhere. Section 51 of the Drilling and Production Regulation states that on-site storage and disposal of wastes must not migrate off site, cause contamination, or pose a hazard to human health and safety. The regulation is not prescriptive, rather regulations are objective based. Approval is subject to OGC being satisfied that the objectives will be achieved. CAPP and other industry operators have thus identified "best practices" that provide the best possible standard for wastewater management.

Safeguarding human health is an important component of all oil and gas exploration and production activities. There are many general health and safety regulations that pertain to proper equipment handling, emergency response, and hydrogen sulfide safety. For example, the *Environmental Management Act* and its regulations have specific requirements related to emissions or discharges that could be harmful to the environment, human health or even aesthetic / nuisance concerns. Insofar as wastewater is concerned, the Oil and Gas Waste

Regulation (OGWR) in section 5(2) states that "vapours emitted while filling, cleaning, or storing tanks and other containers must not subject individuals to 'objectionable odours'." To this point, the OGC notes that: "Determining the point at which an odour is objectionable is not quantitative. The OGWR and Environmental Management Act definitions recognize that odour perception is subjective - people have varying degrees of sensitivity, dependent upon genetic and health issues" (OGC, 2014e).

3.4.2.2 Transport

Wastewater is typically transported by truck or pipeline. Larger industry operators, such as Encana or Apache, are more likely to build pipeline infrastructure than smaller operators because they have the capacity to also build their own treatment or disposal facilities. For this reason, truck transport continues to be the norm in northeast British Columbia and prior to and during hydraulic fracturing, there is an increase in heavy traffic, as required equipment and services, such as graders, water trucks, and other heavy equipment is transported to and from the site (FracFocus Chemical Disclosure Registry, n.d.) particularly given the rate of usage for third party operated disposal facilities (e.g. Tervita Earth Matters). Hydraulic fracturing does not strictly meet the criteria for classification as hazardous waste under British Columbia's Hazardous Waste Regulation; however, it is still tightly controlled under the *Environmental Management Act*, Hazardous Waste Regulation, Oil and Gas Waste Regulation, Transportation of Dangerous Goods legislation and regulations, and appropriate manifests. A *manifest* is a shipping document that travels with the waste from the point of generation, transportation, and disposal or treatment.

If a waste transporter or carrier fails to comply with the requirements and regulations stipulated by the manifest, and is found to be in violation while managing an operator's waste, the industry operator may be held liable as well as the transporter for any damages arising from the violation. Under Part 10, Division 1 of the *Environmental Management Act*, offenders can be fined up to $3 million or imprisoned for 3 years. This is particularly so for cases where negligence is determined to be a factor in the violation. False statements made on a waste manifest by a transporter or carrier of waste may also be punishable with a fine of $200,000. A facility operator may not accept waste that is not accompanied by a manifest or shipping document clearly detailing the constituents of the wastewater (Hazardous Waste Regulation B.C. Reg. 63/88: 5(2)).

As per the *Transport of Dangerous Goods Act* (*TDGA*), trucking transport tanks for any product type must not leak or allow emissions to escape. Because agitation and movement during travel can cause dissolved gasses or volatile organic compounds to be released, transporters are required by the *TDGA* and the Oil and Gas Waste Regulation to control any emissions that may escape from tanks. In the event of a leak or discharge, the emission must be reported and remediated as soon as possible. Under the same Act, local municipalities are vested with the power to mandate the time of travel or route used by wastewater haulers.

Pipelines transporting wastewater (and water used for fracturing) rarely cross provincial boundaries. As such, regulation usually falls solely under provincial jurisdiction and is subject to British Columbia regulations and permitting protocols (the National Energy Board regulates any transmission pipelines crossing provincial boundaries). Pipelines in British Columbia are subject to the *Oil and Gas Activities Act*, and the permits issued under them. 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. Feeder pipelines and gathering pipelines frequently used for collecting and transporting oil and gas wastewater almost always fit these criteria (Notte, 2014). Additionally, pipelines are subjected to Integrity Management Programs (IMPs), a regulatory requirement in British Columbia since their introduction in 1999 (OGC, 2014e). The IMP is a self-assessment, done every 5 years, that describes how an operator's infrastructure meets regulatory requirements. These plans are audited by the OGC for adequacy and conformance to requirements. Where pipelines are found to be out of compliance, the IMP proposes a timeline for rectifying the problem (OGC, 2014e).

3.4.2.3 Treatment

As discussed in Chapter 2, in some cases, wastewater may be stored, treated, and reused in subsequent operations (OGC, 2010). There are no regulatory requirements for on-site wastewater treatment; however, industry operators are encouraged to minimize their water use footprint by recycling water returned from fracturing operations (OGC, 2010). On-site treatment and wastewater recycling uses filtration or sedimentation to remove suspended solids and proppant from fluids, thus reducing costs to industry operators and environmental impacts by reducing truck traffic, vehicle emissions, road wear, and noise associated with transport traffic (PSAC, 2014).

3.4.2.4 Disposal

Disposal of hydraulic fracturing wastewater in British Columbia is limited to underground injection, as per section 7(1) of the OGWR. Disposal options such as surface discharge, or beneficial reuse are prohibited under the *Environmental Management Act*; any unauthorized emission or spill is a violation of the *Environmental Management Act*. Most regulation of underground disposal is achieved through granting permits and licenses to operators, and rules and protocols are further enumerated by the OGC and the MOE. The OGC permits underground disposal of fracturing wastewater and other non-hazardous wastes (formerly termed *non-special wastes*) as per criteria outlined in the OGC Application Guideline (see Table 3.2).

NORMs in Canada are considered distinct from man-made radionuclides and nuclear fuel cycle materials, and are exempt from legislation administered by the Canadian Nuclear Safety Commission. Individual provinces and territories have imposed standards for handling and safety, resulting in inconsistent interpretation and implementation of regulations (Health Canada, 2013). Regulating NORMs focuses on preventing exposure as a means to protect human and environmental health. Therefore, many provincial regulations are administered through health ministries and occupational health and safety organizations. The Federal Provincial Territorial Radiation Protection Committee has issued standards to standardize NORM handling, transport, and treatment requirements between jurisdictions. The British Columbia provincial government defers to these standards.

As seen in Chapter 2, there are numerous injection wells in British Columbia. Currently, there are 112 active approved disposal wells in BC (OGC, personal comm.). These wells are used to access two types of formations:[21]

1. Depleted hydrocarbon pools –have demonstrated the ability to contain a fluid at initial discovery conditions. Depleted pools have already been geophysically assessed to have capacity to contain significant volumes of fluids and demonstrate containment. Once depleted, these reservoirs are considered fit to serve as disposal units for non-hazardous liquid waste, including produced water.
2. Deep aquifers – Those that contain saline water[22] and have excess storage capacity beyond existing water volumes may be deemed viable for non-hazardous waste and produced water disposal. This assessment is dependent upon the size of the aquifer and its geological features.

Disposal formations must be shown to be contained by impermeable cap and base formations, competent to contain fluid within the area of influence.

If a single operator wishes to utilize a spent hydrocarbon pool or saline aquifer for its own disposal purposes, the permitting process is administered by the OGC, pursuant to the *Oil and Gas Activities Act*. This is the most common mechanism for wastewater disposal in British Columbia (Carr-Wilson, 2014). In some cases, operators will utilize a third party or commercial disposal site; this is common practice for small operators who lack the financial resources to operate their own disposal wells (Carr-Wilson, 2014). Any disposal site that accepts third party waste must apply for a permit from the Ministry of Environment under the *Environmental Management Act*. Applications for disposal well approvals are pursuant to "special projects" criteria listed under section 75 of the *Oil and Gas Activities Act*.

Permits are granted for a given disposal reservoir according to information provided in the application process. This information includes, but is not limited to maps of the area indicating location of the proposed well in proximity to other geological features, infrastructure, and industrial operations; reservoir history and geology; volumetric pressure; information about the proposed disposal operations; analysis of water in the disposal formation; and, applicable statements from other subsurface tenants potentially affected by injection (OGC, 2014b). In order to prevent migration of contaminants into groundwater sources, disposal wells are required to be drilled more than 1000 metres below the land surface (OGC, 2014a). The OGC also notes that "pro-active monitoring of penetrated shallow aquifers is recommended practice, though not required at present, and it is advisable to include a monitoring plan in the application" (OGC, 2014b). Following the grant of a permit, the Drilling and Production Regulation further stipulates that: the rate and volume of injected substances must be metered (Division 6, section 74); and

[21] Current maps of active disposal wells in northeastern BC are available on the OGC's website in the section addressing subsurface disposal: *http://www.bcogc.ca/industry-zone/documentation/Subsurface-Disposal*.

[22] Saline, or "salt water" is defined by the Ohio Administrative Code as "any and all non-potable water resulting, obtained, or produced from the exploration, drilling, or production of oil or gas." British Columbia does not specifically define the parameters for saline water in regulations. In Alberta, "brackish" or saline groundwater is defined as having TDS of 4000 mg/L or more, as per Directive 81 (Water Disposal Limits and Reporting Requirements for Thermal In Situ Oil Sands Schemes).

industry operators must submit a monthly statement disclosing the volume of substances disposed of within 25 days of the end of the month that disposal occurred (Division 6, section 75). Also, as per the Drilling and Production Regulation, permit holders may request exemptions from any of the aforementioned regulatory criteria. Industry operators must explain why the regulation cannot be satisfied, propose alternative measures to meet the intent of the regulation, and, where applicable, describe a mitigation strategy for any anticipated effects (OGC, 2014c).

Table 3.2. Required approvals for waste injection (adapted from OGC, 2014b).

Well Type	Waste Type Allowed	Required Approval
Produced Water Disposal (Wastewater Disposal)	produced water; completion fluids; fracturing fluids flushed from the wellbore; flowback water	OGC Special Project (section 75 of *Oil and Gas Activities Act*)
Non-Hazardous Waste Disposal	produced water; completion fluids including recovered fracturing water; boiler blowdown water; tank wash water; rig wash water; spent glycols; drilling waste leachate	OGC Special Project (section 75 of *Oil and Gas Activities Act*) & *Environmental Management Act* Permit

3.4.3 Discussion

Prior to 1998, oil and gas activities in British Columbia were regulated by a myriad of actors. The MEM, MOE, Ministry of Lands and Parks, and Ministry of Forests all handled different aspects of regulation and permitting, as described below. The 1998 *Oil and Gas Commission Act* transferred and consolidated all of these powers under the OGC.

Pertinent regulation for oil and gas handling and disposal in British Columbia dates to the 1930s, when the *Gas Utilities Act* and the *Petroleum and Natural Gas Act* (*PNGA*) (1932) came into force. The *Gas Utilities Act*, however, did not and still does not specifically address the management of wastewater from oil and gas production, and the *PNGA* and related regulations took many iterations and amendments to directly address wastewater management. First of all, while the 1944 *PNGA* did possess the power to enact and enforce regulations in the event they were made, it had few provisions to regulate wastewater management; most provisions within the first *PNGA* that could be broadly applied to wastewater management were prohibitions against pollution occurring during the drilling phase of extraction and were specific to waste of oil and gas, but not wastewater (Order in Council 2033-1961). For example:

> *where any well is a menace to oil, natural gas or water bearing formations, or to life or property, and if remedial measures are considered necessary and the operator of the well fails to use such measures as directed by an officer of the branch, the chief of the branch, at the expense of the operator, shall take such steps…as may be necessary to carry out the remedial purpose" (section 28(6)).*

Thus, the definition of "waste" referred only to "underground or surface loss of potentially recoverable oil or natural gas and wasteful operations." Similarly, the first Drilling and Production Regulations (1944) stipulated that "no salt water and no drilling fluid shall be permitted to flow over the surface of any land" (section 36 (4)), but did not specify how wastewater was to be handled or stored.

The 1954 amendments to the *PNGA* still did not make mention of on-site storage for wastewater. Because most on-site storage at the time was dedicated to containing oil or gas, regulations were imposed by the *Fire Marshall Act* (1922) to prevent ignition events. As per the *PNGA*, 1954, waste oil could be drained into adequate pits and "burned immediately or transported from the site" (section 74(1)), and there was a general requirement that, upon completion of operations, "as soon as weather or ground conditions permit" the operator shall "drain and fill all excavations" (section 71(1)). Aside from this, the 1954 Act did not specifically refer to on-site storage of any other kinds of waste fluids. Waste prevention, on the other hand, was addressed in the *PNGA*, 1954 at section 72(1) stipulating:

> *The operator shall use every possible precaution in accordance with good conservation practice to stop and prevent waste of oil or natural gas in drilling and producing operations and, in storing, piping, or distributing oil or natural gas, shall not use oil or natural gas wastefully or allow it to leak or escape from natural reservoirs, wells, tanks, containers, or pipes.*

At this stage of the *PNGA*, information obtained from operators, including water disposal data, was held confidential (*PNGA*, 1954, section 51(1)f). Since 2012, the OGC has required industry operators to disclose the contents of fracturing wastewater online at FracFocus.ca within 30 days of completing a project.

The 1965 amendment of the *PNGA* then required industry to gain necessary authorizations to operate wells and permitted orders for waste disposal in underground formations (*PNGA*, 1965; RSBC 1960, c 280, s 97 & s 114). However, West Coast Environmental Law (1976) stated "these statutes have no provisions relating directly to the environment" (as quoted in Carr-Wilson, 2014). The Drilling and Production Regulations (1955) made pursuant to the *Petroleum and Natural Gas Act* (1954) regulations made provisions for the use of storage tanks to prevent loss of petroleum or natural gas, and prohibited the use of "unprotected earth excavations" (section 51(1)). The 1976 Drilling and Production Regulations then permitted earthen pits to be used for emergency wastewater storage provided there was only one per site, it did not exceed 6000 square feet, and was operated satisfactorily to the Branch (Division 91). Additionally, Division 96 required injected wastewater to be measured.

As in the regulations for oil and gas handling and disposal, oil and gas wastewater was also not specifically mentioned in British Columbia's hazardous waste regulations for a long time. However, the 1984 Special Waste Regulation (Order in Council 0236-1984) categorized "petroleum product and water mixtures" as a kind of oil waste. This regulation requires that transporters be licensed, and complete and file detailed manifests with the director of the Waste Management Branch. Transport containers were required to be designed and constructed in such a way that:

8 (a) the special waste will not be released into the environment, and

(b) the effectiveness of the packaging of the special waste will not be substantially reduced (Special Waste Regulation, Part 3, section 8).

From this amendment on, wastewater regulations in British Columbia became more comprehensive. For example, British Columbia first relied on Alberta's Drilling Waste Management program guide, which stipulated criteria for mix-bury disposal, landspray, and land farming. Where land farming was proposed, industry operators were required to give notice to the Ministry of Water, Lands and Air Protection (WLAP). In 2002, WLAP's capacity (due to government restructuring) was reduced for activities such as providing advice to industry and decision-makers regarding habitat and ecosystem protection, and directly protecting wildlife, habitat, and fish where risk was deemed to be low (WLAP, 2002). WLAP became part of a redesigned Ministry of Environment in 2005; the same year, the existing Oil and Gas Waste Regulation was brought into force. Also, with the 1996 version of the *PNGA*, recommended modes of transport were first specified. Passing the *Oil and Gas Activities Act* (*OGAA*) in 2008, in particular, signified a substantive change to the legal framework governing all oil and gas activities in British Columbia. The previous regulatory regime was more than 40 years old, and its features were spread among three primary Acts. The *OGAA* clarified the regulatory authority held by the Oil and Gas Commission and its jurisdiction over consultation and notification requirements, geophysical activities, drilling and production activities, pipeline and liquefied natural gas facilities, and fees, levies and security, and consultation with First Nations. Most of these powers existed under pre-existing legislation that was consolidated under the *OGAA*.

Environmental standards are now regulated according to *OGAA* objectives and the objectives contained under the Environmental Protection and Management Regulation. The Environmental Protection and Management Regulation provides for the protection of water, riparian values, wildlife and wildlife habitat, old-growth forests, resource features and cultural heritage resources. In particular, section 6 of the regulation stipulates the following objectives with respect to wildlife and wildlife habitat that are prescribed for the purposes of the definition of "government's environmental objectives" in section 1 (2) of the Act:

a. that operating areas not be located within any of the following:
   i. a wildlife habitat area, unless an operating area will not have a material adverse effect on the ability of the wildlife habitat within the wildlife habitat area to provide for the survival, within the wildlife habitat area, of the wildlife species for which the wildlife habitat area was established;
   ii. an ungulate winter range, unless an operating area will not have a material adverse effect on the ability of the wildlife habitat within the ungulate winter range to provide for the survival, within the ungulate winter range, of the ungulate species for which the ungulate winter range was established;
   iii. a fisheries sensitive watershed, unless an operating area will not have a material adverse effect on the ability of the fisheries sensitive watershed to protect downstream fisheries and watershed values.

The Drilling and Production Regulation (2010) requires that "[a] well permit holder who deposits into an earthen pit drilling fluids that may be harmful to domestic livestock or big game must maintain the pit so as to prevent domestic livestock or big game from ingesting the fluids" (section 51(2)), and Information Letter 09-07 further describes that storage vessels "must have adequate fencing to prevent wildlife access" and "mitigative measures to protect waterfowl including, but not limited to: installation of netting; removal of accumulated sheen; and treatment and removal of hydrocarbons."

British Columbia's Pipeline Regulation was enacted in 2010, and its amendments replaced the Pipeline and Liquefied Natural Gas Facility Regulation (PLNGFR) in 2014. A new feature of the Pipeline Regulation (as of 2011) is that, in addition to utilizing IMPs to manage risk, operators are also required to implement damage prevention programs. The purpose of a damage prevention program is to *anticipate* and prevent damage to the permit holder's pipeline (Pipeline Regulation B.C. Reg. 281/2010, section 7(1)b, emphasis added).

It must be noted that, as seen in the focus and development of wastewater regulations, the emphasis on waste prevention was historically (pre-1976) directed at preventing economic loss, rather than preventing environmental degradation. In the absence of regulations, there was no prior incentive for operators to manage wastewater beyond the most convenient and cost-effective mechanisms. However, current regulations speak to mitigation of environmental consequences.

3.4.4 Summary of findings

Regulations comprehensively addressing wastewater management (handling, storage, treatment, and disposal) are a very new development. All of the current regulations in British Columbia have been enacted after 2010. The *Petroleum and Natural Gas Act* and the *Environmental Management Act* were amended in 2013, and the *Oil and Gas Activities Act* was amended in 2014.

The regulation of hydraulic fracturing wastewater management protocol primarily exists through permitting. There are numerous highly specific criteria that must be addressed during the permitting stage, but few specific requirements after a permit is granted. After receiving a permit, the operator is required to comply with the conditions under which that permit is granted, including the methods proposed for achieving objectives. Where requirements exist, they are often fulfilled by self-reporting mechanisms (such as IMPs) performed by industry operator. Where wastewater disposal is concerned, the OGC requires a Monthly Injection/Disposal Statement to be submitted as a condition of approval, reporting the volume of fluid disposed and average wellhead pressure (FracFocus, n.d.).

Despite the growing intensity of oil and gas activities across the province, British Columbia's laws and regulations have never provided mechanisms to address cumulative impacts posed by drilling activities and the growing volumes of wastewater generated. For this reason, regional cumulative effects studies are underway in British Columbia and Alberta, and are bringing together stakeholders across academia, industry, government, and communities (UNBC Health Research Institute, 2014). Regulations provide management protocols to be implemented at the immediate time of wastewater handling, transport, treatment, and disposal. Regulations addressing wastewater are not new under *OGAA*; in fact, many of the regulatory requirements fall outside *OGAA* and many of the *OGAA* provisions existed in similar form under predecessor legislation, although new iterations of regulations serve to strengthen pre-existing forms. There is limited capacity to address impacts that may arise many years in the future from wastewater disposal (Carr-Wilson, 2014; Howard, 2005); however, British Columbia's *Environmental Management Act* enforces a "polluter pays" principle whereby contaminated site remediation should prioritize "alternatives that provide permanent solutions" (Theroux et al., 2014).

3.5 Duvernay

3.5.1 Policy and regulatory context

The Duvernay in northwestern Alberta is only recently under consideration for development; however, Alberta has been regulating its oil and gas industry for more than 75 years. In 2013, the Alberta Energy Regulator (AER) replaced the Energy Resources Conservation Board (ERCB), and was given authority over jurisdictional functions previously held by Alberta Environment and Sustainable Resource Development (AESRD); although the AESRD continues to develop policy. Like the OGC in British Columbia, the AER serves as the single-window regulator of all oil and gas related activities in the province; all industry operators must apply for licenses from the AER to conduct oil and gas exploration and production activities. The AER's expanded role includes oversight of public lands and geophysical activities under the *Public Lands Act* and the *Mines and Minerals Act*, remediation subject to the *Environmental Protection and Enhancement Act*, and conservation and management of water resources under the *Water Act*. As per its mandate as a life-cycle regulator, the government of Alberta has granted the AER authority to: review and make decisions on proposed energy developments; oversee all aspects of energy resource activities in accordance with government policies; regularly inspect energy activities to ensure that all applicable requirements are met; penalize companies that fail to comply with AER requirements; and hold hearings on proposed energy developments (AER, 2014a).

Alberta is currently launching a pilot play-based regulation (PBR) application process for operators under a "fully unified industrial and environmental regulatory structure" (Jaremko, 2013, p. 149; Ernst and Young LLP. 2015). The process is designed to increase efficiency by streamlining application processes and reducing the number of individual permit applications required for oil and gas exploration and production. The AER (2014b) states that the purpose of the PBR pilot project is to:

- test the efficacy of a new regulatory approach that is more risk based and emphasizes operator performance and considers cumulative effects through management plans;
- establish risk-based, play-based requirements for the operating area;
- test a single application and decision-making process for energy development projects;
- test the effectiveness of the single application and play-based requirements in achieving pilot objectives;
- obtain feedback from stakeholders on the PBR approach; and
- identify any changes to current regulatory approaches that are needed to support PBR.

The Duvernay is the focus of the PBR pilot project and, if successful, will be the first regulatory framework to identify, consider, and attempt to mitigate cumulative effects of energy development projects.

3.5.2 Legislation and regulation

All oil and gas activities in Alberta are subject to the *Responsible Energy Development Act*, 2013 (*REDA*) and the *Oil and Gas Conservation Act*, 2000. The *REDA* is complemented by acts governing specific areas of energy exploration and production, regulations providing detailed guidelines for how legislation is to be satisfied, and directives that set out new or amended requirements for industry operators. The *Oil and Gas Conservation Act* gives the AER authority to make and enforce rules stipulating permissions and methods for all aspects of handling, transport, and disposal of oil and gas wastewater (*Oil and Gas Conservation Act, part 5*). The Oil and Gas Conservation Rules provide the legislative requirements industry operators must abide by, and Directives enumerate the specific means by which requirements are to be met. Other important acts include the *Environmental Protection and Enhancement Act*, 2000 and, to a lesser extent, the *Mines and Minerals Act*, the *Public Lands Act*, and the *Water Act*. The *Environmental Protection and Enhancement Act* prohibits pollution and gives the AER authority to enforce compliance, establish liability, and assign penalties for infractions. The latter acts do not expressly deal with wastewater handling, transport, treatment, or disposal, but may provide guidance for decision-making or determining whether or not an action is permissible. For example, Section 52 of the *Mines and Minerals Act* makes provisions for inspections of injection wells and is relevant for tenure purposes, but operating and construction criteria for injection wells is enumerated in directives. Likewise, the *Public Lands Act* lists general prohibitions for actions occurring on public lands including unauthorized pollution (section 54).

See Figure A1 for a timeline of key legislation, regulation, and various directives in Alberta; Table A2 is a summary of the topics addressed in Figure A1.

3.5.2.1 Handling and storage

Directive 55 (2001), Directive 58 (2006), and Directive 55 (Addendum) (2011) identify the handling requirements imposed on operators for storage practices. They specify criteria for *primary containment* (i.e. storage) reservoirs, *secondary containment* systems, leak detection systems, spill prevention and loss control, weather protection, and procedural requirements for operations.[23] The overarching objectives of wastewater handling directives are to protect public safety and the environment. Directive 55 (Addendum) permits aboveground synthetically-lined walled storage systems (AWSSs), a new kind of storage system designed to contain hydraulic fracturing wastewater:

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[23] *Primary containment* refers to "a tank, vessel, pipe, truck, rail car, or other equipment designed to keep a material within it, typically for purposes of storage, separation, processing or transfer of gases or liquids. The terms vessel and pipe are taken to include containment of reservoir fluids within the casing and wellhead valving to the surface." *Secondary containment* refers to "an impermeable physical barrier specifically designed to prevent release into the environment of materials that have breached primary containment. Secondary containment systems include, but are not limited to, tank dykes, curbing around process equipment, drainage collection systems into segregated oily drain systems, the outer wall of double walled tanks, etc." (Both definitions from the IADC Drilling Lexicon).

Companies producing unconventional oil and gas reserves in other jurisdictions have used aboveground, synthetically-lined wall storage systems (AWSSs) in place of numerous single-walled aboveground tanks. They describe the advantages as including a smaller lease footprint, less truck traffic, fewer spills and releases because there are fewer piping and manifold systems, and fewer freezing issues in winter (Directive 55 – Addendum).

Two or more on-site AWSS may be utilized as impoundments to facilitate wastewater recycling and to minimize the use of freshwater resources (section 2.2). Criteria for construction, approvals, and operating procedures are specific and applicable to all AWSS; however, Directive 55 (Addendum) also mandates that site-specific factors be considered and approved of by a certified professional. Factors under consideration include: substrate stability and bearing capacity; slope and grade; adequacy of surface conditions; and, the need for an intervening geotextile cushion[24] (section 2.2 (6)). Other kinds of containment include: aboveground and underground tanks, containers, lined earthen excavations, and bulk pads (as per Directive 55 – Addendum).

Additionally, storage systems must not present a hazard to wildlife. Industry operators are given agency to decide whether or not to dike aboveground storage tanks, and are "expected to use reasonable judgment to ensure that environmentally sensitive areas are protected" (section 4 (2)). Directive 58 stipulates all other criteria for handling, treatment, and disposal of wastewater that are not addressed in Directive 55 dealing with storage vessel criteria.

3.5.2.2 Transport

The *Transport of Dangerous Goods Act*, 1985 imposed regulations on companies transporting crude oil, oil and gas liquids, or poisonous, radioactive, flammable, and corrosive substances associated with the production of oil and gas. Notably, it exempts pipelines from its provisions, but makes companies accountable for appropriate classification of cargo by ensuring proper handling and establishing liability in the event of infractions. Under Directive 55, wastewater does not meet the criteria for classification as "dangerous oilfield waste" (DOW), but the directive does still require generators and transporters to use waste tracking systems and manifests identifying the waste, its volume and characteristics, where it originated, and its endpoint for treatment or disposal (Part C, Section 8). However, occasionally the Alberta government (specifically, the Department of Transportation and Utilities) grants a Permit for Equivalent Level of Safety to a waste generator or hauler in order to reduce their documentation requirements under certain conditions (Directive 58, Section C, Part 8).

The *Pipeline Act*, Pipeline Regulation, and Canadian Standards Association (CSA) standards applicable to pipeline construction and operation regulate lawful pipeline transport of wastewater. The AER implements a pipeline management and inspection program that considers kinds of fluids transported, location, line size, failure history, and the overall history of company compliance (AER, 2013). Because wastewater can be corrosive and not all companies may

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[24] A sheet of material that is partially impervious to liquid and resistant to penetration damage. It is used as part of an engineered system to provide a filter, or to facilitate proper drainage, and to serve as a cushion for another geomembrane system and provide structural support (IADC Drilling Lexicon, 2014).

implement voluntary BMPs, the AER conducts inspections and investigations into wastewater line failures. Licensees must report any spills, leaks or ruptures, as well as the volume of the spill, pursuant to the 2005 Pipeline Regulation.

3.5.2.3 Treatment

Directive 58 and Directive 58 (Addendum) outline the criteria for treatment of all oilfield wastes. Wastes such as drilling muds, cement returns, and soils must be processed by an approved waste management facility and, upon fulfilling toxicity, salinity, and TDS criteria, are eligible for a wider variety of disposal options than wastewater. The AER promotes reuse, recycling, and recovery as a mechanism to minimize the waste stream. Industry operators may store wastewater pursuant to the criteria discussed above, and treat it to make it suitable for reuse. Off-site treatment facilities are subject to regulatory approval and permitting. As repeated reuse of wastewater concentrates contaminants (Abdalla et al., 2011b), once wastewater reaches a TDS load where it cannot be reused, it may be treated or disposed of.

3.5.2.4 Disposal

Disposal of wastewater is subject to requirements in Directive 51 addressing injection and disposal wells. The oil and gas industry generates other waste products (such as mud and cuttings from drilling activities) that are subject to provisions enumerated in Directive 50. According to Directive 50, there is a variety of management practices available to drilling wastes that are not permissible for produced or flowback water (referred to collectively as wastewater in this assessment). According to Directive 51, shale gas wastewater is not classified according to the same criteria as "oilfield or industrial wastes", and may be disposed of in a Class I or Class II injection well. Class I Wells are used for the disposal of produced water, specific common oilfield waste streams, and waste streams meeting specific criteria; Class II Wells are used for the injection or disposal of produced water or brine equivalent (Alberta IL 94-02 Injection and Disposal Wells). There are two sub-classes for Class I (Class Ia and Ib). Class Ib and II wells require cement casing across all useable groundwater zones[25], but do not require daily monitoring, or stringent operating parameters such as those required for Class Ia wells used for oilfield and industrial wastes. Regulation concentrates on wellbore integrity, compatibility of the formation and injected fluids, ensuring that any NORMs are compatible with the injected fluids, and that injected fluids will not migrate from the injection site to other strata. Few regulatory conditions are imposed after injection.

As noted above for British Columbia, the Alberta government defers to the national standards for NORMs; provincial directives do not expressly deal with TENORMs in wastewater management.

Directive 58 and Directive 58 (Addendum) outline the criteria for disposal of all oil and gas field wastes. As mentioned above, wastes such as drilling muds, cement returns, and soils must be processed by an approved waste management facility, and upon fulfilling toxicity, salinity, and total dissolved solids (TDS) criteria are eligible for a wider variety of disposal options than wastewater. Disposal methods not available for wastewater include landspreading, landspray,

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[25] Directive 51 defines "usable groundwaters" as groundwaters with a TDS content of 4000 mg/L, or less.

and bury-cover. Pursuant to Directive 58, disposal of any liquid waste into landfills is prohibited, and wastewater may not be disposed of through discharge to surface water, even if treated.

3.5.3 Discussion

Energy regulation in Alberta has been evolving for more than 75 years. Significant oil and gas discoveries in Turner Valley between 1914 and 1936 induced a frenzy of development. The natural gas produced, in conjunction with oil and naphtha (or, natural gas liquids), had insignificant commercial value, and 500-600 million cubic feet per day were flared as industrial waste (Jaremko, 2013). Early waste prevention focused on preventing waste of energy resources, but addressing pollution was also a factor. Early regulation lacked specific language to address human and environmental impacts, yet the ERCB's early conservation and safety mandate permitted such considerations to be addressed and responded to. The federal government transferred jurisdiction over natural resources to the province of Alberta under the Natural Resources Acts in 1930. In 1938, the Government of Alberta established the Petroleum and Natural Gas Conservation Board (predecessor of the ERCB) to serve as the oil and gas industry's supervisory body and prevent wasteful practices. While this new regulatory body was able to address wasteful flaring and loss of product during drilling and production, it did not address wastewater.

The Alberta government has been issuing directives to guide resource exploration and production since the 1970s. Some of these early directives are still in effect; however, current regulations and directives pertaining to wastewater handling, transport, treatment, and disposal are no older than two decades. The oldest directive still relevant to regulation was drafted in 1994 and pertains to injection well testing and logging requirements. Until the 1990s, Alberta produced more energy products than pipeline infrastructure had capacity to accept or markets could absorb, and the Energy Resources Conservation Board evolved from solely orchestrating waste prevention to managing the resource including its waste stream (Jaremko, 2013). Growing pollution issues, as were witnessed in Turner Valley with flaring and product waste, demanded restructuring of regulations to address the growing problems of pollution and contamination.

Pursuant to section 3 of the *Energy Resources Conservation Act*, 2000 (*ERCA*), the ERCB evaluated projects according to whether they were considered to be in the public interest, the social and economic effects of the project, and expected environmental impacts. Under the *Responsible Energy Development Act*, 2012 (*REDA*) and its associated regulations, the AER considers project applications according to slightly different criteria than previous applications. Currently, projects are considered according to the social and economic effects of the energy resource activity; the effects of the energy resource activity on the environment; and the impacts on a landowner as a result of the use of the land on which the energy resource activity is or will be located. While there is terminology overlap between the *ERCA* and the *REDA*, the new emphases taken together with the PBR pilot project's concentration on cumulative effects and risk management suggest that the AER's new operating practices may be an improvement over the previous regulatory regime (Jamieson & Ference, 2013).

3.5.4 Summary of findings

Regulation in Alberta has traditionally been very prescriptive. Criteria for on-site handling and construction of storage infrastructure are highly detailed. Additionally, directives and regulations specifically addressing wastewater containment, handling, transport, treatment, and disposal are relatively new developments. Alberta is beginning to follow BC approach by adopting goal-oriented regulations. Implementing a cumulative effects management (CEM) approach in the Duvernay will have benefits for adjudicating the overall performance and consequences of energy development projects. Because consequences of any kind of development may be unanticipated and/or arise at later stages of the project's life-cycle, anticipating inter-connected effects provides additional barriers to negative externalities, or social and environmental costs experienced by parties not directly benefitting from extractive activities. The PBR approach demands a higher level of engagement and collaboration from operators toward each other and other stakeholders. The AER states that the play based regulation pilot project will (AER, 2014c):

a) encourage applicants to collaborate on surface development plans and participate in the pilot in order to:
    a. minimize the number of facilities and other surface impacts during the pilot, and
    b. ensure that effective practices are used to minimize fresh water use and optimize water reuse;
b) ensure transparency by engaging stakeholders on the play-based regulation approach throughout the pilot; and
c) explain the costs and benefits of implementing the play-based approach.

Moreover, the AER intends to use hazard and risk identification according to a range of scenarios to identify optimal parameters for operational performance under different conditions, geographic features, and site-specific issues (AER, 2014b). This approach implements BMPs identified by Baxter et al. (2001), who enumerated specific criteria and stages for improving CEM approaches in Canada. The major features of successful CEM include the following features, in three primary stages (Baxter et al., 2001):

1) Context Scoping
    a) Have all other projects and perturbations in the region been identified?
    b) Does the cumulative effects assessment (CEA) incorporate applicable ecological and social objectives?
    c) Are CEA boundaries clearly identified and explained?
2) Analysis
    a) Are potential cumulative impact problems characterized?
    b) Is a systematic analysis of each identified cumulative impact problem identified?
    c) Are conclusions supported with a decision trail?
3) Management
    a) Is a responsive mitigation plan provided to avert predicted impacts?
    b) Is a goal-oriented, environmental management plan provided?

The stated objectives of the AER's PBR approach and the requirements for its application process incorporate all of these elements. Although social concerns do not explicitly enter the analysis, the PBR pilot project strives to "encourage transparency by engaging stakeholders on the PBR approach throughout the pilot (AER, 2014b). CEM is discussed further in Section 3.9.2 dealing with knowledge gaps relevant to decision makers.

3.6 Marcellus

The Marcellus Shale cross-cuts six state jurisdictions. However, this assessment considers the regulations only for the states of Ohio, Pennsylvania, New York, and West Virginia, given that they are the most active hydraulic fracturing states. New York has imposed a statewide moratorium since 2008, but is included in this study because its unconventional energy potential is similar to that of the other three formations.

3.6.1 Policy and regulatory context

Various state agencies have jurisdiction over oil and gas exploration and production in the Marcellus Shale states, as seen in Table 3.3.

Table 3.3. Marcellus states, regulatory agencies, and regulations.

State	Agency	Legislation
Pennsylvania	Pennsylvania Department of Environmental Protection (DEP); Office of Oil and Gas Management (OOGM)	PA Code, Title 25, Part 1, Subpart C, Article 1, Chapter 78 – Oil and Gas Wells
Ohio	Ohio Department of Natural Resources; Division of Mineral Resources Management	Ohio Revised Code, Title 15, Chapter 1509 Ohio Administrative Code, Title 1501
New York	New York Department of Environmental Conservation; Division of Mineral Resources	Title 6 NYCRR, Chapter 4, Quality Services Sub-chapter B
West Virginia	West Virginia Department of Environmental Protection; Office of Oil and Gas	WV Code of State Regulations (Oil and Gas Agency) Title 35-04 WV Code of State Regulations (Water Resources, Division of Water and Waste Management) Title 47, Series 13

Pennsylvania's Office of Oil and Gas Management (OOGM) develops policy and programs for the regulation of oil and gas development and production pursuant to the *Oil and Gas Act*, the *Coal and Gas Resource Coordination Act*, and the *Oil and Gas Conservation Law*. It oversees all oil and gas permitting and inspection programs, and develops statewide regulation and standards to guide industry operator actions (Pennsylvania DEP OOGM, 2014). Like most other jurisdictions, early development of oil and gas resources "occurred in an unregulated fashion with little thought given to anything but getting the product out of the ground" (IOGCC, 1992, p. 5); because of this, Pennsylvania had upwards of 17,000 open pits and unplugged wells remaining from the early extraction boom (IOGCC, 1992). Regulatory efforts since the 1960s have focused on remediating past pollution and preventing future pollution from mismanaged waste.

Ohio's Department of Natural Resources dates to 1961 when it became apparent that regulation needed to be coordinated under a single agency. The newly created Division of Oil and Gas was responsible for assuring protection of public safety, health, and the environment; promoting orderly and efficient resource extraction and development; and, assuring conservation of natural resources (IOGCC, 1995).

The State of New York banned hydraulic fracturing in December 2014, although a moratorium has been in place since 2008. Nevertheless, New York's Department of Environmental Conservation (NYDEC) administers oil and gas exploration and production through its Division of Mineral Resources (DMR). The DMR is responsible for regulations and permitting. In 2009, the NYDEC issued a draft Supplemental Generic Environmental Impact Statement (SGEIS) proposing regulations for hydraulic fracturing. The SGEIS has been open to a public review process, and has not yet been finalized. The SGEIS itself is not a regulation, but was developed to identify possible risks to the environment, as well as other impacts, and to suggest means for mitigation. One of these means was to impose a moratorium. Article 23 of the *Environmental Conservation Law* was passed in 1963 as the first comprehensive legislation for the oil and gas industry. It wasn't until 1981 that Article 23 was amended to require operators to remedy or prevent adverse environmental impacts arising from development and its waste stream.

West Virginia is one of the oldest natural gas producers in the U.S., dating to 1885 (IOGCC, 1993). In 1990, the State Legislature passed the West Virginia Ground Water Act, and gave the Division of Energy, Oil and Gas authority over permitting for natural gas wells. A year later, the Division of Environmental Protection was created in the same division as the Office of Oil and Gas, and was given authority to oversee all environmental concerns related to exploration and production. These agencies exist in the same capacity today and complement each other as joint regulatory bodies.

The four states' regulatory frameworks share common objectives. In the same or similar terms, jurisdictions require regulators to: 1) develop oil and gas resources, and 2) protect the environment. Other provisions may be included depending upon regional factors. Article 1, Section 27, part of the Pennsylvania Constitution since 1971, is the best example of an enshrined environmental protection mandate. It reads:

> *The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic, and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all of the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people.*

Despite prior legal assumptions that Article 1 was only weakly enforceable, the Pennsylvania Supreme Court held in *Robinson Township v. the Commonwealth of Pennsylvania* that subject to Article 1, Section 27, parts of Act 13 (Pennsylvania's oil and gas law) were unconstitutional.

Chief Justice Ronald Castille writes in the decision that Article 1, section 27 establishes two rights: The first is a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. The second is "a limitation on the state's power to act contrary to this right." These rights are equal in enforceability to other Constitutional rights. The Justices further elaborate that the environmental protection mandate implies a fiduciary responsibility by government to maintain and uphold a public trust.[26]

Because hydraulic fracturing produces significant volumes of waste, and effective management is challenging for operators, there are frequently trade-offs made between the competing interests of environmental conservation and resource development. The U.S. has a keen interest in developing Marcellus shale from an energy security and economics standpoint; however, there are myriad lawsuits, and human health and environmental impacts provoked by water contamination, forest fragmentation, complications arising during wastewater management, and ineffective treatment practices associated with hydraulic fracturing wastewater (Ubinger et al., 2010). Establishing proof of a causal connection between produced water management practices and impacts to surface water or human health is a separate matter. Assigning liability for water contamination is difficult to prove in court. Indeed, many cases are dismissed. However, some plaintiffs have been awarded damages for contamination caused by improper wastewater management practices. In *Fiorentino v. Cabot Oil & Gas.,* No. 09-CV-2284 (M.D. Pa., November 19, 2009) plaintiffs alleged that Cabot spilled diesel fuel onto the ground near their homes, discharged drilling waste into diversion ditches, and allowed three spills within a ten day period, among other things. In 2010, the Pennsylvania Department of Environmental Protection (PDEP) reached settlement terms with Cabot under which the company was permitted to continue extractive activities and the plaintiffs to maintain their suit. Under the settlement, the families collectively received $4.1 million, and PDEP was paid $500,000 by Cabot (Nicholson et al., 2012).[27]

3.6.2 Legislation and regulation

3.6.2.1 Handling and storage

Handling requirements for pits and tanks are contained in state laws, and are uniform in their stipulations for construction and operation for onsite storage and containment systems. All jurisdictions in this assessment of the Marcellus require permits for operating storage systems (Ohio Revised Code 1509.22, Section B2A; PA Code, Title 25, Part 1, Subpart C, Article 1 (*Oil and Gas Act*), Chapter 78.57 a, b; West Virginia Code Title 35, Series 4, Section 16.4). Pursuant to permitting stipulations, all jurisdictions using pits or tanks must construct and operate them in

[26] To read the Supreme Court of Pennsylvania's decision, see: *Robinson Township v. the Commonwealth of Pennsylvania* [Case No. 284], July 26, 2012 Retrieved from: http://www.pacounties.org/GovernmentRelations/Documents/CommonwealthCourtAct13Ruling20120726.pdf

[27] For a brief review of other case law pertaining to water contamination see: Barclay Nicholson, Kadian Blanson, and Andrea Fair. (May 9, 2012). Fracking's Alleged Links to Water Contamination and Earthquakes. *Section of Litigation.* American Bar Association. Retrieved from: *http://apps.americanbar.org/litigation/committees/energy/articles/spring2012-0512-frackings-alleged-links-water-contamination-earthquakes.html*; and Arnold & Porter LLP. (2014). *Hydraulic Fracturing.* Retrieved from: http://www.arnoldporter.com/resources/documents/Hydraulic%20Fracturing%20Case%20Chart.pdf

such a manner as to prevent overflow, leakage, or contamination. Pennsylvania and West Virginia stipulate that a minimum 2 feet of freeboard must be kept at all times, whereas Ohio stipulates that “the level of saltwater in excavated pits shall at no time be permitted to rise above the lowest point of the ground surface level” (Ohio Administrative Code 1501:9-3, Section 8A). All jurisdictions require impoundments to be “liquid tight.” Synthetic, or otherwise impervious, liners, dikes, berms, and/or spill diversion ponds are among methods prescribed by Marcellus jurisdictions to contain wastewater and, in some cases, regulations are highly specific in how such measures are to be implemented and operated. Pennsylvania’s requirements for synthetic liners found in PA Code, Title 25, Part 1, Subpart C, Article 1 (Oil and Gas Act), Chapter 78, Section 78.56(a) 2(i) are among the most specific however, Ohio and West Virginia also provide requirements for liners.

3.6.2.2 Transport

Transport of wastewater is subject to the same kinds of permitting protocols observed in other jurisdictions. Waste haulers and receivers must be licensed, and are subject to liability and compliance enforcement pursuant to state and federal hazardous waste regulations.

3.6.2.3 Treatment

The practice of recycling hydraulic fracturing wastewater is becoming widely accepted throughout the Marcellus region. This is, in part, influenced by regulations implemented by the Susquehanna River Basin Commission (SRBC), which provides limits for water withdrawals, and the Delaware River Basin Commission (DRBC) where there is a ban on drilling activities, which evaluates basin-wide impacts on a regular basis (STRONGER, 2010). Both Basin Commissions issue permits for consumptive water withdrawals. The DRBC has the power to enforce their regulations through fines, and exercises its right to do so (Spellman, 2013). In 2012, Pennsylvania’s Department of Environmental Protection (PA DEP) issued a revised general waste permit pursuant to the *Oil and Gas Act 13* that provides specific criteria and regulations guiding facilities treating wastewater. In particular, it incentivizes reuse by prohibiting any liquid discharge to surface water. Since the revised permit was issued, many new treatment plants have been built and recycling treatment capacity continues to grow across the state.

3.6.2.4 Disposal

Discharging wastewater into waterways is regulated under section 402 of the federal *Clean Water Act*, which establishes the National Pollutant Discharge Elimination System (NPDES) program. In most cases, the NPDES program is administered by states, but criteria and regulations are mandated by the Environmental Protection Agency (EPA). In Marcellus states, it is unlawful to discharge wastewater without such a permit, and protocols are similar in each jurisdiction. For example, in West Virginia, effluent may not be discharged into state waters without such a permit. However, non-NPDES permits may be granted by Executive Order in special circumstances by the Director of the West Virginia Department of Environmental Protection. Also, in Ohio, which requires wastewater to be disposed of in an injection well, exceptions are made where approval is given by the local county commission to permit surface application onto roads (OH Revised Code, Title 15, Chapter 1509.22).

Disposal wells across the U.S. are collectively referred to as *underground injection wells* and are regulated by the federal government pursuant to the *Safe Drinking Water Act* (*SDWA*). While there are six kinds of disposal wells in the U.S., only Class II Wells are approved for disposal of hydraulic fracturing wastewater (EPA, 2012). There are three kinds of Class II wells: enhanced recovery wells; disposal wells; and hydrocarbon storage wells. This assessment focuses on regulations pertaining to Class II disposal wells only, which account for approximately 20% of Class II Wells in the U.S. (EPA, 2012).[28] All disposal wells must be issued permits. Currently, Pennsylvania has nine brine disposal wells,[29] New York had six, West Virginia had seventy-four, and Ohio had one hundred and fifty-nine (Abdalla et al., 2011b). As seen in Chapter 2, operators in Pennsylvania have responded to insufficient injection well capacity by trucking wastewater out of state to other jurisdictions such as Ohio and West Virginia. Because oil and gas wastes are not considered "hazardous" under the federal *Resource Conservation and Recovery Act*, state regulations govern the handling, storage, treatment, and transport of shale gas wastewater prior to disposal. In response to the increase in volume of out-of-state wastewater entering Ohio for disposal, the Ohio Division of Oil and Gas Management passed stricter rules in 2014 under Ohio Revised Code 1509.22 requiring out of state transporters to submit to additional permitting, registration, and electronic tracking conditions. Although it has few injection wells, New York State does not currently face the same challenges as Pennsylvania because of the state-wide ban on hydraulic fracturing; however, if the ban is lifted, wastewater volumes may quickly overwhelm existing capacity.

Section 1422 of the SDWA stipulates the minimum requirements that states must have to meet the EPA's standards for Underground Injection Control (UIC) programs, which, among other things, are intended to establish requirements for industry operator permits, well construction, wastewater disposal, and monitoring and reporting for disposal sites. Once these requirements are met, states can apply for primacy over Class II Wells (i.e. for the state to have primary enforcement responsibility over the disposal wells, rather than the EPA), under section 1422 or 1425 of the *SDWA*. States must provide evidence that their UIC programs are effective (EPA, 2013), including a demonstration that their standards prevent contamination of waterways (SDWA, Section 1425). As discussed below, in the Marcellus, only West Virginia and Ohio have assumed primacy over their UIC programs.

3.6.3 Discussion

Regulations for underground disposal in West Virginia were first enacted in 1969 to guide practices for enhanced recovery and brine disposal, and primacy over the UIC program was granted to the state by the EPA in 1984. In Ohio, the state assumed primacy of its UIC program in 1982, pursuant to the *Safe Drinking Water Act*, 1974 (House Bill 743). Ohio then enacted its comprehensive brine transportation and disposal bill (Amended Substitute House Bill 501, 1985) to expand the Oil and Gas Division's oversight of wastewater transport and disposal as a means

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[28] The other two types are not used for wastewater disposal. Enhanced recovery injects brine, water, steam, polymers, or carbon dioxide into oil-bearing formations to recover residual oil and, in some limited applications, natural gas. Hydrocarbon storage involves injecting liquid hydrocarbons in underground formations where they are stored, generally, as part of the U.S. Strategic Petroleum Reserve (EPA, 2012).

[29] Only one of these Pennsylvania wells is licensed as a commercial disposal well and has limited capacity to accept wastewater. Thus, it is not permitted to accept wastewater from Marcellus fracturing operations. Commercial wells and brine wells are virtually the same, with the exception that a commercial well is licensed to accept third-party waste. There is insufficient capacity in all of these wells, given that there are only seven statewide.

to further protect public health and safety, and the environment. Aside from these, however, improvements in the regulatory regime have clearly not matched the pace of the rapid development of Marcellus resources. Since 2004, wastewater generation from shale gas production in Pennsylvania alone has increased by 570%, and has the potential to completely overwhelm disposal capacity throughout the Marcellus region if production continues at its current rate (Lutz et al., 2013). Rather than an imbalance between development and disposal infrastructure, however, regulatory change reports for Marcellus jurisdictions cite pollution concerns and stakeholder complaints as being the primary drivers for regulatory change (Abdalla et al., 2011a).

The most extreme examples of reactionary regulatory change are the myriad of moratoria enacted in counties across the Marcellus region; New York, in particular, imposed a statewide moratorium in 2008 in response to public concern regarding protection of New York City and Syracuse watersheds (SGEIS, 2011). A ban was implemented by the Governor in December 2014. Pennsylvania's regulations enacted in 2011 (25 PA Code, Chapter 78) were also developed in response to public allegations of health and safety threats (Abdalla et al., 2011a). In April 2011, Governor Corbett and then Pennsylvania Department of Environmental Protection (PA DEP) Secretary Mike Krancer called on the drilling industry to stop sending wastewater to treatment plants that had been permitted prior to August 2010. The PA DEP had passed regulations in 2010 requiring more stringent standards for TDS treatment prior to discharge at publicly owned facilities; however, existing facilities were grandfathered according to the previous regulations, provided they did not increase their input volume of wastewater. As such, in order to meet the new TDS standards and improve water quality in western Pennsylvania, Krancer and Corbett called on the owners of treatment facilities to voluntarily stop accepting fracturing wastewater. As Krancer stated:

> *While the prior administration allowed certain facilities to continue to take this wastewater, conditions have changed since the implementation of the TDS regulations. We now have more definitive scientific data, improved technology and increased voluntary wastewater recycling by industry. We used to have 27 grandfathered facilities; but over the last year, many have voluntarily decided to stop taking the wastewater and we are now down to only 15. More than half of those facilities are now up for permit renewal. Now is the time to take action to end this practice (PA DEP, 2011).*

This regulatory change required any new or expanded facility discharging unconventional wastewater to limit discharges to 500 mg/L for TDS, the same as the federal drinking water standard. Industry compliance with this has produced significant changes in disposal practices; since then, as noted in Chapter 2, reuse and recycling of flowback has never been higher, with some operators at 100% recycling (Mantell, 2011). However, there is some disagreement regarding what "recycling" and "reuse" actually mean. Additionally, because both processes concentrate TDS levels over time, it is not possible to indefinitely recycle or reuse the same wastewater without treating it or blending it with fresh water (Abdalla et al., 2011b). Therefore, while close to 100% of wastewater may be subject to onsite treatment early in its life-cycle, the PA DEP estimates that approximately 70% of wastewater is recycled or reused (Abdalla et al., 2011b). Furthermore, despite greater rates of recycling, intensified drilling activity has increased the total volume of wastewater produced in a given area, as well as associated issues such as an increase in the number of tanker trucks needed for wastewater transport, and an increase in the frequency of traffic accidents (Muehlenbachs and Krupnick, 2014). The EPA is actively involved in examining and mitigating the potential effects of hydraulic fracturing on watersheds and human health. In addition to currently undertaking a national study, the EPA issued a directive to six industry operators holding more than 50% of all permits for exploration and production activities in the Marcellus Shale region asking them to disclose how and where they dispose of or recycle wastewater generated in their activities (EPA, 2014). The EPA directive followed that of Krancer and the PADEP's request that operators voluntarily stop taking gas extraction wastewater to treatment plants.

3.6.4 Summary of findings

All regulators in the Marcellus region have been historically tasked with similar objectives in energy development and, to some degree, conservation as they are presently. For example, Ohio's Substitute House Bill 234, signed in 1965, tasked the Division of Oil and Gas with the objectives of assuring protection of public health, safety, and the environment; promoting the orderly and efficient development of oil and gas reserves; and assuring conservation of natural resources. Because of the occasional conflicts between resource development and environmental conservation, all jurisdictions in the Marcellus have had to occasionally amend and update regulations to effectively deal with wastewater management. Each state has done this in its own way. While New York has banned hydraulic fracturing, Pennsylvania, Ohio and West Virginia have opted to promote natural gas extraction, and regulate wastewater management in unique ways. Pennsylvania has restricted the amount of wastewater sent to treatment facilities. Because of this and the volumes of wastewater transported to Ohio for disposal, Ohio's new regulations also require wastewater haulers to install electronic transponders to monitor all brine shipments (SB 315 Keypoint Summary, 2012). Treatment and disposal of wastewater is, and will remain, a central issue for regulators, industry, and residents of the region.

3.7 Barnett

3.7.1 Policy and regulatory context

The Texas Railroad Commission (RRC), Oil and Gas Division, is responsible for regulating all exploration, production, transportation of oil, gas, and their associated wastes in the state, and thus in the Barnett formation. In particular, its role is to facilitate resource development, prevent pollution, protect the rights of interest owners, and ensure safety (RRC, 2014a).

The RRC was originally created in 1891 to regulate railroads. At this time, oil and gas exploration and production was intensifying, and the volumes produced greatly exceeded storage and pipeline capacities (IOGCC, 1993); water pollution became a serious issue, and excess product stored in earthen impoundments frequently ignited. As such, in 1905, the Texas State Legislature declared a state of emergency regarding the problems associated with oil and gas wells. Laws were enacted to prevent waste, but were not matched with equivalent enforcement capacity. Because pipelines were the most frequently utilized modes of transport for oil and gas products, the RRC was granted regulatory oversight of oil and gas operations in 1917, under the Pipeline Petroleum Law (Senate Bill 68, 35th Legislature, Regular Session). In 1919, the State Legislature passed legislation banning waste and transferring jurisdictional oversight of enforcement to the RRC. Under its new authority, the RRC issued rules under the Texas Administrative Code (TAC), stipulating criteria for oil and gas exploration and production to prevent waste and protect water. One of the most important rules it issued was Rule 20, which specifically addresses the protection of water quality. This rule continues to be an integral part of the regulatory framework and supports the regulations found in Rule 8, which addresses oil and gas wastes.

Since the beginning, regulating the oil and gas industry in Texas has been met with significant conflict. In the 1930s, production had intensified so much that the density of derricks was destabilizing the water table throughout eastern Texas (RRC, 2014a); concurrently, the overproduction of oil caused its market price to crash. When the RRC attempted to regulate production rates, industry operators sought recourse through aggressive litigation, and eventually the state military was called to restore order (STRONGER, 2003). Subsequently, the courts and State Legislature agreed that the RRC had within its jurisdiction to regulate production volumes. Since then, the RRC has been the predominant regulator of oil and gas activities in the State of Texas. Specifically, it holds jurisdiction over energy, transportation, public safety, and environmental protection (RRC, 2014a). Wastewater regulations crosscut all of the aforementioned jurisdictional areas. The RRC regulates through permitting, and publishes guidelines providing criteria by which actions may be undertaken. While the RRC maintains regulatory primacy, the commission entered into a Memorandum of Understanding with the Texas Commission on Environmental Quality (TCEQ) in 1982 to clarify the division of powers. The TCWQ regulates disposal wells.

The Barnett has historically been used in conjunction with conventional oil and gas extraction as source and sealing cap rock for reservoirs. Its economic potential for unconventional development was not realized until the 1980s, when Mitchell Energy utilized hydraulic fracturing and directional drilling technologies. A decade later, drilling activities in the Barnett intensified when natural gas prices began to rise (IOGCC, 1993a). Twenty-five counties are now affected by exploration and production activities associated with the Barnett – four of them are considered “core counties” and twenty-one deemed “non-core counties” (Railroad Commission of Texas, 2015). Denton, one of the core counties in the formation, successfully lobbied to include a hydraulic fracturing moratorium on its 2014 election ballot, which was subsequently passed by citizens.

3.7.2 Legislation and regulation

The RRC actively works with industry to identify ways to minimize the waste stream through recycling or beneficial reuse, and to minimize overall disposal volumes wherever possible (STRONGER, 2003). Rule 8 establishes a hierarchy of preferred methods for wastewater management in the State of Texas (RRC, 2014b): 1) source reduction; 2) recycling; 3) treatment; and 4) disposal.

3.7.2.1 Handling and storage

The backbone of all oil and gas regulation in Texas is the permitting system. Once a permit is obtained, the rules can be permissive. Pursuant to 16 TAC, Part 1, Chapter 3, Rule 3.8, section 47(d)2:

No person may maintain or use any pit for storage of oil or oil products. Except as authorized by this subsection, no person may maintain or use any pit for storage of oil field fluids, or for storage or disposal of oil and gas wastes, without obtaining a permit to maintain or use the pit.

Permits under Rule 3.8 are issued if the Commission determines that the maintenance or use of such pit will not result in the waste of oil, gas, or geothermal resources or the pollution of surface or subsurface resources (16 TAC, Part 1, Chapter 3, Rule 3.8, Section 47(d) 4G). Stipulations for wastewater handling and storage are further enumerated in 16 TAC, Part 1, Chapter 3, Rule 3.8, Section 47 (d) 6A which states:

(i) A person shall not deposit or cause to be deposited into a non-commercial fluid recycling pit any oil field fluids or oil and gas wastes other than those fluids described in subsection (a)(42) of this section [HF wastewater].
(ii) All pits shall be sufficiently large to ensure adequate storage capacity and freeboard taking into account anticipated precipitation.
(iii) All pits shall be designed to prevent stormwater runoff from entering the pit. If a pit is constructed with a dike or berm, the height, slope, and construction material of such dike or berm shall be such that it is structurally sound and does not allow seepage.
(iv) A freeboard of at least two feet shall be maintained at all times.
(v) All pits shall be lined. The liner shall be designed, constructed, and installed to prevent any migration of materials from the pit into adjacent subsurface soils, ground water, or surface water at any time during the life of the pit. The liner shall be installed according to standard industry practices, shall be constructed of materials that have sufficient chemical and physical properties, including thickness, to prevent failure during the expected life of the pit. All liners shall have a hydraulic conductivity that is 1.0 x 10-7 cm/sec or less. A liner may be constructed of either natural or synthetic materials.

3.7.2.2 Transport

All waste haulers in the State of Texas must have a permit. Under the Texas Administrative Code (16 TAC, Part 1, Chapter 3, Rule 3.8, section 8(f)5A), each actor in the entire life-cycle of wastewater transport may be held liable for misinformation, an accident, or unauthorized handling and transport of fracturing wastewater:

No generator or receiver may knowingly utilize the services of a carrier to transport oil and gas wastes if the carrier is required by this rule to have a permit to transport such wastes but does not have such a permit. No carrier may knowingly utilize the services of a second carrier to transport oil and gas wastes if the second carrier is required by this rule to have a permit to transport such wastes but does not have such a permit. No generator or carrier may knowingly utilize the *services of a receiver to store, handle, treat, reclaim, or dispose of oil and gas wastes if the receiver is required by statute or commission rule to have a permit to store, handle, treat, reclaim, or dispose of such wastes but does not have such a permit. No receiver may knowingly utilize the services of a second receiver to store, handle, treat, reclaim, or dispose of oil and gas wastes if the second receiver is required by statute or commission rule to have a permit to store, handle, treat, reclaim, or dispose of such wastes but does not have such a permit. Any person who plans to utilize the services of a carrier or receiver is under a duty to determine that the carrier or receiver has all permits required by the Oil and Gas Division to transport, store, handle, treat, reclaim, or dispose of oil and gas wastes.*

3.7.2.3 Treatment

The Texas RRC suggests that industry operators make all reasonable efforts to reduce the quantity and toxicity of wastes; however, they acknowledge that wastewater can pose a special challenge because volumes are a by-product of extraction and production activities (RRC, 2014b). Thus, recycling and reuse are encouraged. Treatment techniques to address TDS and toxicity may be implemented on- or off-site, and render wastewater suitable for reuse. In order to reduce the administrative complexity experienced by industry operators under the current permitting system, the RRC proposed a set of rules to make on-site, non-commercial wastewater treatment for the purposes of recycling a viable option. These regulations, which took effect in 2013, authorized industry operators to recycle wastewater without a permit. Rule 3.8 of the Texas Oil and Gas Division regulations governing non-commercial fluid recycling, as it is defined under the rule, was designed to encourage Texas operators to “continue their efforts at conserving water used in the hydraulic fracturing process for oil and gas wells.” Rule 3.8(a)(41) defines "non-commercial fluid recycling" as "[t]he recycling of fluid produced from an oil or gas well, including ... fluids produced from the hydraulic fracturing process." Rule 3.8(a)(41) further states that non-commercial fluid recycling can take place on a variety of sites related to oil and gas wastewater management including disposal and injection wells. Additionally, Rule 3.8(a)(41) provides that contractors or oilfield service providers may also be permitted to conduct on-site recycling activities on behalf of primary lease holders. These amendments to the rules, combined with regional water shortages, have substantially increased the utilization of onsite recycling practices.

3.7.2.4 Disposal

Deep injection is the preferred management option in the Barnett. There are 2,458 injection wells reporting maximum monthly injection rates of 1,500 barrels of produced water per month spread across the eighteen counties overlying the Barnett formation (Frohlich, 2012). Additionally there are 152 commercial injection wells in the Barnett that are licensed to accept wastewater from third parties (Tintera, 2008).

The EPA UIC Program is federal, and therefore is applicable to every state. Some states have assumed primacy, or control, over their injection programs, but well classification is nation-wide. Federal disposal requirements as per the *Safe Drinking Water Act*’s UIC Program has already been discussed in the above section on the Marcellus. The Barnett is equally subject to the stipulations of the UIC Program. The Texas Administrative Code (16 TAC, Part 1, Chapter 3, Rule 3.8, section 47(d)1) specifies:

Prohibited disposal methods…no person may dispose of any oil and gas wastes by any method without obtaining a permit to dispose of such wastes. The disposal methods prohibited by this paragraph include, but are not limited to, the unpermitted discharge of oil field brines, geothermal resource waters, or other mineralized waters, or drilling fluids into any watercourse or drainage way, including any drainage ditch, dry creek, flowing creek, river, or any other body of surface water.

16 TAC, Part 1, Chapter 3, Rule 3.98, Section 77 (m) 2 states that:

Except as otherwise specifically provided in this section and subject to all other applicable requirements of state or federal law, a generator of hazardous oil and gas waste must send his or her waste to one of the following categories of facilities for treatment, storage, disposal, recycling, or reclamation:

i. *an authorized recycling or reclamation facility;*
ii. *an authorized treatment, storage, or disposal facility;*
iii. *a facility located outside the United States, provided that the requirements of subsection (v)(1) of this section (relating to exports of hazardous waste) are met;*
iv. *a transfer facility, provided that the requirements of subsection (w)(3) of this section are met;*
v. *if the waste is generated by a CESQG*[30]*, a facility permitted, licensed, or registered by a state to manage municipal or industrial solid waste; or*
vi. *if the waste is generated by a CESQG, a centralized waste collection facility (CWCF) that meets the requirements of subsection (m)(3) of this section.*

[30] Conditionally Exempt Small Quantity Generator. To be classified as a conditionally exempt CESQG, 16 TAC, Part 1, Chapter 3, Rule 3.98 states that the operator: during any calendar month, a generator of hazardous oil and gas waste must: (i) generate no more than 100 kilograms (220.46 pounds) of hazardous oil and gas waste in that calendar month; and (ii) accumulate no more than 1,000 kilograms (2204.60 pounds) of hazardous oil and gas waste on-site at any one time.

Other authorized disposal methods under Rule 3.8, include:

A. *Fresh water condensate. A person may, without a permit, dispose of fresh water which has been condensed from natural gas and collected at gas pipeline drips or gas compressor stations, provided the disposal is by a method other than disposal into surface water of the state.*
B. *Inert wastes. A person may, without a permit, dispose of inert and essentially insoluble oil and gas wastes including, but not limited to, concrete, glass, wood, and wire, provided the disposal is by a method other than disposal into surface water of the state.*
C. *Low chloride drilling fluid. A person may, without a permit, dispose of the following oil and gas wastes by landfarming, provided the wastes are disposed of on the same lease where they are generated, and provided the person has the written permission of the surface owner of the tract where landfarming will occur: water base drilling fluids with a chloride concentration of 3,000 milligrams per liter (mg/liter) or less; drill cuttings, sands, and silts obtained while using water base drilling fluids with a chloride concentration of 3,000 mg/liter or less; and wash water used for cleaning drill pipe and other equipment at the well site.*
D. *Other drilling fluid. A person may, without a permit, dispose of the following oil and gas wastes by burial, provided the wastes are disposed of at the same well site where they are generated: water base drilling fluid which had a chloride concentration in excess of 3,000 mg/liter but which have been dewatered; drill cuttings, sands, and silts obtained while using oil base drilling fluids or water base drilling fluids with a chloride concentration in excess of 3,000 mg/liter; and those drilling fluids and wastes allowed to be landfarmed without a permit.*
E. *Completion/workover pit wastes. A person may, without a permit, dispose of the following oil and gas wastes by burial in a completion/workover pit, provided the wastes have been dewatered, and provided the wastes are disposed of at the same well site where they are generated: spent completion fluids, workover fluids, and the materials cleaned out of the wellbore of a well being completed or worked over.*
F. *Contents of non-commercial fluid recycling pit. A person may, without a permit, dispose of the solids from a non-commercial fluid recycling pit by burial in the pit, provided the pit has been dewatered.*

3.7.3 Discussion

Development in the Barnett has induced municipalities and landowners to legally challenge the supremacy of state regulations and laws with regard to local regulations stipulating set-backs, moratoria, and compensation for infrastructure wear caused by trucks transporting wastewater. Some of the first ever court cases to go to trial and which set precedent for hydraulic fracturing case law have been in Dallas courts regarding air quality impacts suffered by residents in the Barnett, as mentioned in Section 3.2.2. The RRC holds primacy over virtually every activity associated with oil and gas exploration and production. Therefore, the jurisdictional powers of municipalities to limit oil and gas activities is limited to banning actions in their immediate jurisdiction. Furthermore, actions such as moratoria or limits placed on development must be supported by popular opinion. The example of Denton, Texas, mentioned in Section 3.7.1, provides a good example where effective lobbying was successful in its goal of including hydraulic fracturing as a topic on an upcoming election ballot. More recently, research has been done to correlate injection activities with earthquake frequencies (Frolich, 2012).

The Barnett was the first formation where hydraulic fracturing and directional drilling were effectively used to extract marketable petroleum from shale (RRC, 2014a). The State of Texas places a special emphasis on obtaining permits and abiding by the permissions granted by the permit. The RRC has held jurisdiction over all aspects of oil and gas exploration and production, including wastewater, since 1917. In 1985, the Texas Legislature granted the RRC expanded regulatory authority over controlling and disposing of waste and wastewater, and pollution prevention arising from all energy development. In particular, the Texas Natural Resources Code, Title 3 extended the RRC's authority over pipeline transport. Chapters 26, 27, and 29 of the Texas Water Code, and Chapter 91 of the Natural Resources Code enumerate the terms of the RRC's responsibility to protect water resources and prevent pollution.

The RRC uses a combination of regulatory mechanisms to govern how exploration and production wastes and wastewater are managed. Individual permits are requisite for most storage and disposal practices, and the RRC may also issue exemptions by the same method of review. Rules authorize permissible storage and disposal options. No historical waste and wastewater management regulations have been grandfathered under the existing framework of rules and regulations.

3.7.4 Summary of findings

The Barnett Shale has been a major player in North American energy production for many years. Likewise, the RRC has been relatively unchanged in its regulatory functions over oil and gas activities, although the scope of its powers has been increased from time to time. Regulations in Texas stipulate criteria for wastewater handling, transport, treatment, and ultimate disposal via permitting and manifesting processes. Recently, the RRC has relaxed permitting requirements for onsite treatment systems and associated storage as a means to improve water recycling practices. Because so much of Texas is water scarce, recycling is an important means of easing resource stress. Recycling and reuse is not a regulatory requirement, but is encouraged by the RRC. Disposal into injection wells that meet EPA UIC Program criteria is the primary end point for wastewater. Like other jurisdictions, emerging concerns such as public concerns, contamination risks, earthquakes correlated with injection sites, and risks posed to water resources have required new industry standards and regulations to be developed to mitigate and address emerging conditions.

3.8 Cross-Jurisdictional Summary

3.8.1 Inter-comparison of the four focus formations

All jurisdictions considered in this assessment have highly specific regulations for many elements of wastewater handling (storage and transport), treatment, and disposal (see Table 3.4). Permits and exemptions are subject to application by industry operators and review by the regulatory agency (or agencies) working in the jurisdiction on a case-by-case basis. Jurisdictions exhibit considerable homogeneity in regulations, regulatory criteria, and performance measures despite differences in development history, population density, and hydrogeological features.

Table 3.4. Activities and regulatory elements by jurisdiction for wastewater handling, transport, treatment, and disposal.

Activity/Regulatory Element	BC	AB	PA	NY	OH	WV	TX
Pits and Tanks Permitted	Y	Y	Y	Y	Y	Y*	Y
Freeboard	1 m	1 m	2 ft	2 ft	N/A	2 ft	2 ft
Pit Liners	Y	Y	Y	Y	N/A	Y	Y
Transport Tracking/Manifesting	Y	Y	Y	Y	Y	Y	Y
On-site Treatment and Reuse	Y	Y	Y	Y	Y	Y	Y
Treatment at Facilities for Surface/Land Application/ Discharge	N	N	Y	N	Y	Y	Y
Treatment and Discharge to Surface/Ground Water**	N	N	Y	Y	N	Y	Y
Underground Injection***	Y	Y	Y****	Y	Y	Y	Y

N/A denotes no evidence of regulation found. Y or N indicates whether or not regulation is in place, but cannot capture the degree of specificity within a given regulation. Please refer to the regulations sections for each formation for a discussion of regulatory requirements.

* Only pits are regulated.

** Discharge into water bodies in the U.S. is subject to NPDES criteria and permitting, or the state equivalent.

***There are substantive differences in how injection wells are defined in Canada compared to the U.S. (see Section 3.9.1).

**** Due to capacity limitations, significant volumes of wastewater are transported to Ohio and West Virginia for injection.

All of the jurisdictions in this assessment allow industry operators to utilize pits for wastewater storage, but regulations or conditions for permits enumerate specific criteria based on jurisdictional conditions to prevent leaks or spills. With the exception of Ohio, all jurisdictions stipulate minimum criteria for freeboard to prevent overflow and pit liners. Resources for the Future (2014) noted that uniformity across jurisdictions regarding freeboard stipulations is perplexing, given that jurisdictions are subject to different weather patterns and precipitation. Changes in weather patterns and seasonality may create conditions where freeboard criteria should be reviewed.

Landspreading, landspray, and other kinds of surface disposal are prohibited for wastewater from hydraulic fracturing in British Columbia and Alberta, although they may be permitted in other jurisdictions (e.g. Ohio) if there has been some form of preliminary treatment to ensure that discharge meets minimum mandated criteria. Spreading is specifically allowed and is widely used in Pennsylvania (and even considered a "beneficial use"). Other kinds of wastes such as drilling muds, cements, and water associated with activities other than hydraulic fracturing (and therefore, more similar to greywater than fracturing wastewater) may be disposed of in other ways, provided they meet pertinent hazardous waste criteria for salinity, TDS, corrosivity, toxicity, etc. as listed by the state or province in question. Wastewater options are limited given the bulk liquid volumes requiring management and their chemical characteristics; fracturing wastewater does not usually meet current regulatory conditions for surface disposal unless it is treated. Landfills will accept some kinds of solid oil and gas field wastes, but disposal of bulk liquids in landfills is universally prohibited. Oil and gas field wastes, such as cement returns or drilling muds, are suitable for other kinds of disposal only if they are solid wastes and do not share similar properties to wastewater. Ohio mandates that industry operators utilize injection wells, unless the regulator grants permission for wastewater to be sprayed on roads for de-icing purposes. Reuse and recycling are encouraged as a mechanism to reduce reliance on freshwater, but is not a regulatory requirement in any jurisdiction.

Pursuant to British Columbia's Hazardous Waste Regulation, imported wastes must be manifested, and the transporter and receiver must be licensed. In Alberta, the legislation regarding the importation and exportation of all wastes, including oilfield wastes, in an out of Alberta resides within the *Environmental Protection and Enhancement Act* (*EPEA*). Wastes or recyclables entering or leaving Alberta must be classified as non-hazardous or hazardous. AER-regulated oilfield waste management facilities may receive imported recyclables[31] (hazardous or non-hazardous) provided the recyclables are generated from the exploration and production of oil and gas; the waste management process produces a recoverable material; and the facility approval authorizes the receipt of the type of wastes in question.

Treatment options and technologies are rapidly changing. Regulations stipulate thresholds and performance standards that wastewater must meet after treatment occurs. Some treatment options are more costly than others, and thus less desirable to industry operators. Industry operator preference cannot be inferred from regulations alone where a specific methodology or technology is not mandated. On-site treatment for reuse across jurisdictions is regulated according to handling and spill prevention criteria.

Despite the presence of specific regulations governing wastewater, much of the guidance for wastewater handling, treatment, and disposal comes from legislation and regulations making provisions for environmental or safety performance, or prohibitions against pollution. For example, Acts and regulations stipulating protection of species, contamination prohibitions, and remediation standards may not specifically address a particular activity or substance; such laws are effective at placing limitations on negative effects, regardless of the source. Therefore, cross-jurisdictionally, there are innumerable laws, regulations, directives, and rules that may be in some way applicable to shale gas wastewater management. Because shale gas extraction is relatively new, determining how supporting legislation will be applied to energy development projects is an ongoing and evolving endeavour. In British Columbia and Alberta, the regulators are responding quickly to ensure comprehensive regulations. While operators are subject to all

[31] i.e., fracking fluid can be received for purpose of processing to generate a recoverable material.

applicable legislation, the oil and gas regulatory agency usually serves as the single window regulator.

3.8.2 Policy and practice

Changes to policy and regulations tend to be reactive, and are often a response to a particular event (or events) that necessitates change. It is well documented in the literature, Orders in Council, and government publications that incidents, public complaints, and shifting societal objectives (including environmental objectives) influence the evolution and amendment of wastewater regulations. However, this overview considered the introduction of legislation, particular regulations, directives, and the history of regulatory change inclusively; it did not consider the social determinants, economics, or other factors that may have led to changes. As such, the discussion in this chapter cannot directly point out each event that has elicited regulatory change, nor how industry responded to such changes. However, we can observe that hydraulic fracturing has elicited substantial regulatory initiatives. This is an example of regulators and policy-makers reacting to a technology change.

A second kind of influence to policy and practice are best management practices (BMPs) delineated by overarching agencies such as the Canadian Association of Petroleum Producers (CAPP), the Interstate Oil and Gas Compact Commission (IOGCC), or the International Energy Agency (IEA). These organizations, and others, frequently set out best in class BMPs and guidelines for industry operators to voluntarily adopt in order to meet regulatory or performance requirements. However, because BMPs are voluntary and not enforced by regulatory agencies, there are little available data to determine the rate at which individual operators implement BMPs. Therefore, the extent to which they are utilized when compared with operators who do not implement BMPs, and their relative effectiveness, is not known.

3.9 Knowledge Gaps and Research Approaches

3.9.1 Overview of Knowledge Gap One – Disposal Well Classification

Our research indicates that the topic of disposal well classification presents an important knowledge gap and that there are significant differences in how disposal wells are classified and regulated. The adequacy of the regulations for disposal wells in the U.S. has also been questioned. Similarly, the degrees to which the current British Columbia and Alberta disposal well regulations (including the permitting process) are sufficient to protect the environment over the long term are unknown.

Neither Canada nor the U.S. classifies wastewater from hydraulic fracturing as hazardous waste. In the U.S., this includes an exemption from the federal *Resource and Conservation Recovery Act* (*RCRA*), which governs hazardous materials management. Additionally, many jurisdictions in the U.S. also permit beneficial reuses of wastewater, such as spreading it on roads for de-icing or dust control, treatment and discharge, recycling, or reuse in fracturing operations (Carr-Wilson, 2014; Hammer and VanBriesen, 2012; Notte, 2014; Ohio Revised Code, Title 15, Chapter 1509.22; Spellman, 2013; Texas Administrative Code, Title 16, Part 1, Chapter 3). In the U.S., a jurisdiction's choice of disposal method is often determined by numerous factors including local geology, socio-economics and politics (including population density), and capacity of local infrastructure to manage volumes (and increasing volumes) of fracturing wastewater.[32]

In British Columbia and Alberta, only deep well injection is permitted for disposal of wastewater. In British Columbia, depleted hydrocarbon pools and deep saline[33] aquifers are the two options for disposal (as described earlier in this chapter). An application to dispose into a deep water-saturated formation must be shown to have no adverse effects on hydrocarbon potential or usable water in the surrounding area. The application should contain, when applicable, a general discussion and justification for disposal of produced water in the proposed well at the selected location. The requirements are generally non-prescriptive and focused primarily on injection testing, wellbore integrity testing, and monitoring during injection. The OGC takes into consideration the suitability of the proposed reservoir and risks associated with disposal. Pro-active monitoring of penetrated shallow aquifers is recommended practice, though not required at present, and the guideline for the application indicates that it is advisable to include a monitoring plan in the application.

This suggests that the current regulations for injection wells could be improved. The Natural Resources Defense Council (NRDC) in the U.S. makes a number of recommendations to improve regulations for disposal of fracturing wastewater in injection wells. First, it notes that Class II Wells do not have the same stringent environmental protection regulation as do Class I Wells, which are used for hazardous substances. Recently, Class II Wells in Ohio, Texas, Arkansas, Oklahoma, and West Virginia have been criticized for allowing fluid migration into hydraulically-connected zones and causing micro-seismic tremors (Hammer and VanBriesen, 2012). The NRDC notes that, whereas Class I Wells require the injection zone to be drilled below the lowest known drinking water zone to prevent contamination (also a requirement in British Columbia and Alberta), Class II Wells in the U.S. permit injection above and below drinking water zones.

In addition, operators of Class I Wells in the U.S. are required to test for hydro-connectivity as a means to prevent migration and contamination within a 2-mile radius (Hammer and VanBriesen,

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[32] Examples of regulatory requirements for Class I and Class II wells in the U.S. include:

- Wells are sited and geophysically assessed to ensure that there is no hydro-connectivity (fault and fracture free zone) between the injection zone and groundwater (drinking water) sources (Class II Well requirement – UIC Injection Program, EPA, 2013).
- Prior to well construction, project proponents submit information demonstrating that a site is geologically suitable and poses no micro-seismicity risk (Class I Well requirement – UIC Injection Program, EPA, 2013).
- Rather than using available spent hydrocarbon reservoirs or saline aquifers (recommended for disposal wells in British Columbia), Class I Wells in the U.S. must be drilled into zones below groundwater sources (UIC Injection Program, EPA, 2013).
- Operators of Class I Wells are required to monitor and evaluate a 2-mile radius around injection sites for hydro-connectivity and potential contamination (UIC Injection Program, EPA, 2013).

[33] British Columbia does not specifically define the parameters for saline water in regulations. In Alberta, "brackish" or saline groundwater is defined as having TDS of 4000 mg/L or more, as per Directive 81 (Water Disposal Limits and Reporting Requirements for Thermal In Situ Oil Sands Schemes).

2012), whereas operators of Class II Wells are not obligated to follow the same rigorous testing protocol, and have a range of study limited to only a quarter mile. These less stringent regulations are a major concern to policy-makers and environmental decision-makers who argue that such regulations are insufficient for monitoring large projects, particularly multiple large projects in the same area; furthermore, given that local geological features typically make it unlikely that fluid migration will occur in uniform, circular patterns, less stringent regulations may not be sufficient to account for hydrogeological migration (Carr-Wilson, 2014).

These key gaps in regulation are substantiated by Carr-Wilson (2014) and the National Resources Defense Council (2012), who recommended that closing the aforementioned regulatory gaps in the U.S. and applying industry identified best management practices would likely result in significant improvements to long-term environmental protection and cumulative impacts management. Carr-Wilson (2014) have also done some preliminary research to produce recommendations for improving how disposal wells are utilized in British Columbia. This assessment showed that there are significant differences between the U.S. and Canada in how disposal wells are classified and regulated. As with their observations on the U.S. situation, the degree to which the current British Columbia and Alberta regulations (including the permitting process) are sufficient to protect the environment over the long term is unknown. Thus, detailed comparison of the two regulatory approaches alongside outcomes is a potential avenue for research.

The International Energy Agency (IEA) makes a number of recommendations pertinent to wastewater well management. It emphasizes that contamination and fluid migration can be prevented by employing best practices in well construction and design, systematic and ongoing verification of equipment and infrastructure integrity, and proper maintenance to ensure that there is no breakdown over the lifetime of the infrastructure in use. The IEA specifically recommends that regulators:

> "…put in place robust rules on well design, construction, cementing and integrity testing as part of a general performance standard and that gas bearing formations must be completely isolated from other strata penetrated by the well, in particular freshwater aquifers. Regulations need to ensure wells are designed, constructed and operated so as to ensure complete isolation. Multiple measures need to be in place to prevent leaks, with an overarching performance standard requiring operators to *follow systematically all recommended industry best practices*. This applies up to and including the abandonment of the well, i.e. through and *beyond the lifetime of the development* (IEA, 2012, emphasis added)."

3.9.2 Approaches, Strengths and Weaknesses - Disposal Well Classification

One **approach** would be to use case studies and detailed examinations of disposal well regulations to assess whether increased consistency in classification across jurisdictions would be likely to lead to improved environmental protection and regulatory efficacy. The **strength** of this approach is that it is based on existing sources and therefore would be a cost effective means of conducting research. The **weakness** of this approach is that it would, by definition, be limited to existing findings and would not provide a mechanism for direct engagement. The **cost** of this approach if it focused on the jurisdictions examined in this study would range from $100,000 to $250,000.

A second **approach** would be to bring regulators from the jurisdictions studied together to discuss the disparate classifications of disposal wells and evaluate the potential to reach a higher level of consistency. This would involve a conference, or a series of conferences and workshops supported by other engagement mechanisms such as videoconferences and exchange/review of documents. The **strength** of this approach is that by directly engaging regulators, an exchange of current and future plans for this topic could take place. It would therefore be considered a more proactive approach than the first suggestion. As well, it may be supported by industry in that greater consistency across jurisdictions would be expected to result in improved efficiency in well construction and disposal practices. The **weakness** would be the potential difficulty of convincing regulators that it is worth their time, and the obviously greater expense considering the time, travel and facility arrangements involved. The **cost** of this approach if it focused on the jurisdictions examined in this study would range from $300,000 to $500,000.

3.9.3 Overview of Knowledge Gap Two - Regulatory Outcomes, Compliance and Best Management Practices, and Terminology

This study and others cited in this study have identified which waste water practices and infrastructure requirements are regulated, how they are regulated, and the level of detail imposed within the regulations. It is acknowledged that assessing whether regulations are enforced, identifying the compliance rate of industry operators, and defining a regulator's capacity to enforce are as important as the regulation itself (e.g. Richardson et al., 2014). This observation, supported by our research, leads to the conclusion that significant knowledge gaps exist in the areas of regulatory outcomes, compliance and Best Management Practices, and terminology.

With respect to regulatory outcomes, the identified gap involves determining how the 'quality' of a regulation affects the intended outcomes. The gap arises primarily because of the historical lack of necessary data for conducting such an assessment. However, this study found that all of the jurisdictions reviewed have been producing incident reports for at least six years. This suggests that, using those reports, data sets could be developed to explore questions such as:

- Can the net change in the frequency and severity of wastewater incidents serve as a proxy for assessing improvements in regulatory efficacy?
- To what degree has regulatory change affected water management practices, wastewater recycle rates, disposal capacity, and the frequency of micro seismic events?
- How are the rates and types of complaints lodged by residents of shale gas producing regions linked to a particular aspect of a regulation and do the residents perceive risk as being reduced through regulatory activity?

A second knowledge gap exists with respect to adopting BMPs – particularly with respect to the industry's use of disposal wells. In its recommendation (above), the IEA does not specify how a regulator should encourage industry operators to follow voluntary BMPs. Each jurisdiction has highly specific criteria for how wastewater management is to be conducted; however, there is little incentive for most industry operators to exceed the expectations of the regulator. Indeed, industry operators may find it prohibitively costly to do so. In Canada, British Columbia and Alberta are shifting towards goal-oriented regulations, which may incite industry to voluntarily follow BMPs. However, given that the goal-oriented approach is relatively new, there is little information available on its relationship to BMP adoption. Developing case studies on these jurisdictions' experiences in adopting goal-oriented approaches has the potential to offer decision-makers in all jurisdictions a means to evaluate the relationship between regulatory approaches and BMP adoption.

The third knowledge gap lies in the area of regulatory compliance. Significant research has been done on the state of existing regulations and their robustness, but the extent to which they are obeyed is not currently known – especially with respect to initial levels of compliance. British Columbia's Forest Practices Board (2011) conducted an audit of the oil and gas industry and determined that initial rates of operator compliance were roughly 60%. Other jurisdictions lack this kind of data because of confidentiality agreements with industry operators, lack of reporting, and/or lack of capacity to conduct audits. Furthermore, such data are beyond the scope of content considered within reviews conducted by agencies such as STRONGER. Assessing the quality of regulations and their relationship to industry compliance is a crucial aspect of wastewater management. Within Canadian formations, research could examine the CAPP recommended BMPs, and then compare the IEA's recommendations and determine the extent to which they are reflected (recognizing that this in part overlaps with the first knowledge gap identified above).

The fourth knowledge gap relates to the clarity of the terminology used in regulations aimed at ensuring the long-term integrity of infrastructure used for wastewater storage, transport and disposal. An examination of this topic would be beneficial for assigning performance standards and goal-oriented actions. For example, the IEA does not provide a definition of what it means by "store and dispose of produced and wastewater safely," a sub-category of its golden rule for treating water responsibly. Also, there is no specified definition of what the IEA's term "beyond the lifetime of the development" indicates. It is highly possible that the lifetime of wastewater (interpreted as the time span during which the waste water remains toxic to a harmful degree) may greatly exceed the lifetime of the infrastructure used to contain it.

Further, while pit and tank liners in Alberta and British Columbia must eventually be disposed of in a landfill, there is no codified protocol in directives or regulations to determine when the disposal must occur. Similarly, re-use and maintenance of other infrastructure over the lifetime of industry activity is not addressed beyond prohibitions of pollution and the expectation that operators and haulers keep infrastructure in "good repair," and "free of leaks."

3.9.4 Approaches, Strengths and Weaknesses - Regulatory Outcomes, Compliance and Best Management Practices, and Terminology

The single, recommended **approach** to addressing the above four gaps is to create a multi-disciplinary research team with sufficient expertise to provide background knowledge in the areas of: regulatory development, implementation and enforcement, behavioral science, and organizational theory. The team would then determine whether a series of case studies, conferences, interviews, or other methods would be the most effective paths to pursue. Creating the team, then relying on the members establishing the specific approach could be perceived as counterintuitive. But the recommendation is based on the observation that the four gap areas are extremely complex, and in this case it may make sense for the approach to be based on expert assessment.

The **strength** of this approach is that it could provide groundbreaking research, which could then be applied to other industries beyond addition to hydraulic fracturing. The **weakness** would be the potential expense – although as recommended in other gaps areas, adopting a phased approach that would begin with a pilot project covering perhaps two jurisdictions could mitigate this. Another weakness would be the 'leap of faith' required in establishing a team charged with examining specifically identified gaps but without a mandated approach to addressing them. The **cost** of this approach, including assembling a team of experts, would be in excess of $500,000.

3.9.5 Overview of Knowledge Gap Three - First Nations Regulatory Capacity

The final knowledge gap in this chapter involves the engagement of First Nations, which is a critical consideration in the development of hydraulic fracturing projects. Our research indicates that First Nations have not imposed regulations for wastewater handling, treatment, and disposal on their lands. However, federal and provincial governments are obliged to consult with First Nations under the Canadian Constitution. In some cases, First Nations have established formal organizations to negotiate their own development rights in the face of widespread concern about the impacts of shale gas development.[34] *Tsilquot'in Nation v. British Columbia* [2014 SCC 44], a recent Supreme Court Decision, provides the impetus for further research on the government's fiduciary responsibility to consult, and the ability of First Nations to exert authority over their traditional lands in unceded territories such as British Columbia.

3.9.6 Approaches, Strengths and Weaknesses - First Nations Regulatory Capacity

Because no literature on this topic was found in this study, the single research **approach** recommended to addressing this gap is a consultation exercise with First Nations groups involved in hydraulic fracturing. The consultations would result in information on the current, and potential future, ability of First Nations communities to develop and deploy wastewater treatment regulations. If it appears that indigenous capacity could not be developed, other alternatives for a more empowered approach by First Nations could be explored. The **strength** of this approach is that it would gain first hand knowledge and indications of the relative desire and ability of First Nations communities to regulate. The **weakness** is that there is likely to be considerable disparity in regulatory ability among First Nations communities, and the development of a single applicable path forward may prove an elusive goal. There also may be disparity between the regulations in effect for non-First Nations jurisdictions and First Nations jurisdictions, in which case consistency of standards and practices becomes important. This approach is scalable and depending on the number of First Nations communities involved the **cost** could range from $100,000 to $250,000.

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[34] For example: Treaty 8 includes the Sicannie (Sikanni), Slavey, Beaver (Dane-Zaa), Cree, and Saulteau peoples, as well as the Fort Nelson First Nation. The first five Nations have organized themselves into the Treaty 8 Tribal Association to better coordinate and negotiate their rights in the context of development projects and Treaty 8. The Dene Tha' primarily reside in Alberta, but hold traditional lands in Northeastern BC. The terms of the treaty permit the government to pursue development projects subject to the duty to consult. The Treaty 8 Tribal Association has made it clear that they are "not opposed to development *per se,*" but that they wish the Province to undertake a cumulative impact assessment to ensure that future generations will be able to practice their traditional rights (Treaty 8 Tribal Association, 2014).

CHAPTER 4: STAKEHOLDER CONCERNS RELATED TO HANDLING, TREATMENT, AND DISPOSAL OF HYDRAULIC FRACTURING WASTEWATER

4.1 Introduction

Recently, the practice popularly known as fracking, a process that combines hydraulic fracturing with horizontal drilling, has spawned a "shale gas revolution" (Voser, 2012; Wang, Chen, Jha, & Rogers, 2014). Seizing on these breakthroughs, some actors have heralded a "golden age of gas" (Birol & Corben, 2011), positing natural gas as a possible "bridge fuel" to a more sustainable energy future (MIT, 2010). At the same time, the rapid expansion of unconventional shale development has generated numerous environmental, health, and safety concerns (e.g. Howarth, Santoro, & Ingraffea, 2011; Jackson et al., 2013; McKenzie et al., 2014). One emerging set of concerns relates to the handling, treatment, and disposal of wastewater generated as a result of hydraulic fracturing.

The seriousness of these concerns has prompted the involvement of a growing number of stakeholders, defined as "any group or individual who can affect, or is affected by, the achievement of a corporation's purpose" (Freeman, 1984, p. vi). In the case of unconventional shale development, concerned stakeholders may include company employees, oil and gas regulators, host communities, and environmental activists, among others. Historically, neither oil and gas exploration and development companies, nor provincial and state oil and gas regulators have been accustomed to the level of scrutiny that unconventional shale development has generated. This level of scrutiny creates a number of challenges with respect to how stakeholder concerns are addressed.

These challenges are complicated by the fact that, in many cases, the necessary data are simply not available. For example, a recent report on the environmental impacts of shale gas extraction by the Council of Canadian Academies (CCA) indicated that "many of the pertinent questions are hard to answer objectively and scientifically, either for lack of data, for lack of publicly available data, or due to divergent interpretations of existing data" (CCA, 2014, p. 216). These difficulties are due in part to that fact that some of the concerns involve situations in which it is not possible to fully enumerate all future states, let alone assign probabilities to them (Knight, 1921; Piore, 1995).

Given this state of affairs, it is perhaps unsurprising that opinions about hydraulic fracturing among members of the general public range from support to indifference to opposition. In fact, different polls often yield vastly different results. For instance, an October 2014 poll commissioned by The Council of Canadians found that "70% of Canadians support a national moratorium on hydraulic fracturing until it is scientifically proven to be safe" (Council of Canadians, 2014). Conversely, a June 2013 CBC/Radio Canada poll found that opinions regarding unconventional shale development in New Brunswick were almost evenly split, with 49% supporting and 44% opposing hydraulic fracturing activities (McHardie, 2014). Perhaps more interesting, scholars recently suggested that public opinions of hydraulic fracturing, at least in the U.S. context, vary predictably based on socio-demographic factors (Boudet et al., 2014). For instance, age, education, frequent television use, and conservative political ideology are significant predictors of support for hydraulic fracturing, whereas female gender, an egalitarian worldview, and frequent newspaper use reduce support for hydraulic fracturing.

Against this backdrop, operators and regulators have become concerned about their social license to operate (SLO). Although there is no single agreed upon definition of SLO (Raufflet, Baba, Perras, & Delannon, 2013), it is generally defined as the extent to which a project, company or industry is perceived by stakeholders as being acceptable and legitimate (Gunningham et al., 2004; Joyce & Thomson, 2000; Thomson & Boutilier, 2011). Although unconventional shale development implicates many potential stakeholders, operators and regulators have increasingly recognized the need for stakeholders (e.g. First Nations, community members, nongovernmental organizations [NGOs], and landowners) to be given explicit consideration (e.g. Chesapeake Energy Corporation, 2013; Encana, 2013; Ridge, 2014).

In this chapter, we focus on:

- Identifying concerns related to hydraulic fracturing wastewater handling, treatment, and disposal from the perspectives of these stakeholders;
- The extent to which concerns have emerged throughout the Montney, Duvernay, Marcellus, and Barnett shale formations;
- How the concerns within these formations have changed (if at all) over time; and
- The extent to which stakeholder concerns differ across formations and time.

We investigate these issues in three ways. First, in section 4.2, to ground our analysis conceptually, we review the nascent literature on SLO, and connect this concept with others such as sustainability, corporate social responsibility, stakeholder management, and cumulative effects. Building on this review, in section 4.3, we investigate the extent to which these concepts appear in newspaper articles across the provinces and states associated with the Montney, Duvernay, Barnett, and Marcellus shale formations. We also investigate the extent to which these same newspapers have reported on issues related to hydraulic fracturing in general, and wastewater treatment and disposal of fluids specifically. As a complement to this quantitative content analysis, we identify examples of stakeholder concerns that have emerged via other media, such as nongovernmental reports and blogs.

4.2 Social License to Operate

We began our analysis of stakeholder concerns related to hydraulic fracturing wastewater handling, treatment, and disposal by reviewing prior literature on SLO. Despite growing use of the term *social license to operate* by industry and regulators, to our knowledge, no comprehensive academic review of this work has been undertaken previously. In formulating this portion of the report, we searched academic databases, and followed forward and backward citations within these results. This literature served as the basis for our discussion of the emergence of this concept, its definition, as well as its relationship to related concepts such as sustainability, corporate social responsibility, stakeholder management, and cumulative effects.

Recent use of the concept of SLO has been traced to Jim Cooney, a Canadian mining executive who proposed the idea during a 1997 meeting with World Bank personnel in Washington

(Thomson & Boutilier, 2011). The term reportedly surfaced again during a May 1997 World Bank-sponsored conference, at which point it was assimilated into the mining industry's vocabulary. At the time, the mining industry was facing increasingly negative sentiment in the wake of environmental damage resulting from spills, tailings pond mismanagement, and community frustrations with project organization (Thomson & Boutilier, 2011). Given this context, SLO was conceived initially by industry as a means of addressing community relation problems while avoiding regulatory or governmental involvement (Joyce & Thomson, 2000).

With the Internet facilitating the rapid spread of information in the late 1990s, communities became more aware than ever of the potential for lasting environmental damage, economic impacts related to jobs and land values, health impacts, and general boom and bust phenomena. Indeed, more communities were (and still are) choosing to become involved in the process of resource development, whereas in the past the process was nearly devoid of extensive community consultation (Joyce & Thomson, 2000). Social unacceptability dramatically impacted the viability of resource extraction projects in communities all over the world; as such, social risk was the driving force behind the need for SLO (Joyce & Thomson, 2000). Furthermore, strategic business practices are at least partially driven by a goal of increasing social capital. The potential SLO for both current and future projects is considered to be greater in communities with more social capital (Yates & Horvath, 2013).

4.2.1 What is SLO?

Although SLO has been a prominent topic in industrial discourse, it remains both intangible (Franks & Cohen, 2012) and difficult to measure (Parsons, Lacey, & Moffat, 2014). This is primarily due to the fact that the concept itself is contingent on the vested interests of concerned parties, which can vary by project and industry (Shepard, 2008). For instance, some have characterized SLO as a kind of insurance policy against the possibility that stakeholders might negatively impact operations, and even prematurely end a project (Nelsen, 2006). Of course, there are no formal bureaucratic means for obtaining social license, as it is not administered by an agency, and differs with each industry, project and community (Joyce & Thomson, 2000; Klein, 2012; Thomson & Boutilier, 2011). Indeed, there are no explicit documents, policies, or written confirmation that SLO exists at all. For this reason, SLO has been described as a relational concept that identifies how well a project is accepted, approved, and even co-owned by a community (Thomson & Boutilier, 2011; Seegar, 2011). Under such a definition, a company has obtained SLO once it has gained the "broad acceptance of society to conduct its activities" (Joyce & Thomson, 2000, p. 52).

Others have defined SLO as a more dynamic and evaluative process, with expectations determined by local stakeholders and citizens more generally about how a business should operate (Gunningham, Kagan, & Thornton, 2004). For instance, public opinions are not static, and thus SLO can be impaired or lost as perceptions change (House, 2013). Likewise, the standards to which a business should operate are subject to change. Because of this fluidity, maintaining SLO is a continuous practice that requires constant attention in order to maintain rapport within a community (Nelsen, 2006; Thomson & Boutilier, 2011).

Although similar in terms of general application, SLO differs from *free prior and informed consent* (FPIC). FPIC is obtained during the period prior to development of a forthcoming project, while SLO is maintained throughout the project life-cycle (Thomson & Boutilier, 2011). Some have compared SLO to techniques such as *Strengths, Weaknesses, Opportunities, and Threats* (SWOT) and *Political, Economic, Social, and Technological* (PEST) analyses, as each emphasizes environmental and community considerations (Shepard, 2008). However, these latter approaches are entirely company-centric, whereas SLO requires integration and collaboration with a community throughout the entire process (Shepard, 2008).

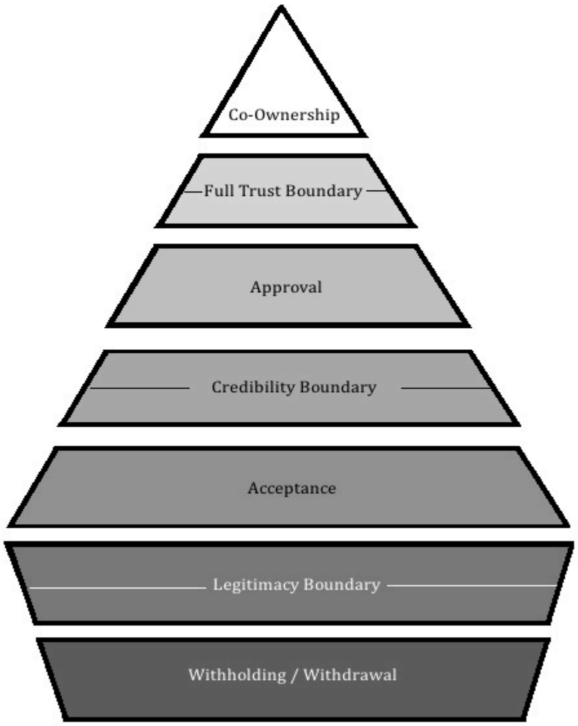
Despite growing agreement that SLO matters, different firms are likely to respond with very different environmental and social management practices (Howard-Grenville, Nash, & Coglianese, 2008). This heterogeneity in response compounds the challenge of creating a common definition of what constitutes SLO within an industry, let alone across heterogeneous industries. Nonetheless, many actors within the resource sector have embraced SLO in an attempt to secure stakeholder engagement and improve project feasibility, as suggested by Moffat and Zhang (2014). In the United States, some investors in unconventional resource development projects have requested thorough reporting on environmental and community concerns, consistent with SLO concerns (House, 2013; Liroff, 2012). For example, in 2012, shareholders requested that ExxonMobil and Chevron disclose short- and long-term environmental and community impacts, suggesting that maintenance of SLO requires full disclosure regarding risk, challenges, and best management practices over the entire course of gas development (As You Sow, 2012; Schwartzel, 2011).

Although SLO is most prominent in the mining sector, other industries have attempted to apply the SLO concept as well. Thornton, Kagan, and Gunningham (2009) investigated environmental management in the trucking industry and noted that SLO was barely considered by trucking firm managers. For instance, firm-level variance on toxic emissions was explained almost entirely by economic factors; their interpretation was that regulatory pressure is required in order to incent practices beyond compliance.

4.2.2 How to obtain SLO

As an early proponent of SLO, the mining industry has pioneered the process of obtaining social license. For instance, Thomson and Boutilier (2011) conceptualized the process as a "pyramid" consisting of three unique levels: legitimacy, credibility, and full trust (see Figure 4.1). First, legitimacy is vital for a company to convey alignment with community values (Joyce & Thomson, 2000). Communities consider the manner in which relationships are constructed, questioning whether there is (seemingly) genuine respect on the part of project and/or company authorities. Then, once a project is seen as legitimate, it moves to the credibility stage. Transparency is critical at this stage, which is based on open dialogue between community members and industry representatives. Over the course of this process, community members discern whether or not a company will deliver on the initial promises and commitments they made. Project approval is determined based on successful "credibility litmus tests" (Thomson & Boutilier, 2011). To reach the full trust stage entails much more than fulfilling commitments and keeping promises; instead, the focus returns once again to building relationships. Integrating the community as a partner in the project is fundamental to moving across the full trust boundary into the co-ownership stage (Thomson & Boutilier, 2011). When co-ownership exists, a community assumes responsibility for a project and its members begin to advocate for the project to other interest groups as though it was their own.

Figure 4.1. Resource-based view of obtaining social license to operate, including boundary criteria.



Adapted from: Thomson & Boutilier (2011).

4.2.3 The relationship between SLO and other concepts

SLO overlaps with other terms widely utilized within industry and academia, and by other concerned groups. The key characteristics for similar terminology are summarized in Table 1. Corporate social responsibility (CSR) for example, refers to the contributions of a business' activities to economic, social, and environmental sustainability (Jenkins & Yakovleva, 2006). CSR provides a framework for understanding companies' attitudes and relationships with stakeholders (Wheeler, Fabig, & Boele, 2002), and thus is an umbrella term used to indicate the extent to which a company is both required and willing to act in order to generate socially feasible projects. Wilburn and Wilburn (2011) distinguished the terminology by suggesting that SLO is a model nested within a larger CSR strategy. A very similar term to CSR is corporate responsibility (CR). Encana (2014) described CR as a consideration that "encompasses the corporate response to the governance, ethical, financial, economic, environmental and social performance issues facing today's corporations" (p. 1).

Another way to delineate how corporations view stakeholders is through the lens of *stakeholder management*, which can be compared to social issue management. Clarkson (1995) suggested that "it is necessary to distinguish between stakeholder issues and social issues because corporations and their managers manage relationships with their stakeholders and not with society" (p. 10). Thus, stakeholder management would suggest allegiance to interests that are salient to stakeholders, but may not transcend into the realm of social best interest or the broader social discourse.

SLO also has some overlaps with *sustainability* and *sustainable development* (Nelsen, 2006), defined as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission, 1987, p. 41; for reviews see Garud & Gehman, 2012; Kidd, 1992). Since the term is adaptable to different values, sustainability can be a community-defined operational term, which can positively contribute to the integration of stakeholder perspectives in project success indicators (Business for Social Responsibility, 2003); by asking impacted stakeholders about their shared values and beliefs, a company gains valuable insight into what it can do to ensure that the community's perception of sustainability is upheld throughout the life of the project (Shepard, 2008).

Lastly, *cumulative effects* refers to the "changes to the biophysical, social, economic and cultural environments caused by the combination of past, present and 'reasonably foreseeable' future actions" (Renewable Resources & Environment, 2007, p. 1). Cumulative effects are successive, incremental, and can be both positive and negative; thus, each additional project can potentially impact prospective projects (Franks, Brereton, Moran, Sarker, & Cohen, 2010). As such, cumulative effects management necessitates cross-company collaborative approaches in order to efficiently "produce better sustainable development outcomes" (Franks et al., 2010, p. 7). This approach requires industry players to work outside of specific company mandates.

Table 4.1. Summary of terminological characteristics for social license to operate and related terms

Term	Key characteristics
Social License to Operate (SLO)	• Specific to each unique project • Process: legitimacy, credibility, full trust • Consistent consultation with stakeholders over life of project • Not guaranteed based on past success/failure of firm
Corporate Social Responsibility (CSR) / Corporate Responsibility (CR)	• Firm-driven policy, may be overarching • Firm is willing (not required) to act • Does not require action on specific projects for success • Variation between firms, industries
Stakeholder Management	• Can be selective, based on vested and non-vested stakeholders • Broader social concerns are not necessarily included • Firm interested in satisfying a defined group of stakeholders
Sustainability / Sustainable Development	• Value-based • Broad societal concept that transcends the firm • Can refer to environmental, social, or economic sustainability
Cumulative Effects	• Extends beyond firm policies and procedures • Collaborative management, may be inter-firm and multi-industry • Effects are successive and incremental in nature

4.2.4 Current status of SLO

As it became more widespread in the mining industry, obtaining SLO came to be regarded by industry as a way to move new projects forward (Nelsen, 2006). A wave of industry-focused literature has been developed regarding SLO processes and development. Yet, academic literature is limited on this subject (Prno & Slocombe, 2012).[35] For instance, a recent review concluded "most definitions have been generated by practitioners and policymakers," whereas "definitional and theoretical developments from academic researchers…remain scarce" (Raufflet et al., 2013, p. 2224).

More recently, Moffat and Zhang (2014) proposed and tested a model of the key structural components of social license, namely impacts on social infrastructure, intergroup relations, and perceived procedural fairness within mining operations. By focusing on social psychological trust behaviours, the authors suggested that the perceived potential impact of a project is the factor that least affects a community's trust in a company; rather, genuine procedural fairness and high quality community interactions are most important for facilitating more effective and positive projects.

In Canada, recognition and use of the term SLO has become increasingly commonplace within the resource extraction industry, as exemplified by the Canadian Association of Petroleum Producers (CAPP) President Dave Collyer's focus on industry-directed communication around social license at the Synergy Alberta Conference in 2011 and the DUG Canada Conference in 2012 (Collyer, 2011; Collyer, 2012). Industrial leaders in Canada also tend to publicly discuss social license. For example, Imperial Oil Ltd. CEO Bruce March proclaimed that providing energy for the world's needs will require SLO (*Alberta Oil Magazine*, March, 2012). In contrast, industry members in the United States tend to shy away from the term social license and instead employ concepts such as sustainability, corporate social responsibility or stakeholder management.

4.2.5 Current status of SLO with regard to hydraulic fracturing

The practice of obtaining SLO for oil sands development has created a more advanced and perhaps challenging starting point for the hydraulic fracturing industry in Canada. For example, the Alberta Energy Minster publicly mentioned the need for members of the unconventional oil and gas industry to obtain social license not long after shale gas technology had begun to be applied to formations across Canada (Wingrove, 2012). In its 2013 annual report, the Canadian Society for Unconventional Resources (CSUR) suggested that the "need for advocacy, relative to industry participants attaining social license, has never been more evident" (CSUR, 2013, p. 29).

Canadian firms Encana, Imperial Oil Ltd. and Painted Pony Petroleum Ltd. are actively involved in hydraulic fracturing throughout the study area and have discussed SLO and related terms several times in publicly available communications. Encana, which is active in the Montney and Duvernay formations, has a comprehensive corporate responsibility policy:

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[35] The limited academic literature regarding SLO is primarily focused on Australian mining (Moffat & Zhang, 2014; Parsons et al., 2014).

> Encana is committed to conducting our business ethically, legally and in a manner that is fiscally, environmentally and socially responsible, while delivering strong financial performance. We believe demonstrating our commitment to corporate responsibility is integral to creating long-term shareholder value. Protecting and enhancing our reputation and our social license to operate is key to our sustained financial success. (Encana, 2014a, p. 1)

Imperial Oil, also active in the Montney and Duvernay formations, described its approach to stakeholder concerns and SLO in its 2011 *Corporate Citizenship Summary Report* as "our ability to meet both stakeholder expectations as well as ensure responsible development [which is] critical to our long-term business success" (Imperial Oil, 2011, p. 11). A small firm operating exclusively in the Duvernay formation, Painted Pony Petroleum Ltd., does not include the term SLO in its CSR materials, but stated that: "sustainability means conducting our business in a way that preserves our relationships with the community, the environment and our stakeholders for the future. It means acting as a corporate citizen that gives back to the communities where we live and work" (Painted Pony Petroleum Ltd., 2014).

In contrast, we found no references to SLO in a selective review of several large U.S.-based firms' publicly available plans. Range Resources Corporation, active in the Marcellus formation, did not include the term social license to operate in its *Corporate Responsibility Report*. However, the report did indicate that Range Resources' "corporate responsibility platform is intentionally flexible to assure we continue to adapt as necessary and meet the ever-changing needs of Range stakeholders" (Range Resources Corporation, 2013, p. 2). Chesapeake Energy, active in both the Barnett and Marcellus regions, has published three corporate responsibility reports since 2011, which follow the Global Reporting Initiative (G3.1) sustainability guidelines. The 2013 report stated that Chesapeake is "committed to increasing [its] reserve base for business sustainability" (Chesapeake Energy Corporation, 2013, p.3); however, this is the only reference to sustainability throughout the report.

4.3 Media Coverage of Hydraulic Fracturing-Related Concerns

In the next phase of our analysis, we examined the extent to which newspaper media reported on hydraulic fracturing and stakeholder concerns related to: 1) SLO and related concepts; 2) general environmental, social, and political matters of concern; and 3) specific examples of wastewater-related concerns. In all three cases, we determined whether an article referred to hydraulic fracturing by searching for the keyword *hydraulic fracturing*, or any of the following alternative keywords: *fracking*, *hydrofracking*, *shale gas*, and *unconventional gas*. Collectively, we refer to these five keywords throughout the analysis as *hydraulic fracturing terms*. Our results are based on the appearance of particular combinations of these keywords between January 1, 2008 and June 30, 2014, which marks the end of our study window. A complete list of the newspapers included in our keyword searches is listed in Appendix B.

Our literature review revealed that SLO is just one of several accountability concepts that have been discussed in relation to hydraulic fracturing specifically, and resource development more generally. Other related concepts include sustainability and sustainable development, corporate social responsibility and corporate responsibility, stakeholder management, and cumulative effects. Accordingly, during the next phase of our research, we investigated the extent to which

SLO and these related accountability concepts were actually invoked in connection with newspaper coverage of hydraulic fracturing.

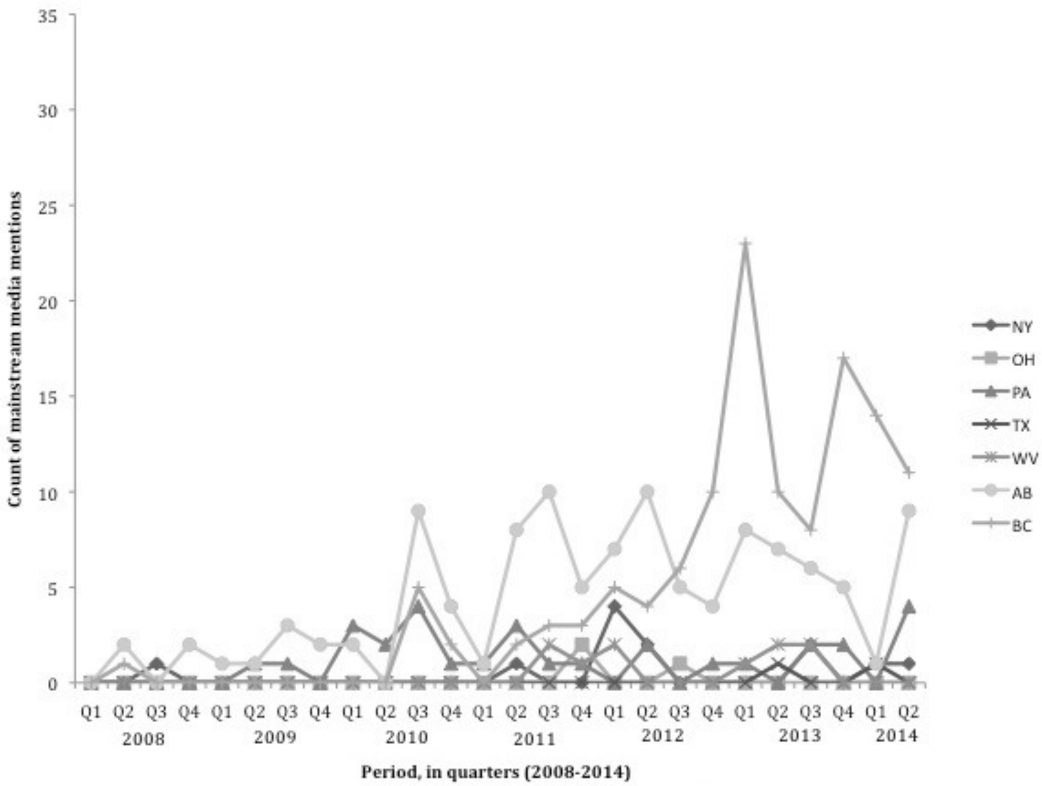
Specifically, as shown in Table 4.2, we performed 35 separate keyword searches, pairing each one of the five hydraulic fracturing terms (shown in the columns) with one of the seven accountability concepts (shown in the rows). Data for this portion of our research is based on the Factiva and Canadian Newsstand Complete databases, which were used to search American and Canadian daily print newspapers, respectively, in each of the four shale formations. (See Appendix B for a complete list of the newspapers included in our keyword searches.)

Table 4.2. Keyword searches related to accountability and hydraulic fracturing

Accountability concepts (ROWS = r)	Hydraulic Fracturing terms (COLUMNS = c)				
	Hydraulic fracturing	Fracking	Hydrofracking	Shale gas	Unconventional gas
Social license (licence) to operate	(r_1,c_1)	(r_1,c_2)	(r_1,c_3)	(r_1,c_4)	(r_1,c_5)
Sustainability	(r_2,c_1)	(r_2,c_2)	(r_2,c_3)	(r_2,c_4)	(r_2,c_5)
Corporate responsibility	(r_3,c_1)	(r_3,c_2)	(r_3,c_3)	(r_3,c_4)	(r_3,c_5)
Corporate social responsibility	(r_4,c_1)	(r_4,c_2)	(r_4,c_3)	(r_4,c_4)	(r_4,c_5)
Sustainable development	(r_5,c_1)	(r_5,c_2)	(r_5,c_3)	(r_5,c_4)	(r_5,c_5)
Cumulative effects	(r_6,c_1)	(r_6,c_2)	(r_6,c_3)	(r_6,c_4)	(r_6,c_5)
Stakeholder management	(r_7,c_1)	(r_7,c_2)	(r_7,c_3)	(r_7,c_4)	(r_7,c_5)

Overall, we found that newspaper coverage of SLO and/or related accountability concepts in connection with hydraulic fracturing was higher in Alberta and British Columbia than in Pennsylvania, New York, West Virginia, Ohio, or Texas. This overall trend is depicted in Figure 4.2. In Appendix C, we provide a quarter-by-quarter summary of these data. As will be seen in the following sections on the use of each accountability-related term, divergence in the use terms suggests regional, conceptual, temporal and/or perceptual differences in the understanding and prominence of the investigated accountability concepts.

Figure 4.2. Media coverage of any accountability concept with hydraulic fracturing-related terms.

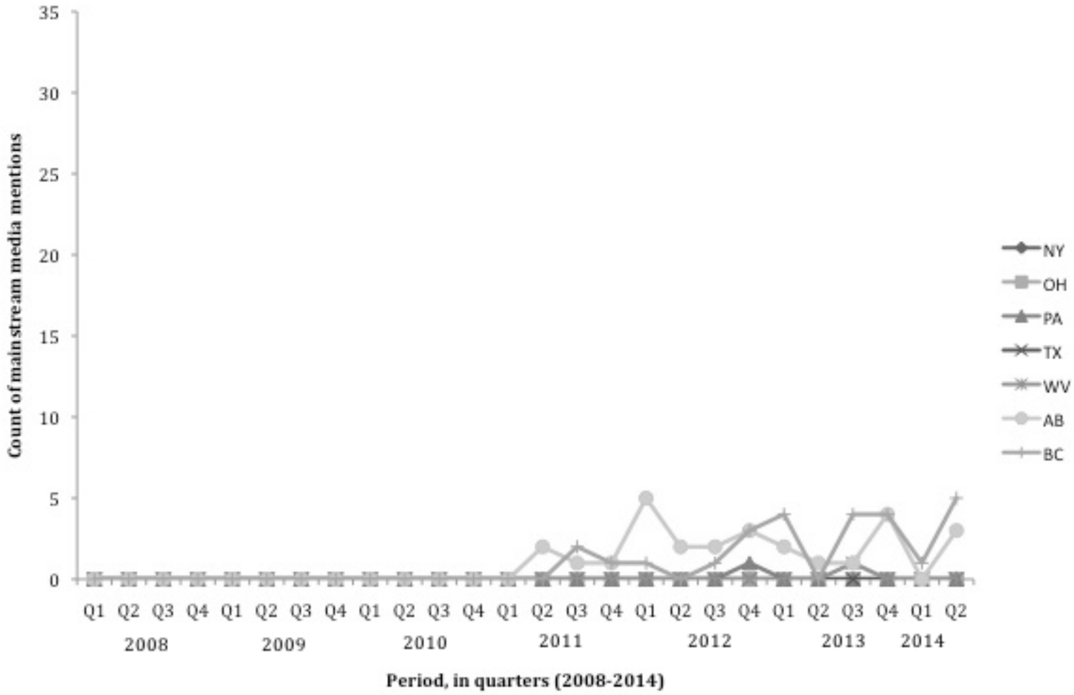


4.3.1 Media coverage of SLO and Hydraulic Fracturing

With regard to SLO specifically, media coverage was scant across all four shale formations studied, with slightly more coverage in Alberta and British Columbia than in the five U.S. states (see Figure 4.3). In fact, the American media failed to mention SLO almost entirely: SLO was not mentioned in publications in Ohio, New York, or Texas between 2008 and 2014, and there were only two total mentions associated with hydraulic fracturing in West Virginia and Pennsylvania newspapers. Moreover, these latter two cases were the result of direct quotes from interviews with industry executives.

By comparison, a number of Canadian newspaper articles specifically described activities related to securing SLO within the context of hydraulic fracturing and the oil and gas industry, or extended the discussion of SLO to the resource sector more generally. In British Columbia, SLO was discussed in 10 newspaper articles between 2011 (when it was first mentioned along with hydraulic fracturing) and 2014; in Alberta, 15 stories were published between 2011 and 2014 in which SLO was mentioned. In both provinces, the earliest mention of SLO appeared concurrently on September 17, 2011, in the *Times-Colonist* (Victoria) and the *Edmonton Journal*. Both stories reported on the appointment of Andre Boisclair, a former Quebec environmental minister, to an advisory position with Questerre Energy Corporation, which was described to be working towards securing SLO in Quebec (*Edmonton Journal*, 2011; *Times-Colonist*, 2011).

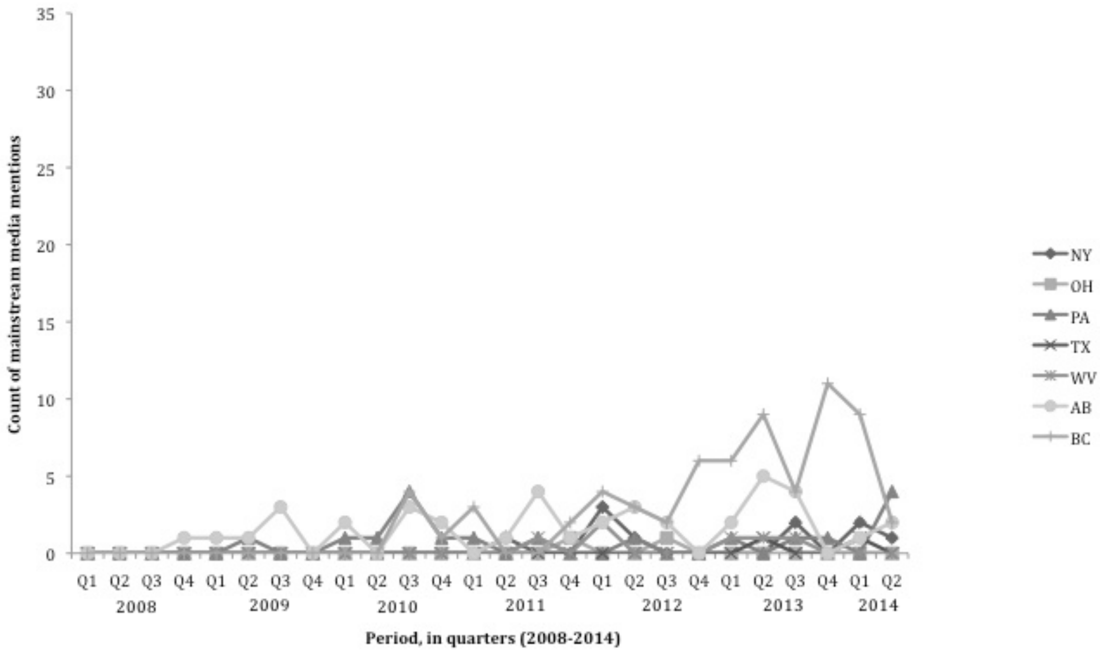
Figure 4.3. Media coverage of SLO and hydraulic fracturing.



4.3.1.1 Media coverage of sustainability and hydraulic fracturing

Of the five accountability concepts studied, *sustainability* appeared most frequently in newspapers in British Columbia, with 67 articles in total (see Figure 4.4). Sustainability also was consistently mentioned in connection with hydraulic fracturing terms throughout the 2008-2013 period in Alberta-based newspapers. Compared with the other accountability concepts, newspapers within the Marcellus formation provided greater coverage, including 17 articles in Pennsylvania, 10 articles in New York, 6 articles in West Virginia, and 3 articles in Ohio. Texas newspapers provided virtually no discussion of sustainability in relation to hydraulic fracturing terms. By comparison, the results for *sustainable development* were similar to those for SLO. This concept was mentioned in American newspapers in conjunction with hydraulic fracturing terms only 6 times between 2008 and 2014, whereas it was mentioned in newspapers published in Alberta and British Columbia 23 and 26 times, respectively, between 2008 and 2014.

Figure 4.4. Media coverage of sustainability and hydraulic fracturing.



4.3.1.2 Media coverage of CSR/CR and hydraulic fracturing

Substantially more articles in both Alberta and British Columbia included the keywords *corporate social responsibility* or *corporate responsibility* in conjunction with hydraulic fracturing terms. In Alberta, this combination of terms was used in 28 articles between 2008 and 2014, with the frequency of such articles declining after 2011 (10 were published in 2011, 6 in 2012, and 4 in 2013). In British Columbia, 25 articles were published with this combination of terms, 15 of which were published in 2013. By comparison, there was minimal coverage of either term in American newspapers. Within the Marcellus region, there were only 5 total mentions of either term in conjunction with hydraulic fracturing terms: 4 articles in Pennsylvania, and 1 in West Virginia.

4.3.1.3 Media coverage of cumulative effects and hydraulic fracturing

In our search for the use of *cumulative effects* with hydraulic fracturing terms, we found that 3 articles were published in New York and 4 in Pennsylvania. In Alberta and British Columbia, a total of 18 articles included this combination of terms between 2008 and 2014 - 9 in Alberta and 9 in British Columbia.

4.3.1.4 Media coverage of stakeholder management and hydraulic fracturing

Finally, we searched for the term *stakeholder management*. This term was not mentioned in connection with hydraulic fracturing in any articles published in any of the provinces or states we studied.

4.3.2 Media coverage of hydraulic fracturing concerns

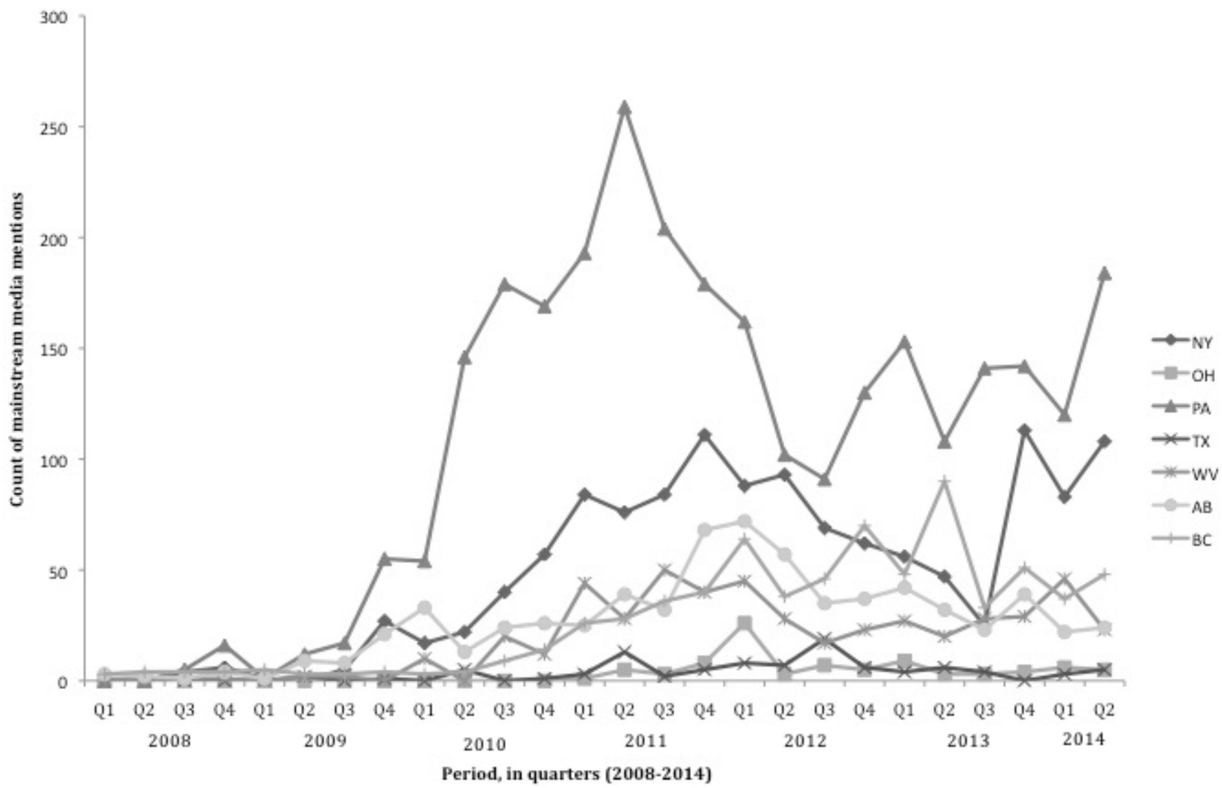
Next, we investigated the extent to which specific concerns were discussed in newspaper coverage of hydraulic fracturing. We identified examples of such *matters of concern* (Latour, 2004a, 2004b) based on our review of published literature and reports, consultations with colleagues who research various hydraulic fracturing related issues, and Google searches using phrases such as "concerns about hydraulic fracturing." From these sources, we distilled our searches of newspapers in the four formations to the specific matters of concern terms shown in Table 4.4. We performed 45 separate keyword searches, pairing each of the five hydraulic fracturing terms (shown in the columns) with one of the nine potential matters of concern (shown in the rows). We further grouped these keywords into three categories: general concerns, wastewater concerns, and political concerns (as shown in Table 4.5). We again relied on Canadian Newsstand Complete for Alberta and British Columbia newspapers. However, given the volume of published articles, we utilized LexisNexis rather than Factiva for the U.S. states, as we found it was more conducive to tabulating trends in spreadsheet format.

Table 4.4. Keyword searches related to matters of concern and hydraulic fracturing.

Matters of concern terms (ROWS = i)	Hydraulic Fracturing terms (COLUMNS = c)				
	Hydraulic fracturing	Fracking	Hydrofracking	Shale gas	Unconventional gas
Health	(i_1,c_1)	(i_1,c_2)	(i_1,c_3)	(i_1,c_4)	(i_1,c_5)
Contaminate	(i_2,c_1)	(i_2,c_2)	(i_2,c_3)	(i_2,c_4)	(i_2,c_5)
Chemical	(i_3,c_1)	(i_3,c_2)	(i_3,c_3)	(i_3,c_4)	(i_3,c_5)
Waste	(i_4,c_1)	(i_4,c_2)	(i_4,c_3)	(i_4,c_4)	(i_4,c_5)
Produced water	(i_5,c_1)	(i_5,c_2)	(i_5,c_3)	(i_5,c_4)	(i_5,c_5)
Flowback water	(i_6,c_1)	(i_6,c_2)	(i_6,c_3)	(i_6,c_4)	(i_6,c_5)
Wastewater	(i_7,c_1)	(i_7,c_2)	(i_7,c_3)	(i_7,c_4)	(i_7,c_5)
Moratorium	(i_8,c_1)	(i_8,c_2)	(i_8,c_3)	(i_8,c_4)	(i_8,c_5)
Ban	(i_9,c_1)	(i_9,c_2)	(i_9,c_3)	(i_9,c_4)	(i_9,c_5)

Looking across the three categories of concerns, it is clear that newspapers in Pennsylvania and New York provided much more frequent coverage than the newspapers in other states and provinces. Additionally, as shown in Figure 4.5, Pennsylvania coverage peaked in mid-2011, although it was surging again as of mid-2014, the end of our study window. The pattern was somewhat similar in New York, with a peak at the end of 2011, and again in mid-2014. Conversely, newspapers in Ohio and Texas provided persistently minimal coverage of hydraulic fracturing related concerns.

Figure 4.5. Media mentions of matters of concern and hydraulic fracturing.



In Table 4.5, we provide a tabular summary of these same data, grouped by keyword category; these three categories will each be discussed separately in the following sections. Any articles with multiple keywords were truncated into a single entry, and thus the counts reflect the total number of unique articles mentioning one or more of the general concern keywords. Appendix D provides a quarter-by-quarter view of these same data.

Table 4.5. Media coverage of hydraulic fracturing related concerns by jurisdiction.

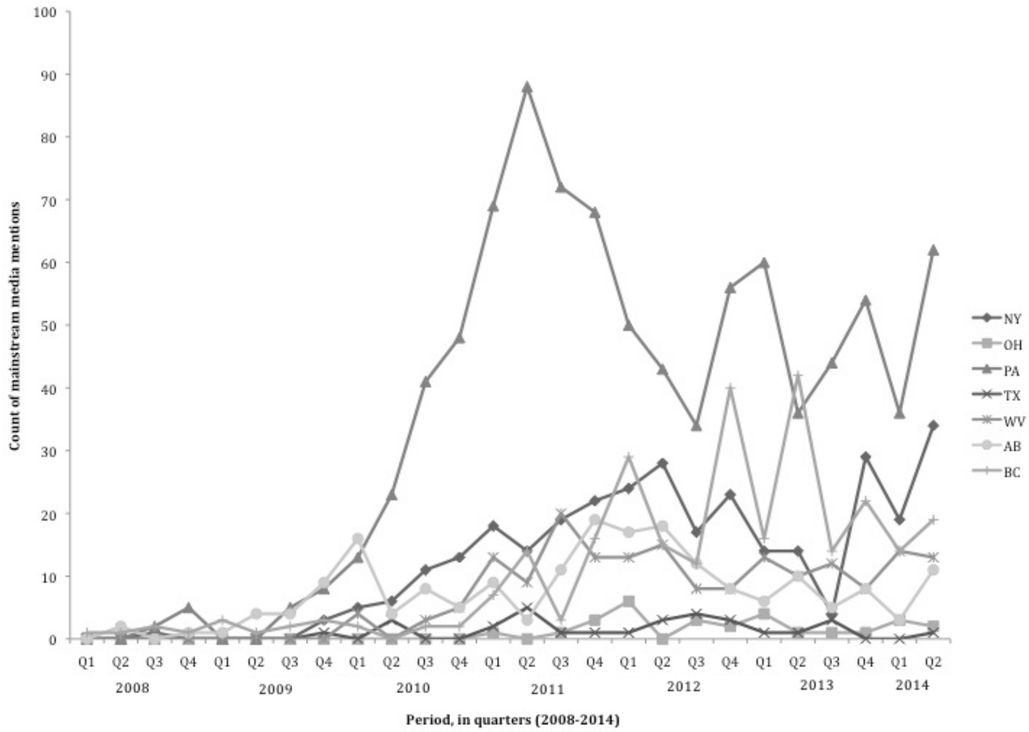
State/Province	General concerns (health, contaminate, chemical, waste)	Wastewater concerns (wastewater, flowback water, produced water)	Political concerns (ban, moratorium)
New York	1253	143	436
Ohio	89	32	32
Pennsylvania	2745	489	698
West Virginia	538	58	128
Texas	100	21	21
Alberta	858	29	177
British Columbia	892	56	177

4.3.2.1 Media coverage of general concerns related to hydraulic fracturing

We used four keywords to evaluate media coverage of hydraulic fracturing related general concerns: *health*, *contaminate*, *chemical*, and *waste*. Figure 4.6 shows the prevalence of *health* as a hydraulic fracturing related concern, since it was the most common keyword in this category. In Pennsylvania, 939 articles were printed between January 2008 and June 2014 that mentioned health and hydraulic fracturing, with approximately one-third of these articles published in 2011. This level of coverage is substantially higher than in any of the other provinces and states we studied. In New York, 336 articles were published on the same topics and, in West Virginia, nearly 200 articles were published; despite also being located in the Marcellus region, Ohio newspapers only printed 29 articles on health concerns related to hydraulic fracturing. Meanwhile, Texas newspapers printed only 30 articles dealing with health and hydraulic fracturing.

In results not shown, we found similar discrepancies among publications in the five U.S. states for the three other terms used to proxy general concerns. For instance, Pennsylvania newspapers printed 245 articles mentioning *chemical*, 133 articles mentioning *contaminate* and related variants, and 124 articles mentioning *waste*. Newspapers in Alberta printed 198 articles mentioning *health* and hydraulic fracturing terms, compared with 286 articles in British Columbia. There was a somewhat similar balance of articles mentioning contaminate and hydraulic fracturing terms, with 202 articles published in Alberta and 194 in British Columbia. Comparatively, coverage of *chemical* and hydraulic fracturing terms was substantially higher in Alberta (381 articles) than in British Columbia (280 articles). *Waste* and hydraulic fracturing terms received less coverage in both provinces, with 77 articles mentioning the term in Alberta, and 132 in British Columbia.

Figure 4.6. Media mentions of health concerns and hydraulic fracturing.

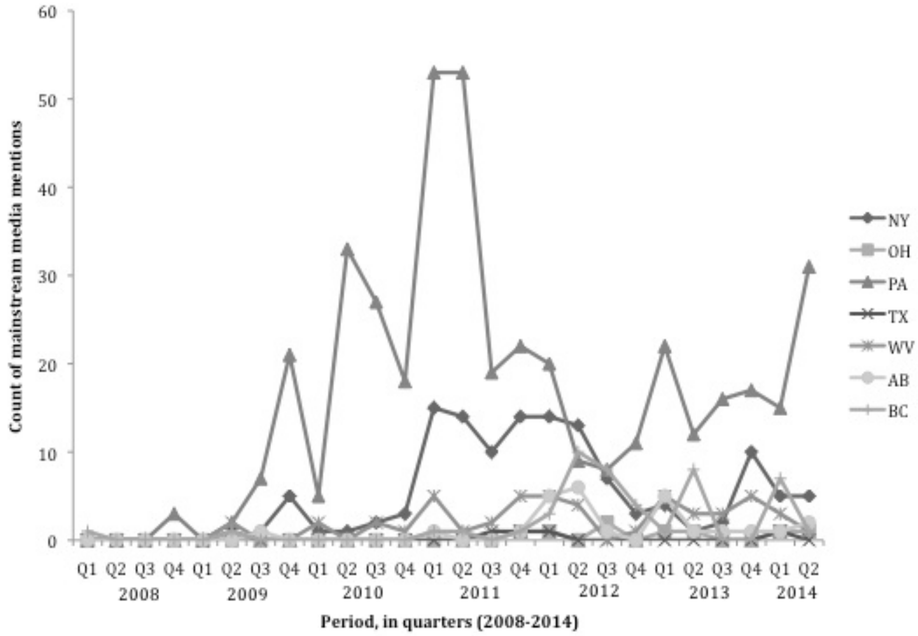


4.3.2.2 Media coverage of wastewater concerns related to hydraulic fracturing

Three keywords were used to evaluate media coverage of hydraulic fracturing wastewater concerns: *wastewater*, *flowback water*, and *produced water*. Beginning in 2008, newspaper coverage of *wastewater* and hydraulic fracturing ramped up in Pennsylvania (432 articles, 147 of which were published in 2011 alone), New York (136 articles), and West Virginia (53 articles), but there was minimal coverage in both Ohio (9 articles) and Texas (5 articles), as identified in Figure 4.7. Similarly, Pennsylvania newspapers provided more coverage of *flowback water* and *produced water* in connection with hydraulic fracturing terms than the other four U.S. states. Pennsylvania newspapers published 37 articles that discussed flowback water, and 20 articles that discussed produced water; neither of these terms was mentioned more than five times by newspapers in New York, West Virginia, Ohio, or Texas.

By comparison, Canadian newspapers provided very little coverage of these wastewater terms. For instance, Alberta newspapers reported on wastewater and hydraulic fracturing just 26 times between January 2008 and June 2014, and only mentioned *flowback water* or *produced water* 1 time each since 2008. Similarly, in British Columbia, newspapers mentioned wastewater and hydraulic fracturing just 49 times since 2008, with 25 of these articles published in 2012 alone. Newspapers in British Columbia failed to mention *flowback water* at all, and mentioned *produced water* just 6 times since 2008.

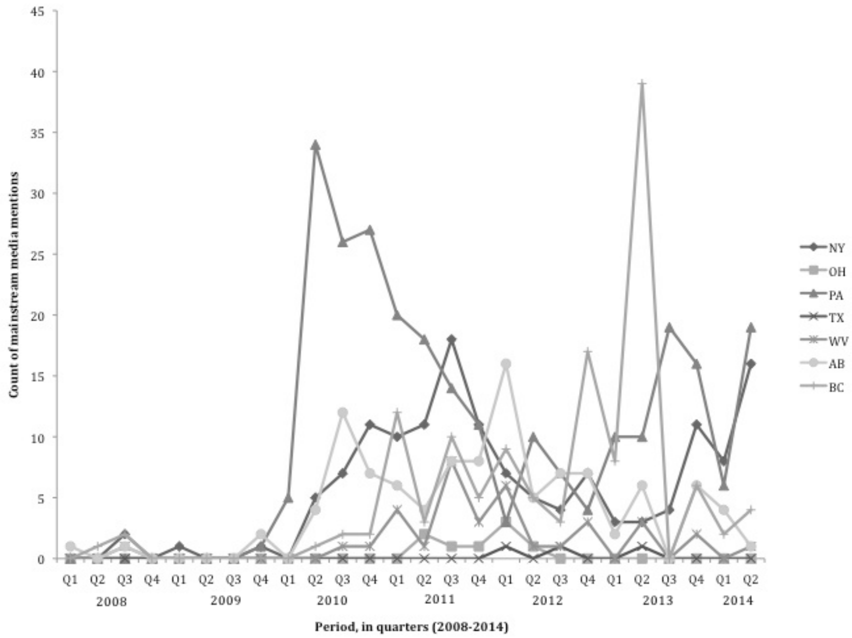
Figure 4.7. Media mentions of wastewater concerns and hydraulic fracturing.



4.3.2.3 Media coverage of political concerns related to hydraulic fracturing

We used two keywords to investigate media coverage of hydraulic fracturing-related political concerns: *moratorium* and *ban*. Figure 4.8 shows the prevalence of articles on moratorium and hydraulic fracturing. Throughout the Marcellus shale formation, the frequency of these two terms varied, with newspapers in New York and Pennsylvania providing the most prominent coverage. Since 2008, there were 227 mentions of *ban* and hydraulic fracturing in New York newspapers and 158 mentions of *moratorium*, with the bulk of the articles published from 2011 through 2014. In Pennsylvania newspapers, there were 266 mentions of *ban*, with a spike in 2011 (83 articles) and again in 2013 (61 articles); 261 articles in Pennsylvania mentioned *moratorium*, 92 of which were published in 2010. West Virginia's coverage of both terms was less prominent, with a total of 55 articles that include *ban* and 37 articles that include *moratorium*. Ohio- and Texas-based publications provided even less coverage of both terms. In Ohio newspapers, *ban* was mentioned in 8 articles and *moratorium* in 9, all of which were published in 2011 or 2012; in Texas newspapers, *ban* was mentioned in 3 articles and *moratorium* in 5 articles. In Alberta, *ban* was mentioned in conjunction with hydraulic fracturing terms in 99 articles published since January 2008, with more than half of these (54) published between 2011 and 2012; similarly, *moratorium* was mentioned in 109 articles, with the bulk of these (84) published between 2010 and 2012. In British Columbia, these political concern terms largely appeared between 2011 and 2013; *ban* was mentioned in in 45 articles, and *moratorium* was mentioned in 131 articles.

Figure 4.8. Media coverage of moratorium and hydraulic fracturing.



4.3.3 Media coverage of specific wastewater concerns

Next, we investigated specific examples of wastewater-related concerns, such as concerns associated with wastewater disposal methods and treatment options. We chose keywords for this search based on our review of published literature and reports, as well as consultations with the study's other authors, industry executives, oil and gas regulators, and other stakeholders. For instance, stakeholder interviews by the Pacific Institute suggested that two of the dominant water-related concerns regarding hydraulic fracturing in the U.S. include wastewater management and groundwater contamination (Cooley & Donnelly, 2012). We identified ten potential keywords as a result of this process. However, compared with the two prior research phases, this phase yielded substantially less fruitful results. The first issue was that several of these keywords, including *pit*, *pond*, *spreading*, and *landfill*, proved unusable because they sometimes generated false positives, making interpretation unreliable. Accordingly, we focused on the six terms listed in Table 4.6. As a result, we performed thirty separate keyword searches, pairing each of the five hydraulic fracturing terms (shown in the columns) with one of the six specific wastewater concerns (shown in the rows). In addition, in all cases we included the term *water* as part of our search query.

Table 4.6. Keyword searches related hydraulic fracturing and specific wastewater concerns

Wastewater concern terms (ROWS = w)	Hydraulic fracturing terms (COLUMNS = c)				
	Hydraulic fracturing	Fracking	Hydrofracking	Shale gas	Unconventional gas
Injection well(s)	(w1,c1,water)	(w1,c2,water)	(w1,c3,water)	(w1,c4,water)	(w1,c5,water)
Impoundment(s)	(w2,c1,water)	(w2,c2,water)	(w2,c3,water)	(w2,c4,water)	(w2,c5,water)
Treatment	(w3,c1,water)	(w3,c2,water)	(w3,c3,water)	(w3,c4,water)	(w3,c5,water)
Reuse	(w4,c1,water)	(w4,c2,water)	(w4,c3,water)	(w4,c4,water)	(w4,c5,water)
Discharge	(w5,c1,water)	(w5,c2,water)	(w5,c3,water)	(w5,c4,water)	(w5,c5,water)
Illegal dumping	(w6,c1,water)	(w6,c2,water)	(w6,c3,water)	(w6,c4,water)	(w6,c5,water)

The second issue we encountered during this phase was that the selected keywords seldom appeared in the jurisdictions we studied during the January 2008 to June 2014 period, suggesting very limited coverage of these issues. *Treatment* was the most prominent wastewater concern in the majority of jurisdictions between 2008 and June 2014 (Figure 4.9). Across the Marcellus region, the combination of terms was mentioned in 317 articles in Pennsylvania, 96 articles in New York, 32 articles in West Virginia, and 3 articles in Ohio. In Texas, 7 newspaper articles included these keywords. In Alberta, 34 articles included this set of terms, while in British Columbia, the keywords were mentioned in 33 articles. The majority of coverage in Alberta and British Columbia occurred in 2012 and 2013, in 21 and 24 articles, respectively. In comparison to the discussion about treatment of hydraulic fracturing wastewater, coverage of the other five specific wastewater concerns was even more scant. Overall, as Figure 4.10 shows, there were relatively few mentions of *injection well(s)* in conjunction with hydraulic fracturing terms and *water* in the seven jurisdictions we studied. This combination of terms first appeared in 2 articles in Alberta in 2008, and has been mentioned in a total of 10 articles; elsewhere, the terms were mentioned in 3 articles in British Columbia, 34 articles in Pennsylvania (most of which were published in 2011); 12 articles in New York, 14 articles in West Virginia and 10 articles in Ohio. *Injection well(s)* was mentioned in Texas newspapers approximately once each year.

Figure 4.9. Media coverage of treatment and hydraulic fracturing.

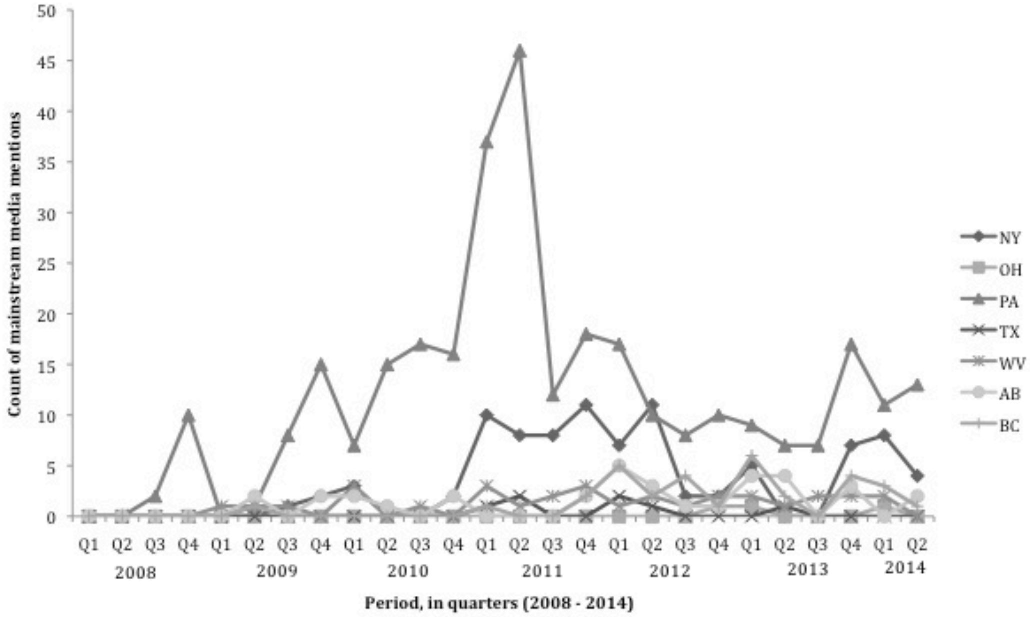
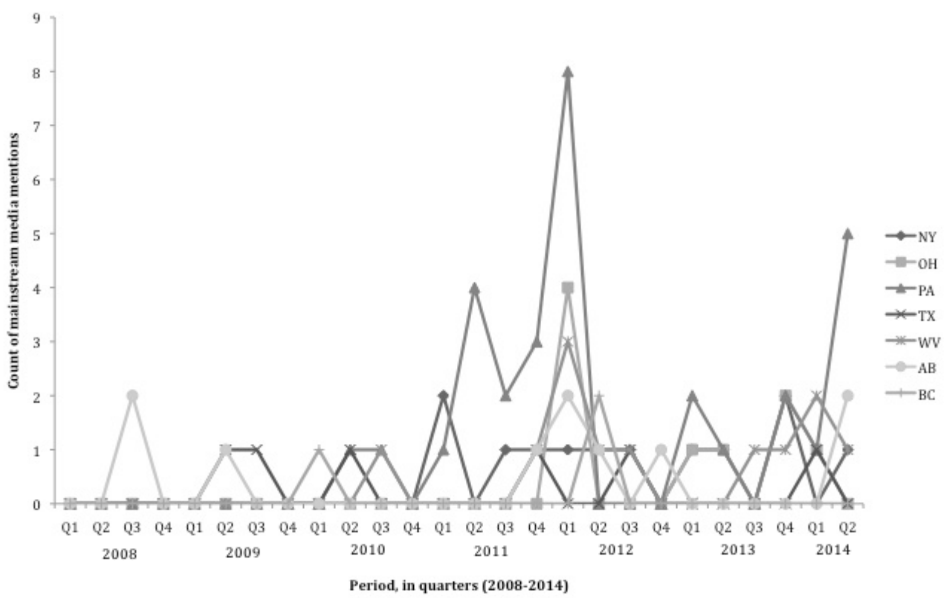


Figure 4.10. Media coverage of injection well(s) and hydraulic fracturing.



The appearance of *impoundment* with hydraulic fracturing terms and water was minimal for every region except Pennsylvania. Between 2008 and 2014, Pennsylvania newspapers published 76 articles with these terms, while in every other jurisdiction the terms received 3 or fewer mentions across the entire period. The occurrence of *reuse* with hydraulic fracturing terms and water showed a similar trend. In Pennsylvania newspapers, 56 articles were published; in New York, 13; and 5 or fewer articles were published in Ohio, West Virginia, and Texas. In Alberta and British Columbia, 14 and 18 newspaper articles mentioning *reuse* were published, respectively. For *discharge*, hydraulic fracturing terms and water, 133 articles appeared in newspapers in Pennsylvania, 26 in New York, 12 in West Virginia, and 2 in Ohio. No articles published in Texas included the term. In Alberta newspapers, *discharge* was mentioned in 3 articles, while in British Columbia, it was mentioned in 17 articles (10 of which were published in 2012). One of the most interesting findings was the lack of coverage related to *illegal dumping*. Only 10 articles published throughout all the jurisdictions studied mentioned the term. One article was published in New York, 6 in Pennsylvania, and 3 in West Virginia. Newspapers in Texas, Alberta and British Columbia did not print any articles with this set of keywords. In Table 4.7, we summarize the findings of our wastewater-specific concerns search.

Table 4.7. Media coverage of wastewater specific concerns by jurisdiction.

State/Province	Injection well	Impound-ment	Treatment	Reuse	Discharge	Illegal dumping	Total mentions
New York	12	3	96	13	26	1	**151**
Ohio	10	0	3	1	2	0	**16**
Pennsylvania	34	76	317	56	130	6	**619**
West Virginia	14	3	32	5	12	0	**66**
Texas	6	0	7	2	0	3	**18**
Alberta	10	2	32	14	3	0	**61**
British Columbia	3	1	33	18	17	0	**72**

4.3.4 Putting concerns in perspective

The results of the first media search suggest that *SLO* is a relatively obscure and limited term, most often appearing in Canadian rather than American newspapers, and typically invoked by industry rather than by the public. Additionally, from the results of the other media searches, it is clear that substantial differences exist across and within the seven jurisdictions we studied in terms of the amount of newspaper coverage related to hydraulic fracturing terms. In order to compare the relative differences between each jurisdiction, we developed a simple ratio by dividing the number of "concerns" articles by the number of "accountability" articles published in each province/state between January 2008 and June 2014. When calculating this ratio, we only counted total unique articles. More than one concern may have been identified in a single article; in order to better control for publication frequency, our index truncates concerns by article rather than by frequency of term use. Therefore, the totals in Table 4.8 may vary from those reported earlier in this chapter. The result is a rough indicator of the general tenor of hydraulic fracturing-related newspaper coverage in a region in terms of concerns versus accountability. As seen in Table 4.8, the index resulting from our media searches is substantially higher in the majority of Marcellus states (New York, Pennsylvania, and West Virginia) than in the other three jurisdictions.

Table 4.8. Concern versus accountability index

Region	Total concern mentions	Total accountability mentions	Concern to accountability ratio
New York	1278	12	107
Ohio	88	3	29
Pennsylvania	2822	30	94
West Virginia	496	10	50
Texas	94	2	47
Alberta	692	126	5
British Columbia	715	112	6

4.3.5 Emerging concerns related to hydraulic fracturing

In addition to our structured media searches, during the course of our research we noticed that an array of nongovernmental organizations (NGOs), blogs, and even movies expressed concerns about hydraulic fracturing. Although a variety of constraints prevented us from quantitatively tracking these sources, in the section below we spotlight several notable wastewater handling, treatment, and disposal concerns. The issues discussed in this section are neither exhaustive, nor representative. Instead, using a process of theoretical sampling (Lincoln & Guba, 1985), we selected issues that exemplify and illustrate the breadth and depth of the hydraulic fracturing debate. Of course, the trajectories these concerns may take remains to be seen; some may become irrelevant, while others could become salient issues. The topics we identified include: 1) induced seismicity from wastewater disposal; 2) aquifer contamination from untreated wastewater (often referred to as "frack water" injected into disposal wells; 3) leaking impoundments; 4) improperly treated wastewater reintroduced into the ecosystem; 5) municipal water treatment plants that are unprepared to effectively treat the waste accepting wastewater from industrial operations; 6) radioactive materials present in wastewater; 7) spreading of untreated wastewater; and 8) illegal dumping of untreated wastewater. We use these themes to highlight various hydraulic fracturing concerns that have been expressed via these less traditional media sources throughout Alberta, British Columbia, Pennsylvania, New York, West Virginia, Ohio, and Texas.

4.3.5.1 Induced seismicity from wastewater disposal into orphaned wells

Induced seismicity from deep well injection is becoming a salient and growing global concern. Journalist and author Andrew Nikiforuk outlined the alleged link between wastewater injection and seismic activity through a widespread investigation published on *The Tyee*, an independent online magazine focused on improving democratic conversation (Nikiforuk, 2011). Nikiforuk referred to a report inferring that traditional deep well injection had triggered earthquakes, particularly when both injection and extraction were local (Nicholson & Wesson, 1992); Nikiforuk suggested that concerns around seismicity are therefore not new to the oil and gas industry. The recent shale gas revolution has significantly increased the frequency of deep well injection, and the conversation around potential seismicity is extensive.

Another report appeared in *Time* on the Ohio Department of Natural Resources' public link between seismic activity and shale gas development (Walsh, 2014b). The report suggests that the number of earthquakes of magnitude 3.0 and greater grew substantially between 2010 and 2013 along with shale gas activity, which increased from approximately 20 wells per year from 1970 to 2000 to over 100 annually from 2010 to 2013.

4.3.5.2 Aquifer contamination from untreated wastewater injected into disposal wells

The University of Alberta Augustana Campus enacted the Alberta Voices project in 2013, which focuses on the experiences of Albertan landowners and their concerns about hydraulic fracturing (Asfeldt, Bortolon, Rathnavalu, & Mundel, 2013). The vision of this project, communicated through film by two undergraduate students, is to "give voice to those whose troubling experiences with hydraulic fracturing and associated activities may not have not been considered in Alberta's discussion of oil and gas development" (Asfeldt et al., 2013). One story featured in the project describes an elderly landowner troubled by an abandoned well in Athabasca during the 1990s (Asfeldt et al., 2013). As detailed by the landowner, an abandoned well was situated on her property. After drilling a new 42-inch well bore at the same site, she found an abundance of water deep below the surface, "polluted with some sort of substance, which looked like oil" (Cecil Lewis, as told by Asfeldt et al., 2013). After a tireless experience with government and environmental experts, she was eventually told that naturally occurring oil was the cause for the water contamination. However, her own personal investigation pointed to a waste injection well nearby, which the landowner identified as the more likely root of the alleged water contamination. However, she reportedly was unable to obtain any conclusive evidence or additional support from government or industrial agencies.

Case: Well #2240 in Northeastern British Columbia
Since 1968, over 41 billion liters of wastewater have been injected into well #2240 in Northeastern British Columbia (Hume, 2014). A recent report commissioned by the Fort Nelson First Nation suggests that current disposal practices inadequately track contaminated wastewater from hydraulic fracturing operations in the region, and that the integrity of well #2240 is unknown (Carr-Wilson, 2014). Potential concerns around this well include: "surface spills during re-injection; improper seals in old cement around well casings permitting toxic leaks into shallow aquifers; migration of water upward from deep wells to contaminate shallow and surface groundwater travelling through subterranean rock layers" (Hume, 2014).

4.3.5.3 Leaking impoundments

On April 1, 2014, State Impact National Public Radio reported potential groundwater contamination due to improperly regulated reserve pits just north of Dallas, Texas (Fehling, 2014). Upper Trinity Groundwater Conservation District Manager Bob Patterson discussed the poor regulation and requirements for industry to hold their drilling wastes in Texas reserve pits. Patterson identified clear concerns about how unlined, potentially unpermitted and rarely inspected reserve pits can potentially leach into clean drinking water sources and contaminate the underlying aquifer. This concern is exacerbated by the manner in which unlined pits are addressed post-fill. Chemical leaching could occur upon well initiation, and Patterson even insinuated that the residual waste is often rototilled back into the surface soil.

Another incident of industrial leakage that was negatively viewed by the public happened in Pennsylvania. EcoWatch reported that a plug was removed from a wastewater holding tank at a drilling site in 2010, resulting in the release of 57,000 gallons of hydraulic fracturing fluid (Atkin, 2014). The Pennsylvania Attorney General filed criminal charges; however, Exxon denied the possibility of enduring environmental impacts and suggested that these charges would discourage other companies from engaging in responsible environmental practices.

Case: Range Resources Corporation fined for leaking fluids from impoundment
Range Resources has been under investigation by the DEP due to salt residue near Amwell Township in Washington County, Pennsylvania (Hopey, 2014). On April 18, 2014, the Pittsburgh Post-Gazette reported that Range Resources was currently being investigated based on a self-reported potential salt leakage within an inactive impoundment. The DEP subsequently penalized Range Resources with a $4.15 million fine for a total of six violations related to the leakage of flowback fluid into soil and groundwater in September (Colaneri, 2014b). Additionally, Range Resources agreed to a landmark consent agreement that increases the standard for five of the impoundments; this will improve practices for future impoundments statewide (Colaneri, 2014b).

4.3.5.4 Improperly treated wastewater reintroduced into the ecosystem

The possibility of "partially treated" wastewater re-entering the public drinking water supply was realized after specific incidents that occurred between June 2009 and June 2010 (Voices, 2011). Voices of Central Pennsylvania, an independent community newspaper and blog, highlighted the locations of wastewater treatment plants (WTPs) in Pennsylvania watersheds and the associated downstream towns utilizing drinking water from each creek, river, tributary or stream. The article suggested that interfaces between WTP discharge and fresh water sources could be problematic, reflecting concerns related to inadequately treated public drinking water in many areas of Pennsylvania.

In August 2009, it was alleged that Tapo Energy discharged various "petroleum-based" materials into a tributary of Buckeye Creek in Doddridge County, West Virginia (West Virginia Department of Environmental Protection, 2009; Wilber, 2012). Witnesses subsequently reported a "red gel" on the surface of the water. Although the West Virginia DEP followed up and coordinated onsite clean up and reclamation, the agency was unable to draw conclusive evidence to suggest that Tapo Energy had intentionally discharged fluid into the creek (West Virginia Department of Environmental Protection, 2009).

4.3.5.5 Municipal water treatment plants accepting wastewater from industrial operations

The NRDC's comprehensive wastewater management report, *In Fracking's Wake* (Hammer, VanBriesen, & Levine, 2012), identified the challenges for wastewater disposal in Pennsylvania. Neither municipal sewage facilities (known as publicly owned treatment works, or POTWs) nor industrial centralized waste treatment (CWT) facilities are typically equipped to manage the total dissolved solids (TDS), radioactive materials and the myriad chemicals commonly found in produced and flowback water. Oftentimes these wastes are merely diluted during "treatment" and returned to surface waters, creating potential environmental damage (Hammer et al., 2012).

4.3.5.6 Radioactive materials present in wastewater

Concerns related to radiation also impact landfill disposal. An article in Forbes reported on an incident at a South Huntingdon, Pennsylvania landfill when a truck containing hydraulic fracturing waste from a well pad set off radiation alarms (McMahon, 2013). The truck in question was quarantined because radium 226, a naturally occurring radioactive material (NORM), was found in a high enough quantity to emit 96 microrem per hour, far beyond the landfill rejection threshold of 10 microrem per hour. This level is also 84 times higher than the EPA standard for air pollution (McMahon, 2013).

In the aforementioned *New York Times* article, "Regulation Lax as Gas Wells' Tainted Water Hits Rivers," Urbina (2011) discussed a plethora of internal Environmental Protection Agency (EPA) documents highlighting the potential dangers of hydraulic fracturing operations. One of the major political and public contributions of this pivotal piece highlights how radioactivity in wastewater is a hazard to the fresh water supply:

> The documents reveal that the wastewater, which is sometimes hauled to sewage plants not designed to treat it and then discharged into rivers that supply drinking water, contains radioactivity at levels higher than previously known, and far higher than the level that federal regulators say is safe for these treatment plants to handle. (Urbina, 2011)

Case: Alleged radioactivity impacts health of Airdrie rancher's herd and family
Closely related to concerns related to wastewater treatment is the suspected persistence of naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive materials (TENORM) in hydraulic fracturing wastewater. In Airdrie, Alberta in 2013, an Albertan cattle rancher pointed the finger at heavy industry and the hydraulic fracturing process for killing 10% of his herd, creating dead patches of grass throughout his farm, and creating unknown health effects for his wife, whose hair was falling out (Gillis, 2013). Radioactive materials were specifically blamed for the damage to his livelihood and farm. However, this farmer suggested that non-disclosure agreements were preventing other ranchers from speaking out.

4.3.5.7 Untreated wastewater spread onto roads

The NRDC's report on the disposal of high-volume wastewater from hydraulic fracturing activities within Pennsylvania also mentioned the practice of spreading wastewater onto roads to control dust (Hammer et al., 2012). This report determined that spreading wastewater from hydraulic fracturing operations onto roads has a high potential for environmental harm, especially when exacerbated by precipitation (Hammer et al., 2012). An additional concern associated with this practice is that produced water can actually negate already existing agents applied to roads (e.g. for de-icing and dust control), resulting in chemical runoff and potential contamination of surface waters and groundwater (Hammer et al., 2012). New York has been allowing produced and flowback water to be spread onto roads in at least 29 municipalities, according to Riverkeeper (see "The Facts about New York and Fracking Waste," 2014).

4.3.5.8 Illegal dumping of untreated wastewater

Interestingly, the term *illegal dumping* was mentioned rarely based on the targeted keyword search. For example, the only article in New York that explicitly suggested the practice appeared in the *New York Times* and described how residents in south Texas-Mexico border counties are experiencing substantial poverty despite the oil "boom" (Fernandez & Krauss, 2014). Gardendale, a border town in the Eagle Ford shale region, is said to be an illegal dumping ground for nearby shale development and processing. Although the article did not include any specific details about the alleged illegal dumping – what is being disposed of, which companies are responsible, and any legal action that has taken place – several alleged accounts appeared on alternative media sites.

One incident discussed by Urbina (2011) in the aforementioned *New York Times* article is the potential contamination of the Monongahela River Basin Mine Pool, which is located on the Allegheny Plateau in southwest Pennsylvania. According to the supporting EPA documents accompanying the article, the EPA became aware of four cases of wastewater disposal into the Gateway Mine that occurred into the between June and August 2010. An estimated 1.5 to 2.8 million gallons of wastewater were disposed of illegally (Urbina, 2011).

In Texas, a tanker truck spilled approximately 1,260 gallons of unidentified hydraulic fracturing waste over an 8-mile span of road between the rural communities of Falls City and Hobson (Hasemyer, 2014). With civil charges already pending through the Texas Commission on Environmental Quality, Sheriff Dwayne Villanueva is also seeking criminal charges, as the truck was not being operated in a responsible manner (Hasemyer, 2014).

In Ohio, a subcontractor caught dumping drilling wastes into a storm sewer, was fined $1 million, and is currently facing criminal charges for violating the *Clean Water Act* (De Leon, 2014). Ring of Fire Radio reported that both benzene and toluene were found in a tributary of the Mahoning River after activities that occurred between November 2012 and January 2013. This case is unique, as it is the only notable incident addressed in this literature review that denotes criminal activity and clear violation of law, as admitted by the defendant and proven in court.

Case: Dumped hydraulic fracturing waste makes its way into Dawson Creek
DeSmog Canada described a recent allegation by Dawson Creek city staff of illegal dumping within city limits (Linnitt, 2014). According to city officials, there have been two clear instances between February 2013 and July 2014 in which flowback waste was inappropriately dumped into the Dawson Creek water treatment system via holding tanks. Subcontractors were targeted as the culprits in this series of incidents, since large companies' hydraulic fracturing operations are regularly subcontracted to other firms. Although this incident was reported by the Alaska Highway News on July 30, 2014 (Wakefield, 2014), it was outside the temporal and spatial boundaries of our keyword search (i.e., it was not in one of the seven jurisdictions we studied, nor was it within the timeframe of our study).

4.3.6 Other concerns noted around hydraulic fracturing

Alberta Environment and Sustainable Resource Development (ESRD) solicited opinions about water-related issues through a series of "Water Conversations" (Alberta Environment and Sustainable Resource Development, 2013). Concerns around water demand and use, and hydraulic fracturing activities were expressed during public consultations in 20 cities and towns across the province. Members of the general public attended and shared their experiences, knowledge and concerns related to hydraulic fracturing. The concerns raised during Water Conversations 2013 tended to echo those identified in our newspaper searches (Figure 4.11).

Notable themes that emerged from the Water Conversations include:

- More information must be made publicly available since most residents do not fully understand the hydraulic fracturing process;
- Transparency will likely facilitate public confidence;
- Members of the public would appreciate more industrial accountability, transparency and innovation;
- Baseline monitoring should occur to ensure that contamination from drilling is prevented, with continual monitoring supplemented by enforcement if required;
- More groundwater mapping is required; and
- Regulations must protect water resources and caution should be exercised, given the pace of development.

Figure 4.11. Authors' word cloud analysis of Alberta Water Conversations 2013 literature.

Although the water-related discourse among non-governmental organizations (NGOs) is prominent, our research did not yield many extensive reports around specific wastewater concerns, with the exception of the Pacific Institute's report on water resource use in hydraulic fracturing (Cooley & Donnelly, 2012).

Concerns related to water demand are also prominent in the literature. To remain within scope, we only include two prominent incidents of concern. The Western Canada Wilderness Committee and the Sierra Club of British Columbia filed a lawsuit against Encana for using a series of short-term water approvals rather than engaging in more onerous practice of pursuing a long-term water use license (Keller, 2014). By skirting the full license to use water, Encana has been able to avoid completing a comprehensive impact assessment. An Ecojustice lawyer suggested that impacted and potentially affected stakeholders have thus been prohibited from voicing project-related concerns.

In Pennsylvania, State Impact National Public Radio visually identified the amount of water used throughout the hydraulic fracturing process, and concluded that "fracking" the average well in the state requires 4.4 million gallons of liquid, of which 63% is surface water, 20% is public water, and 15% is recycled from previous hydraulic fracture treatments; the other 2% is comprised of propants and other chemicals (StateImpact, 2013). This relatively benign pictorial depiction of water use for the typical hydraulic fracturing site spurred 42 user comments, referring to freshwater as a finite resource, highlighting that multiple fracturings require substantially more water, naming other uses for freshwater (namely golf courses) and debating the new role of renewable energy sources, given significant national promotion of natural gas as a "clean energy source" (StateImpact, 2013).

4.3.7 Hydraulic fracturing on the big screen

The movie *Gasland*, directed by Josh Fox, was released on September 15, 2010, and is widely credited with sparking major international debate over hydraulic fracturing (Thaxton, 2012). *Gasland* became the impetus for Fox's subsequent grassroots movement that led to the *Fracturing Responsibility and Awareness of Chemicals (FRAC) Act* being proposed in the U.S. Congress and widespread public involvement in the hydraulic fracturing debate (Thaxton, 2012). The purpose of the film rebuttal to *Gasland*, *FrackNation*, was to "search for the fracking truth" (*FrackNation*, 2014), and challenge many of the claims made in the *Gasland* movie. In addition, Hollywood filmmakers made their own statement about hydraulic fracturing in a film about potential shale development in a small American town (*Promised Land*, 2013).

Thanks to funding from Shell, The Rational Middle Media Group produced a video series on hydraulic fracturing and other contentious energy-related issues (*Rational Middle Energy Series*, 2014). In the videos, the challenges of shale gas development are explored through the lens of economic prosperity, environmental concerns and the fundamental switch to an energy future with greater possibility. At the time of this publication, the series had not yet addressed wastewater concerns.

4.4 Knowledge Gaps and Research Approaches

4.4.1 Overview of Knowledge Gap - Stakeholder Concerns

The third knowledge gap is based on the findings from the research undertaken for this report that social acceptance of hydraulic fracturing is essential; yet it varies extensively across time and place. A comprehensive understanding of operator and regulator approaches for gaining and retaining social acceptance remains elusive. All organizations depend on social acceptance for their survival and success. SLO is the latest articulation of this principle and our analysis indicates decreased levels of trust in industry and government, both in terms of procedures and outcomes. As our research indicates, conventional understandings of risk management may not be adequate for dealing with grand challenges such as hydraulic fracturing, and organizational practices, which may have gone unnoticed or unchallenged in the past, may no longer apply, particularly in the context of the changing role of social media.

4.4.2 Approaches, Strengths and Weaknesses - Stakeholder Concerns

Given the broad scope of this knowledge gap, two possible approaches are proposed. Both would involve ambitious theoretical and empirical examinations of the impact of the industry-regulation concerns on organizational legitimacy in the hydraulic fracturing industry (and vice versa). They would address issues such as, trust in organizations, cultural theories of risk, and organizational values practices. They could also explore the relationship between sustainability frameworks by industry and SLO. For instance, one of the industry reviewers for this study emphasized the need to further explore the relationship between triple bottom line reporting, a particular approach to sustainability in which organizations report on their financial, environmental, and social costs and benefits. Interest in triple bottom line accounting has been growing among business, governments and nonprofits. But there are important questions to consider. For instance, does the use of triple bottom line accounting by industry result in increased stakeholder receptivity to hydraulic fracturing activities? Essential to both suggested approaches is contextualizing the research questions through the lenses of technology, relationships, time and culture.

The **first approach** would be to undertake a meta-analysis, which comprises statistical methods for contrasting and combining results from different studies to identify patterns among study results, sources of disagreement among those results, or other interesting relationships that may come to light in the context of multiple studies. Sources would include any published studies of statistical relationships of interest. The **strength** of this approach is that by using existing sources of information a research team could be quickly assembled and begin work. An obvious **weakness** is that by relying on existing information, personal contact with and insight from stakeholders would not be obtained. A **second weakness** is that this approach might not capture the rapid pace of innovation in the industry. The estimated **cost** of this approach (depending on the size of the team and the scope of the mandate) would be $150,000 to $400,000.

The **second approach** would involve new primary research, including nationwide interviews and focus groups with stakeholders from industry, government (policy makers and regulatory bodies), communities, environmental groups, and media representatives. The **strength** of this approach is that it is extremely comprehensive, and would draw on a wide variety of existing knowledge supplemented by insight and shared experience from stakeholders which could be applied at the local level, while acknowledging that there is no single recipe for social acceptance and that solutions must be developed organically. A **second strength** is that it is scalable. One tactic could involve a more fine-grained study of regional discourses, for instance, differences between Pittsburgh and Dimock, Pennsylvania, between Denton and Fort Worth, Texas, or between Alberta and New Brunswick. Specific projects under this approach could be focused on a subset of the shale plays examined in this study, with subsequent projects building on the results of earlier efforts. As a result, the cost of implementing the approach would also be scalable. A **third strength** is that an independent, multi-academic institution research team could conduct it. This would potentially avoid the any perceived bias that sometimes occurs when consultations are conducted by government or industry.

One **weakness** of the approach is that it could ultimately result in complex, multi-disciplinary project, which would take considerable time, resources and commitment to undertake. However, as noted above, developing a pilot project that would address the issues in a specific, constrained geographic space could mitigate this. Lessons learned from the pilot could then be applied to a broader agenda. Another **weakness** could be the receptivity by industry to participate. Review comments provided by one industry association demonstrated a degree of skepticism as to whether the findings would be useful.

Acknowledging that any projects undertaken under this approach would be scalable, it is estimated that the **cost** could range from $150,000 for a narrowly defined pilot project to more than $1,000,000 for a national consultative approach.

CHAPTER 5: CONCLUSION

This objective of this study was to: examine wastewater handling, treatment, and disposal practises[36] as they apply to the hydraulic fracturing industry; identify knowledge gaps; and suggest research approaches to address the gaps. Despite the high level of concern by stakeholders, to date there has been no comprehensive, comparative examination of *wastewater management* practices involving handling, treatment, and disposal. This is at least in part because plays and formations vary greatly in: geological and hydrological structure, estimated reserves, mix of reserves (oil, gas, condensates), length of time active recovery has been under way, breadth of collected data, proximity to major populations, regulatory regimes, number of political jurisdictions responsible for regulation, and options available for wastewater management under the existing jurisdictional policies – which make a comparative review difficult.

Without the ability to go back in time to collect baseline data and retroactively establish regulations to the beginning of each formation's development, our comparison allows us to, in effect, compose a microcosm of the issues associated with handling, treatment, and disposal of hydraulic fracturing wastewater. This methodology allows a "before" and "after" picture to be developed. It is important to note that this study is not intended to provide a complete history of all issues involved in the three subject areas explored. Rather, the intent was to compile sufficient information to identify knowledge gaps and research approaches, recognizing that this study involved extensive research and the compilation of considerable details in each area.

The methodology for the study involved establishing three teams of researchers, each devoted to a specific task area representing a key issue in wastewater management. The three task areas were: *water treatment and disposal practises; regulatory policy regimes and voids within and across jurisdictions; and stakeholder concerns*. This study focused on four formations that enabled a comparison of jurisdictions with extensive experience in hydraulic fracturing wastewater management to those with less. The selections were the Duvernay and Montney formations in Canada, and the Barnett and Marcellus formations in the United States.

The research presented and the identification of knowledge gaps was the result of extensive literature reviews from numerous sources, interviews and briefings with subject matter experts, exchanges of information among team members, and feedback from advisory panels. In February 2015 a draft of the final report was circulated to an advisory group consisting of representatives from industry, government, and academia, four of which responded with detailed suggestions for technical corrections and revisions. This was combined with feedback provided by the CWN advisory and technical review committees and used to influence the final selection of knowledge gaps and approaches and to ensure technical accuracy.

The study culminates in the identification of knowledge gaps and approaches to filling those gaps within the three task areas. Following is a summary of the knowledge gaps by task area:

[36] Although not specifically referred to in the original terms of reference for this study, the practice of water reuse is also investigated.

Water treatment and disposal practices: Inconsistencies in reporting can result in missing information for individual wells in the three disposal well databases reviewed (geoScout, Accumap and FracFocus). We observed gaps pertaining to: the fate of wastewater, the source of water used, water injection and production, and chemical analysis. The most prominent knowledge gap is that the fate of hydraulic fracturing wastewater is absent. In other words, it is not clear what portion of a well's wastewater is reused/recycled, treated, surface discharged, or deep-well injected. This lack of information prohibits any direct analysis of wastewater management practices for the hydraulic fracturing operations based on the available information in databases. We also found that the databases examined may not serve the information needs of stakeholders external to the regulatory and industry communities, while acknowledging that the databases were not designed specifically for that purpose.

Regulatory policy regimes and voids within and across jurisdictions: Our research indicates that there are significant differences in how disposal wells are classified and regulated across jurisdictions. The adequacy of the regulations for disposal wells in the U.S. was identified as a knowledge gap, and the degrees to which the current British Columbia and Alberta disposal well regulations (including the permitting process) are sufficient to protect the environment over the long term remains unknown. Our research also leads to the conclusion that significant knowledge gaps exist in the areas of regulatory outcomes, compliance and Best Management Practices, and terminology, particularly in how those factors incite and contribute to environmentally sustainable practices. We also found that First Nations have not imposed regulations for wastewater handling, treatment, and disposal on their lands, and a knowledge gap lies in the ability of assess the capacity of First Nations communities to regulate hydraulic fracturing activity.

Stakeholder concerns: We found that social acceptance of hydraulic fracturing is essential; yet it varies extensively across time and place. A comprehensive understanding of operator and regulator approaches for gaining and retaining social acceptance remains elusive, thus presenting a knowledge gap. As our research indicates, conventional understandings of risk management may not be adequate for dealing with grand challenges such as hydraulic fracturing, and organizational practices, which may have gone unnoticed or unchallenged in the past, may no longer apply, particularly in the context of the changing role of social media.

APPENDIX A: TIMELINES OF LEGISLATION, REGULATIONS, AND DIRECTIVES IN BRITISH COLUMBIA AND ALBERTA FOR CHAPTER 3

Figure A.1. Timelines for legislation, regulations, and directives in British Columbia (BC) and Alberta (AB).

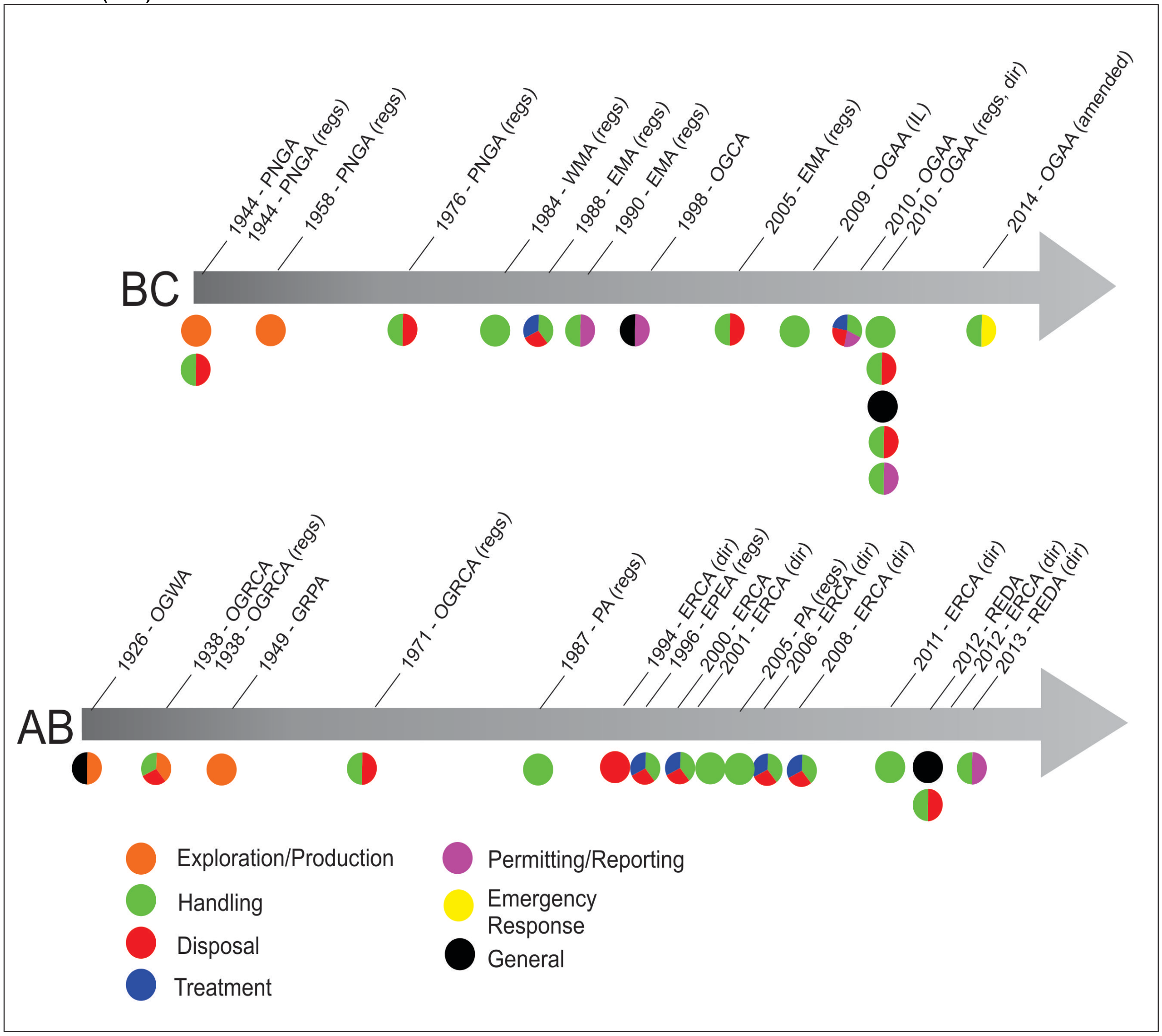


Table A.1. Timeline of British Columbia legislation, regulations, and directives.

Act or Regulation, Amendment, Directive, Industry Letter	Topics Addressed
1944 – *Petroleum and Natural Gas Act*	General stipulations pertaining to exploration and production. Few provisions for wastewater.
1944 – Drilling and Production Regulations (*Petroleum and Natural Gas Act*)	Handling and disposal: Onsite storage, pollution prevention.
1958 – Regulation Governing the Drilling of Wells and the Production and Conservation of Oil and Natural Gas	*No mention of wastewater handling, treatment, transport, or disposal.

(*Petroleum and Natural Gas Act*)	
November 10, 1976 – Drilling and Production Regulations amended (*Petroleum and Natural Gas Act*)	Handling and disposal: Earthen pits, injection, pollution prevention.
January 30, 1984 – Special Waste Regulation amended (*Waste Management Act*)	Handling: Storage tanks for transport, pollution prevention.
February 18, 1988 – Hazardous Waste Regulation (*Environmental Management Act*)	Handling, transport, treatment and disposal: Exemptions for oil and gas wastes, spill prevention, storage criteria.
August 10, 1990 – Spill Reporting Regulation (*Environmental Management Act*)	Handling: Reporting criteria for spills/accidents
1998 – *Oil and Gas Commission Act*	Oil and Gas Commission created
July 28, 2005 – Oil and Gas Waste Regulation (*Environmental Management Act*)	Handling and disposal: Storage tanks, underground injection.
March 12, 2009 – OGC Industry Letter 09-07: Storage of Fraccing Fluid Returns (*Oil and Gas Activities Act*)	Wastewater handling: Storage
2010 – *Oil and Gas Activities Act* (consolidated *Oil and Gas Commission Act*, the *Pipeline Act*, and the *Petroleum and Natural Gas Act*)	Handling, treatment, transport and disposal: Requirements for permits, special projects, enforcement, pollution prevention, remediation.
October 4, 2010 – Pipeline Regulation (*Oil and Gas Activities Act*)	Handling (transport): pipelines.
October 4, 2010 – General Regulation (*Oil and Gas Activities Act*)	Handling, treatment, and disposal: "innovative technologies" permitted to store or dispose of wastewater.
October 4, 2010 – Environmental Protection and Management Regulation (*Oil and Gas Activities Act*)	All oil and gas activities: Protection of wildlife and the environment.
October 4, 2010 – Drilling and Production Regulation (*Oil and Gas Activities Act*)	Wastewater handling and disposal: Onsite storage, injection, and pollution prevention.
December 6, 2010 – Directive 2010-07: Reporting of Water Production and Flowback Fluids (Drilling and Production Regulation; *Oil and Gas Activities Act*)	Handling: Metering and reporting.
October 1, 2014 – Emergency Management Regulation (*Oil and Gas Activities Act*) (consolidated emergency management regulations addressed in Drilling and Production Regulation, the Consultation and Notification Regulation, and the Pipeline and Liquefied Natural Gas Regulation)	Handling: Spill prevention plans, emergency management,

Table A.2. Timeline of Alberta legislation, regulations, and directives.

Act or Regulation, Amendment, Directive, Industry Letter	Topics Addressed
1926 – Oil and Gas Wells Act	General waste prevention; No regulations passed or enforced
November 22, 1938 – Oil and Gas Resources Conservation Act	Waste prevention, storage, handling; wastewater not specifically dealt with under prevention
1938 – Oil and Gas Resources Conservation Regulation (*Oil and Gas Resources Conservation Act*)	Waste prevention, storage, handling; wastewater not specifically dealt with under prevention
1949 – Gas Resources Preservation Act	Allows development and removal of natural gas from AB
1971 – Oil and Gas Conservation Rules (*Oil and Gas Resources Conservation Act*)	Storage, handling, "control of fluids," disposal – injection.
1987 – Pipeline Regulation (*Pipeline Act*)	Transport
March 1, 1994 – Directive 51: Injection and Disposal Wells	Disposal - injection
1996 – Waste Control Regulation (*Environmental Protection and Enhancement Act*)	Handling, treatment, disposal, pollution prevention
2000 – Energy Resources Conservation Act	Handling, transport, treatment, disposal, environmental protection
June19, 2000 – ID 2000-4: An Update to the Requirements for the Appropriate Management of Oilfield Wastes	Handling, treatment, disposal
December 1, 2001 – Directive 55: Storage Requirements for the Upstream Petroleum Industry (*Energy Resources Conservation Act*)	Handling, storage
2005 – Pipeline Regulation (*Pipeline Act*)	Transport
February 1, 2006 – Directive 58: Oilfield Waste Management Requirements for the Upstream Petroleum Industry (*Energy Resources Conservation Act*)	Handling, treatment, disposal
December 23, 2008 – Directive 58 (Addendum): Oilfield Waste Management Facility Approvals	Handling, treatment, disposal
October 10, 2011 – Directive 55 (Addendum): Interim Requirements for Aboveground Synthetically- Lined Wall Storage Systems, Updates to Liner Requirements, and Optional Diking Requirements for Single-Walled aboveground Storage Tanks (*Energy Resources Conservation Act*)	Handling, storage
2012 – Responsible Energy Development Act	Powers of the regulator
May 2, 2012 – Directive 50: Drilling Waste Management (*Responsible Energy Development Act*)	Handling, transport, storage, and disposal of drilling wastes
May 15, 2013 – Directive 17: Measurement Requirements for Oil and Gas Operations (*Responsible Energy Development Act*)	Handling, measurement of water volumes

APPENDIX B: NEWSPAPER SOURCES FOR CHAPTER 4

Below, we list the newspapers used for our keyword searches.

Canada

In Canada, we searched newspapers published in Alberta and British Columbia to identify stakeholder concerns related to the Montney and Duvernay shale formations. We selected newspapers based on three criteria: daily publication frequency, estimated circulation distribution of 5,000 or greater; and inclusion in the Canadian Newsstand Complete database. In Alberta, 9 daily newspapers had circulations of 5,000 or more. Of these, the *Calgary Herald* and *Edmonton Journal* were available on the Canadian Newsstand Complete database. In British Columbia, 15 daily newspapers had circulations of 5,000 or more, 13 of which were available on Canadian Newsstand Complete (Table A.1).

Table A.1. List of potential Canadian newspaper sources.

Province	Newspaper	City/County	Circulation (estimate)	Database availability
Alberta	Calgary Herald	Calgary	708,371	Yes
	Calgary Sun	Calgary	431,881	No
	Edmonton Journal	Edmonton	583,328	Yes
	Edmonton Sun	Edmonton	303,324	No
	Fort McMurray Today	Fort McMurray	10,570	No
	The Daily Herald Tribune	Grande Prairie	21,843	No
	Lethbridge Herald	Lethbridge	117,279	No
	Medicine Hat News	Medicine Hat	64,731	No
	Red Deer Advocate	Red Deer	72,492	No
British Columbia	Daily Townsman	Cranbrook	23,495	Yes
	Dawson Creek Daily News	Dawson Creek	11,000	Yes
	Alaska Highway News	Fort St. John	10,715	Yes
	Kamloops Daily News	Kamloops	85,000	Yes
	The Daily Courier	Kelowna	80,872	No
	The Daily Bulletin	Kimberley	5,660	Yes
	Nanaimo Daily News	Nanaimo	75,233	Yes

	Penticton Herald	Penticton	42,239	No
	Alberni Valley Times	Port Alberni	23,964	Yes
	Prince George Citizen	Prince George	72,828	Yes
	Trail Times	Trail	11,448	Yes
	The Province	Vancouver	840,185	Yes
	The Vancouver Sun	Vancouver	970,709	Yes
	Times Colonist	Victoria	314,760	Yes
	Peace Arch News Daily	White Rock	14,800	Yes

Note: All data based on authors' analysis of Canadian Newsstand Complete and the *Daily Newspaper Circulation Report* (Newspapers Canada, 2014).

United States

In the United States, newspapers published in Pennsylvania, New York, Ohio and West Virginia were used to identify stakeholder concerns related to the Marcellus shale formation, and newspapers published in Texas were used in the case of the Barnett shale formation. Initially, we used the same criteria to identify U.S. newspapers that we used to identify Canadian newspapers. However, since populations in both regions are substantially higher, a substantially larger pool of potential newspapers exists. In order to maintain manageable search parameters, we began our search with large, highly circulated major daily newspapers in each state. In Ohio, these included the *Dayton Daily News*, the *Columbus Dispatch*, the *Cincinnati Enquirer* and *The Plain Dealer* (Cleveland); of these, only the Dayton Daily News was available in both the LexisNexis and Factiva databases. We selected *The New York Times* and *Buffalo News* for New York, and both were accessible via LexisNexis and Factiva. For West Virginia, we selected *Charleston Gazette* and the *Herald-Dispatch*, yet only the *Charleston Gazette* was available on both LexisNexis and Factiva.

For Texas and Pennsylvania, to account for the denser rural populations and scale of direct resource extraction, we included smaller county newspapers published in counties with direct extraction activity as identified by U.S. Mineral Resources ("Areas of Operation," 2012). In Pennsylvania, we reduced the list of all potential newspapers to 13 publications with circulations greater than 5,000, of which 6 were available on the LexisNexis and Factiva databases. For Texas, we included a total of 8 newspapers based on location; however, 2 did not fulfill the circulation criterion: the *Weatherford Democrat* (Parker County) and the *Cleburne Times-Review* (Johnson County) (Table A.2). Due to the lack of available Texas newspapers on LexisNexis, we included these 2 publications despite their failure to meet this criterion. Including both the *Weatherford Democrat* and the *Cleburne Times-Review*, 4 Texas-based publications were available on both LexisNexis and Factiva.

Although the Factiva database enables access to more selected newspaper sources than LexisNexis, data output for the larger searches was not manageable.

Table A.2. List of potential newspaper sources in the United States.

State	Newspaper	City/County	Circulation (estimate)	Database availability
Pennsylvania	Philadelphia Inquirer	Philadelphia	363,883	both
	Pittsburgh Post-Gazette	Pittsburgh	245,065	both
	Pittsburgh Tribune Review	Pittsburgh	65,000	both
	Intelligencer Journal/ Lancaster New Era	Lancaster	78,819	both
	Altoona Mirror	Blair County	27,732	F
	Beaver County Times	Beaver County	31,038	F
	The Bradford Era	McKean County	9,071	neither
	Citizens' Voice of Wilkes-Barre	Luzerne County	44,051	both
	Herald-Standard of Uniontown	Fayette County	21,072	F
	McKeesport Daily News	Allegheny County	11,489	neither
	Sharon Herald	Mercer County	16,650	neither
	Standard of Hazleton	Luzerne County	20,008	F
	Johnstown Tribune-Democrat	Cambria County	32,623	LN
Ohio	Dayton Daily News	Dayton	93,425	both
	The Columbus Dispatch	Columbus	136,023	F
	Cincinnati Enquirer	Cincinnati	144,165	F
	The Plain Dealer	Cleveland	246,571	F
West Virginia	Charleston Gazette	Charleston	35,621	both
	The Herald-Dispatch	Huntington	27,505	F
New York	The New York Times	New York	1,586,757	both
	Buffalo News	Buffalo	147,085	both
Texas	Houston Chronicle	Houston	384,007	F

	San Antonio Express-News	San Antonio	139,099	F
	The Dallas Morning News	Dallas	405,349	F
	Denton Record-Chronicle	Denton	10,865	F
	Fort-Worth Star Telegram	Fort-Worth	195,455	both
	Austin American-Statesman	Austin	125,305	both
	Weatherford Democrat*	Parker County	3,839	both
	Cleburne Times-Review*	Johnson County	3,842	both

Note: All data from authors' analysis of Factiva, LexisNexis and Mondo Times online newspaper databases, unless otherwise cited (Mondo Times, 2014). We also included the *Weatherford Democrat* and *Cleburne Times-Review* (< 5,000 circulation) based on database availability.

APPENDIX C: MEDIA COVERAGE OF ACCOUNTABILITY AND HYDRAULIC FRACTURING BY QUARTER AND JURISDICTION

Year, Quarter		State/Province						
		New York	Ohio	Penn-sylvania	West Virginia	Texas	Alberta	British Columbia
2008	Q1	0	0	0	0	0	0	0
	Q2	0	0	0	0	0	2	1
	Q3	1	0	0	0	0	0	0
	Q4	0	0	0	0	0	2	0
2009	Q1	0	0	0	0	0	1	0
	Q2	0	0	1	0	0	1	0
	Q3	0	0	1	0	0	3	0
	Q4	0	0	0	0	0	2	0
2010	Q1	0	0	3	0	0	2	0
	Q2	0	0	2	0	0	0	0
	Q3	0	0	4	0	0	9	5
	Q4	0	0	1	0	0	4	2
2011	Q1	0	0	1	0	0	1	0
	Q2	1	0	3	0	0	8	2
	Q3	0	0	1	2	0	10	3
	Q4	0	2	1	1	0	5	3
2012	Q1	5	0	0	2	1	7	5
	Q2	2	1	1	1	1	10	4
	Q3	0	1	0	0	0	5	6
	Q4	0	0	1	0	0	4	10
2013	Q1	0	0	1	1	0	8	23
	Q2	0	0	0	2	3	7	10
	Q3	2	0	2	2	0	6	8
	Q4	0	0	2	0	0	5	17

2014	Q1	1	0	0	0	1	1	14
	Q2	1	0	4	0	1	9	11

Note: Lighter shading indicates coverage in more than 5 articles; darker shading indicates coverage in more than 10 articles.

APPENDIX D: MEDIA COVERAGE OF HYDRAULIC FRACTURING CONCERNS BY QUARTER AND JURISDICTION

Year, Quarter		State/Province						
		New York	Ohio	Penn-sylvania	West Virginia	Texas	Alberta	British Columbia
2008	Q1	0	0	0	0	0	3	3
	Q2	0	0	0	0	0	2	4
	Q3	4	0	5	0	1	1	4
	Q4	6	0	16	0	1	4	4
2009	Q1	1	0	1	0	0	1	5
	Q2	0	0	12	2	2	9	3
	Q3	5	0	17	0	2	8	3
	Q4	27	0	55	1	0	21	4
2010	Q1	17	0	54	0	10	33	3
	Q2	22	0	146	5	0	13	4
	Q3	40	0	179	0	20	24	9
	Q4	57	0	169	1	12	26	14
2011	Q1	84	1	193	3	44	25	26
	Q2	76	5	259	13	28	39	28
	Q3	84	3	204	2	50	32	36
	Q4	111	8	179	5	40	68	40
2012	Q1	88	26	162	8	45	72	64
	Q2	93	3	102	7	28	57	38
	Q3	69	7	91	19	17	35	46
	Q4	62	5	130	6	23	37	70
2013	Q1	56	9	153	4	27	42	48
	Q2	47	3	108	6	20	32	90
	Q3	25	3	141	4	28	23	33

	Q4	113	4	142	0	29	39	51
2014	**Q1**	83	6	120	3	46	22	37
	Q2	108	5	184	5	23	24	48

Note: Lighter shading indicates coverage in more than 50 articles; darker shading indicates coverage in more than 150 articles.

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