APPENDIX H
Review of Water Resources in Western Newfoundland in a Hydraulic Fracturing Context

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Prepared for:
Newfoundland Hydraulic Fracturing Review Panel
c/o Office of Associate Vice-President (Research)
Bruneau Centre for Research and Innovation, IIC-3067
Memorial University of Newfoundland
St. John's, NL, A1C 5S7

Prepared by:
Graham A. Gagnon & Lindsay A. Anderson
Dalhousie University
1360 Barrington St. D514
Halifax, NS B3H 4R2
T: 902.494.6070 | F: 902.494.3105
water@dal.ca

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1.0 INTRODUCTION

The water demand for unconventional oil and gas operations (e.g. hydraulic fracturing) varies geographically, but the impacts can be substantial at a localized scale (e.g., up to to 50 million liters per well) (Nicot and Scanlon, 2012). In addition to the quantity of water used, there have been concerns raised regarding the impact of hydraulic fracturing on water quality, as incidents of groundwater contamination from methane with have been reported in exploration intensive areas of the United States (e.g. Pennsylvania, Colorado), although the origins of methane in these are still under investigation. Waste streams generated as a result of hydraulic fracturing include flowback and produced water. In Canada, there is an increasing need to characterize, treat, and manage these streams in an appropriate manner. All of these issues are important elements in this challenging and dynamic field, but they also strongly influence the governance requirements and the concerns of neighboring communities.

The mandate of the Newfoundland and Labrador Hydraulic Fracturing Review Panel (NLHFRP) is to conduct a public review and advise the Minister of Natural Resources on the socio-economic and environmental implications of the hydraulic fracturing process with respect to the possible exploration and development of the petroleum resources of Western Newfoundland.

As one of the Panel members, Dr. Gagnon has been tasked to examine and gather information on specific topic areas regarding hydraulic fracturing in oil and gas operations in Western Newfoundland and provide specific responses to specific questions outlined on the NLHFRP website (www.nlhfrp.ca).

The objective of this review was to provide additional insight on the implications of hydraulic fracturing in the context of water quality and quantity in Western Newfoundland.

The following is a brief outline of this report's scope of work:

1. **Literature review:** A review of peer-reviewed literature was conducted in a water quality, quantity, and wastewater management context in order to further the understanding of hydraulic fracturing. A review of regulatory-based literature in jurisdictions that have well-established hydraulic fracturing operations was also conducted.

2. **Regulatory Review:** A review of regulatory processes and industry best management processes in other jurisdictions that have well-established hydraulic fracturing operations was conducted.

3. **Review of water resources in the Port au Port area:** A review of publicly available water quality and quantity data for the Port au Port area was conducted in order to understand local water resources.

4. **Case study to consider potential risks to water resources:** Using the information gathered in the review of water resources in the Port au Port area, a case study using Port au Port region as a potential for hydraulic fracturing site was conducted with knowledge that a focused discussion on Port au Port would generate concepts that can be applied along the coast of Western Newfoundland.

2.0 TECHNICAL APPROACH

2.1 Literature Review

The first step in the review process was to gather existing literature on hydraulic fracturing from sources including:

- Peer reviewed journal articles
- Technical reports
- Other documents that are deemed to be relevant to the context of the Panel mandate

The review was conducted on topics including but not limited to:

- Water demand for hydraulic fracturing;
- Possible impacts to groundwater including contamination pathways from hydraulic fracturing (e.g. fugitive gas, migration of fracturing fluid);
- Possible impacts to surface water including drinking water sources;
- Management of wastewater (flowback and produced waters) generated from hydraulic fracturing processes (e.g. treatment, disposal, reuse) and;
- Regulatory frameworks and best management practices related to hydraulic fracturing water and wastewater from other jurisdictions

The goal of this review was to contribute to the identification of environmental risks to water resulting from hydraulic fracturing operations. We also provided information on regulatory processes and industry best management processes in other jurisdictions that have well-established hydraulic fracturing operations.

2.2 Regulatory Review

Additionally, the actions that are relevant to the oil and gas industry in Newfoundland and Labrador were reviewed in this section. This review provides an overview of the current regulatory process in Newfoundland and Labrador related to oil and gas operations and recommends any changes needed in order to mitigate risk to the environment in terms of protecting water resources.

2.3 Review of Water Resources in Port au Port

Available ground, surface, and other water data from Port au Port was reviewed to evaluate the following:

- Water quantity
- Water quality
- Water use (e.g. domestic, municipal, industrial, commercial)
- Alternative water sources (e.g. seawater)

Sources of data included:

- Provincial water quality reports
- Data from well water reports
- Hydrogeology reports
- Online portal (Department of Environment and Conservation – Water Resources and Management Division)

The review of water data from Port au Port was used to define the water situation in Port au Port and to discuss the viability of various water sources in a hydraulic fracturing water-use context.

2.4 Conceptualization of Potential Water and Wastewater Management Options in Port au Port

The information obtained from Task 2 was used to conceptualize and discuss the possible scenarios for managing various aspects of water and wastewater related to the hydraulic fracturing process in the context of Port au Port.

Specifically, the objective of this task was to provide further insight on:

- The volumes of water required for hydraulic fracturing in Port au Port in comparison to the availability of water resources (e.g. surface and ground water)
- Possible alternative water sources (e.g. seawater)
- Possible risks to ground and surface water in Port au Port (e.g. water shortages, risk of contamination, treatment discharges)
- Options for management of wastewater generated during hydraulic fracturing operations that are feasible/ applicable for Port au Port (e.g. treatment and disposal or reuse options)

3.0 LITERATURE REVIEW

3.1 Review of Hydraulic Fracturing in a North American Context

In recent years, unconventional shale gas exploration (e.g. high volume hydraulic fracturing) has been gaining more attention in part due to the significant volumes of water used. The following section highlights water use/demand for hydraulic fracturing in areas across the United States and Canada.

3.1.1 Water Use/Demand for Hydraulic Fracturing

3.1.1.1 United States

In the United States, Shale gas exploration is dominant in Texas in the Eagle Ford, Bakken, and Haynesville Shales in addition to the Marcellus Shale of Pennsylvania and New York. The following section reviewed peer reviewed journal publications related to water demand or use for unconventional hydraulic fracturing operations.

Gregory et al. (2011) provided an overview of the water management challenges associated with the production of shale gas via hydraulic fracturing in the United States, noting that between 400 and 4000 m^3 of water are used for drilling fluids to maintain downhole pressure, in addition to the 7000 to 18000 m^3 of water required for the hydraulic fracturing of each well. According to Vengosh et al. (2014), water use varies from 8,000 m^3 to 100,000 m^3 per unconventional well, while Gallegos et al. (2015) reports median annual water volumes for 2014 of 15,275 to 19,425 m^3 per well to hydraulically fracture horizontal oil and gas wells in the United States.

Jackson et al. (2014) considered the range of depths and the water use for recent hydraulic fracturing operations across the United States. Results indicated that water use for hydraulic fracturing varied widely across the states but the states with the highest water use rates per well from 2010 to 2013 were Arkansas (~19,600 m^3), Louisiana (~19,300 m^3), West Virginia (~18,900 m^3), Pennsylvania (~17,000 m^3), and Ohio (~16,200 m^3). Interestingly, 5% of the data set were hydraulically fractured wells with depths shallower than ~1.5 km using more than 3,800 m^3 of water, and were located primarily in Arkansas, Oklahoma, Pennsylvania, Kansas and Texas.

Nicot and Scanlon (2012) reviewed water use for shale gas production in Texas Haynesville Shale, Barnett Shale, and the Eagle Ford Shale and showed that net water use for shale gas based on 2008 data was 16,100 to 23,000 m^3 10,600 to 15,000 m^3 and 21,500 m^3 for Eagle Ford, Barnett, and Texas Haynesville Shales respectively. Nicot and Scanlon (2012) also projected that the total net water use for shale gas in the Eagleford, Barnett, and Texas Haynesville shales would increase by an additional 1870, 1050, and 525 Mm^3 by 2060, respectively.

Scanlon et al. (2014) compared water use for hydraulic fracturing for unconventional to water use for conventional oil within the Eagle Ford and Bakken shales in Texas, which accounted for two-thirds of U.S. unconventional oil production in 2013. It was found that water use for hydraulic fracturing in the Eagle Ford shale (2009-2013) was relatively constant at between 17,900 and 18,500 m^3 per well. Water use per well for hydraulic fracturing in the Bakken shale (2005-2013) was nearly half that of the Eagle Ford at 7580 m^3 and the differences were mostly attributed to geological differences.

According to Horner et al. (2014), who evaluated overall water use and management in the Bakken Shale Oil Play of North Dakota, water consumption per well has increased from ~6,345 m^3 to 9,000 m^3 per well between 2008 and 2012.

In the Marcellus shale, reported water use for hydraulic fracturing ranges from 15,120 m^3 to 21,200 m^3 per well (Clark et al., 2013). Similarly, Jiang et al. (2014) estimated the life cycle water consumption and wastewater generation impacts for Marcellus shale gas wells under the current conditions in Pennsylvania (e.g. accounting for various combinations of reuse treatment and deep-well injection disposal of flowback and produced water). Jiang et al. (2014) observed that under the current conditions, Marcellus shale gas wells consume approximately 20,000 m^3 of fresh water per well over a life cycle, in which 65% is directly consumed at the well site and the remaining 35% is consumed indirectly across the supply chain.

It is commonly reported that unconventional oil and gas wells are drilled "many hundreds of meters" below the surface, however there remains controversy over lack of a definition for this depth. In general water requirements for hydraulic fracturing increase with depth. Jackson et al. (2015) evaluated the range of depths and water use of recent hydraulic fracturing operations in the United States by analyzing over 40,000 observations reported to the FracFocus database from 2008 to 2013. Unsurprisingly, approximately 84% of the wells analyzed in the database were a mile or more in depth, however an unexpected number of wells were drilled within one mile or less to the surface. Jackson et al. (2015) found that 12 states had 50 or more wells within one mile of the surface. Texas, Arkansas, California, and Oklahoma had 2872, 1224, 804, and 502 occurrences of fracturing within one mile of the surface, respectively. California and Arkansas had 88 and 85% of their hydraulically fractured wells within one mile of the surface. Interestingly, approximately 5% of the data set contained water wells that were less than one mile from the surface and used more than 1x106 gallons of water and were located in Arkansas, Oklahoma, Pennsylvania, Kansas, and Texas. Finally, 1% of the data set (primarily located in Arkansas) contained wells that were shallower than 3,000 feet but used more than 1x106 gallons of water (Jackson et al. 2015).

3.1.1.2 Canada

Shale gas production in Canada is dominant in British Columbia in the Montney Play Trend and in the Horn River Basin (Rivard et al. 2014). Reported water use for each play vary. For example, between 1,900 to 7,800 m^3 (Johnson and Jonson, 2012) and 10,000 to 25,000 m^3 (Precht and Dempster, 2012) have been reported for the Montney Play Trend. For the Horn River Basin, water usage has been reported to be 35,000 m^3 (Johnson and Jonson, 2012) as well as 25,000 to 75,000 m^3 (Precht and Dempster, 2012).

The differences in water use between major plays in British Columbia was evaluated by Johnson and Jonson (2012). Using data from approximately 500 wells, Johnson and Johnson (2012) showed that there is an order of magnitude of difference for water use between the Montney Play Trend and the Horn River Basin in British Columbia. Water use in the Montney Trend (where energized CO_2 treatments are generally used) was approximately 1900 m^3 per well and the Horn River Basin uses 30,000 m^3 per well due to the use of high-volume slickwater treatments.

According to Chapman and Veneables (2012), water demands for hydraulic fracturing in the Montney Trend in British Columbia require between 5,000 and 30,000 m^3 per well. The source of water in the Montney formation are estimated at 65% surface water, 10% shallow groundwater, 10% deep groundwater, and 15% flowback fluid (Chapman and Veneables, 2012).

In Alberta, water use for slickwater hydraulic fracturing has been estimated to be 50,000 m^3 per well (Precht and Dempster, 2012). Reported water use for hydraulic fracturing on the east coast of Canada varies, in part due to limited data availability. In the Utica Shale of Quebec, for each fracturing stage, between 1,500 to 2,000 m^3 which translates to between 12,000 and 20,000 m^3 per well (for 8 to 10 fracture stages) (BAPE, 2011). In New Brunswick, the volumes of water required for hydraulic fracturing of two horizontal wells were approximately 20,000 m^3, and in Nova Scotia reports of between 5,900 and 6,800 m^3 for the two wells that have been hydraulically fractured so far (Rivard et al., 2013).

Table 1. summarizes water use estimates (per well) for hydraulic fracturing in the United States and Canada.

Table 1. Summary of water use for hydraulic fracturing.

LOCATION	WATER USE (M^3/WELL)	DATA SOURCE
Eagle Ford (TX)	16,100-23,000[1] 17800-18550[2]	1 – Nicot and Scanlon (2012) 2 – Scanlon et al. (2014)
Barnett (TX)	10,600-15,000	Nicot and Scanlon (2012)
Haynesville (TX)	21,500	Nicot and Scanlon (2012)
Bakken (TX)	7,570[1] 6,345-9,000[2]	Scanlon et al. (2014) 1 – Horner et al. (2014)
Marcellus (PA, NY)	15,151-21,198[1] 20,000[2]	2 – Clark et al. 2013 1 – Jiang et al. (2014)
Montney Play Trend (BC)	1,900-7,800[1] 10,000-25,000[2]	1 – Johnson and Jonson, 2012 2 – Precht and Dempster, 2012
Horn River Basin (BC)	35,000[1] 25,000-75,000[2]	1 – Johnson and Jonson (2012) 2 – Precht and Dempster (2012)
Duvenay (AB)	~50,000	Precht and Dempster (2012)
Utica (QC)	12,000 to 20,000	BAPE (2011)
Frederick Brook (NB)	20,000	Rivard et al. (2014)
Horton Bluff (NS)	5,900 to 6,800	Rivard et al. (2015)

3.1.1.3 Discussion

According to the USEPA (2015a), cumulative water use for hydraulic fracturing from 2011-2012 in the United States represented only 1% of total annual water use. In 2013 metro Vancouver used over 350 x 10^6 m^3 of water, compared to 5.3 x 106 m^3 for hydraulic fracturing during the same period. For comparison, in northeastern British Columbia, the natural gas industry uses less than 1% of annual water runoff (Government of British Columbia, 2014). Consider the water use for agricultural purposes in California, which is approximately 41 x 109 m^3 per year (California Department of Water Resources, 2015). Municipalities in California consume just under 12 x 109 m^3 per year on average (California Legislative Analysis Office, 2008). When compared to approximately 250,000 m^3 water used for hydraulic fracturing in California in 2012, the water use for hydraulic fracturing does not appear to be as significant.

Similarly, when compared to other fossil fuel types, shale gas uses less water per unit of energy, however, it does consume large quantities of water in a short time period. Table 2 below portrays a comparison of water use for the various types of fossil fuels including natural gas.

Table 2. Water use for various fossil fuels (CCA, 2014).

FUEL TYPE	WATER USE (GALLONS/MILLION BTU)
Unconventional Shale Gas	0.6-1.8
Oil (Primary Production)	1.4
Oil (Secondary and Enhanced Recovery)	62-65
Oil Sands	13-33

Several researchers (Rahm and Riha, 2012; Freyman, 2014; Vengosh et al., 2014) have all stressed the importance of evaluating the cumulative impacts of hydraulic fracturing on water resources at a regional or local scale as opposed to at the national or statewide level. Freyman (2014) emphasized that evaluating local-level water use impacts is "the best sale for understanding water sourcing risks". For example, for some counties in Texas, the water demand for hydraulic fracturing is projected to reach the same level as residential water consumption (Freyman, 2014). Communities with small water supplies or those that rely groundwater resources are particularly vulnerable to the impacts of the water demand exerted by the shale gas industry, as they often do not have the financial resources to build infrastructure to import water (Freyman, 2014).

Mauter et al. (2014) highlight that water usage for hydraulic fracturing may not pose a significant impact on total local water consumption in some regions, however, in others it may exert water demands that could induce competition, price increases, and accelerated water depletion. Like other researchers, Mauter et al. (2014) demonstrated that in the Eagle Ford shale of Texas, overall water use for hydraulic fracturing is only a fraction of the total annual water consumption in the region, however, in smaller counties it can account for a significant fraction of local water budgets. This information highlights the importance of scale when evaluating the impacts of hydraulic fracturing on water resources. An in depth review of water resources should be conducted in areas considering unconventional oil and gas activity in order to understand the potential effect of hydraulic fracturing operations on local water resources.

3.1.2 Impacts on Water Quality

Much of the concern raised by the public and in scientific literature has been surrounding the issue of the impact of hydraulic fracturing on water quality. In particular, drinking water contamination from stray gas migration, fracturing fluids and formation water all have been considered potential pathways for water contamination. The following sections will review literature on the potential for unconventional shale gas exploration to impact ground and surface water quality.

3.1.2.1 Groundwater

Stray Gas

Stray gas contamination occurs when natural gas leaks up from: intermediate layers through poorly constructed and/or faulty well casings, through the well annulus, or through abandoned wells within the shale formation (Vengosh et al. 2014).

The presence of stray gas (e.g. methane) in drinking water wells in areas where shale gas development occurs remains one of the greatest concerns associated with hydraulic fracturing (Vengosh et al. 2014). This is in part due to the large number of both public and private wells in the vicinity of hydraulic fracturing operations that rely on groundwater for potable and agricultural use. According to the USEPA (2015), between 2000 and 2013, over 9 million people lived within one mile of a hydraulically fractured well. During the same period, nearly 7,000 public drinking water sources were located within one mile of at least one hydraulically fractured well. Much of the attention on stray gas contamination of drinking water wells has been focused in Pennsylvania (Marcellus Shale) as over 30% of residents in counties where shale gas operations occur rely on shallow groundwater wells for drinking water.

It is critical to understand the original of methane for identifying groundwater contamination pathways. Several researchers have attempted to connect elevated methane concentrations in shallow groundwater wells to shale gas extraction. For example, a study by Osborn et al. (2011) documented systematic evidence for methane contamination of drinking water sources accompanying gas well drilling and hydraulic fracturing in the Marcellus and Utica Shale formations of northeastern Pennsylvania and upstate New York. Groundwater samples from 60 private water wells were analyzed for dissolved gas concentrations including methane. Methane concentrations were present in 85% of wells across the region regardless of shale gas operations, however, concentrations were considerably higher (17 times, 19.2 mg/L) in areas where active drilling (defined as 1 or more gas well within 1 km) compared to non-active areas. The average methane value in active drilling areas was consistent with a thermogenic methane source, while the methane concentrations in the non-active drilling areas were consistent with biogenic or mixed sources.

Similarly, Jackson et al. (2013) analyzed 141 drinking water wells in northeastern Pennsylvania to understand the relationship between the proximity to shale gas wells with natural gas concentrations and isotopic signatures. Well water in homes less than 1 km from natural gas wells contained methane concentrations that were approximately 6 times higher than for homes > 1 km away. Overall, dissolved methane was present in 82% of the wells sampled, and in 12 of the wells methane concentrations were greater than 28 mg/L (the threshold for immediate remediation set by the US Department of the Interior).

Darrah et al. (2014) used noble gases to identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales in order to answer whether elevated levels of hydrocarbon gases in drinking water aquifers near gas wells are natural or anthropogenic, and to understand the mechanisms of contamination. The noble gas and hydrocarbon content of 113 domestic groundwater wells from the Marcellus Shale, and 20 groundwater wells overlying the Barnett Shale were measured, allowing Darrah et al. (2014) to identify eight clusters of fugitive gas contamination that showed increased contamination over time. In the eight clusters of contamination, the proportions of thermogenic hydrocarbon gas were significantly higher relative to background groundwater concentrations – four of which were linked to gas leakage through the failure of annulus cement and three were linked to faulty casings through the use of noble gas isotopes and hydrocarbon data.

Finally, Rabinowitz et al. (2015) evaluated the relationship between the proximity to natural gas wells and reported health status via household survey of 492 persons in 180 households with ground fed wells in an area of active natural gas drilling in Pennsylvania. Gas well proximity for each home was compared to frequency of respiratory, dermal, gastrointestinal, cardiovascular, and neurological symptoms. A model was adjusted for age, sex, household education, smoking, awareness of environmental risk, work type, animals in house. The number of skin conditions were higher among residents living <1 km away from the nearest gas well compared to those that were >2 km away. Respiratory problems were also reported more frequently in households <1 km away from gas wells.

On the contrary, other research (Boyer et al., 2011) suggests that methane in groundwater is less related to shale gas development. Boyer et al. (2011) conducted a large-scale study of water quality in 233 private drinking water wells near active Marcellus gas wells in Pennsylvania. Both pre and post drilling samples were collected from 48 private water wells located within 2,500 feet (downhill gradient) of a Marcellus well pad, while the remaining 185 were collected within 5,000 feet of a completed Marcellus gas well site. Dissolved methane results were not similar to previous results by Osborn et al. (2011), as there were no statistically significant increases in methane concentration after drilling and there were no correlations to distance to drilling activity. Boyer et al. (2011) did, however, recommend the need for more intensive studies focused on the occurrences and sources of methane in water wells surrounding hydraulic fracturing operations.

Molofsky et al. (2013) also evaluated methane sources in groundwater in northeastern Pennsylvania. Throughout Susquehanna County, 1,701 water wells were tested for methane and results showed that on a regional scale, methane concentrations were correlated to hydrogeographic features and topographic position as opposed to shale gas extraction, indicating that methane concentrations are independent of hydraulic fracturing activity in Susquehanna County (Molofsky et al., 2013).

Brantley et al. (2014) argues that in northern Pennsylvania, geological effects are likely facilitating the fast migration of groundwater and methane. Furthermore, Brantley et al. (2014) note that methane present in Pennsylvania groundwater are present naturally and have been reported long before Marcellus gas drilling.

Baldassare et al. (2014) evaluated more than 2,300 gas and water samples for molecular composition and stable isotope composition of methane and ethane in northeastern Pennsylvania and found that microbial and thermogenic gases occur in some shallow aquifer systems above the Marcellus Formation. Baldassare et al. (2014) observed that the gases were present before Marcellus Formation drilling activity and that thermogenic gases were predominantly present in the upper portion of the Marcellus Formation that encompasses the potable aquifer system, which were distinct from the gases in the middle portion.

Siegel et al. (2015) also performed a follow-up study to Osborn et al. (2011) and Jackson et al. (2013) to examine the relationship between dissolved methane and proximity to oil and gas wells. Methane concentrations in over 11,000 water well samples from northeastern Pennsylvania were evaluated, two orders of magnitude larger than previous studies. Contrary to findings from Osborn et al. (2011) and Jackson et al. (2013), Siegel et al. (2015) found that there was no significant relationship between dissolved methane concentrations in domestic water samples and proximity to oil and gas wells.

Interestingly, a recent review of scientific literature on hydraulic fracturing and the impact on water resources by the United States Environmental Protection Agency (USEPA) entitled "Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources" mentions several instances where mechanisms such as casing and cementing design or failure have lead to contamination of drinking water wells (e.g. Bainbridge, Ohio; Mamm Creek, Colorado), however, the USEPA did not find any widespread, systemic impacts on drinking water resources in the United States as a result of hydraulic fracturing (USEPA, 2015a).

Li et al. (2016) evaluated the ionic composition of deep aquifers containing methane in order to decide if contaminants were transported concurrently into the aquifer with the gas phase or were naturally occurring in the aquifer. Three types of water were studied – uncontaminated deep confined aquifer, deep confined aquifer containing thermogenic methane, and produced water from nearby horizontal oil and gas wells in order to determine whether deep confined aquifers containing methane were influenced by the nearby oil and gas wells in the Wattenberg Field of the Denver Julesburg Basin in Colorado. Li et al. (2016) demonstrated that deep aquifer water containing thermogenic methane did not share similarities with produced water with respect to the Cl/TDS ratio, however it shared similarities with uncontaminated groundwater. According to the methodologies used in this work the deep aquifer water containing thermogenic methane in the Wattenberg Field have not been in contact with aqueous phase contaminants from oil and gas operations.

Migration of Hydraulic Fracturing Fluid

In addition to the potential impacts of methane or fugitive gas on groundwater resources, there has been concern regarding the chemicals used in hydraulic fracturing fluids. Using publicly available chemical information databases, Stringfellow et al. (2014) identified and categorized 81 common chemicals used in hydraulic fracturing based on toxicity as well as physical and chemical data. Findings from Stringfellow et al. (2014) suggested that there are deficiencies in the current state of knowledge, as toxicity information was not available for 30 of the chemicals.

Researchers have suggested that natural and anthropogenic underground fractures could serve as pathways for hydraulic fracturing fluids resulting in the possible contamination of groundwater.

Vengosh et al. (2014) discusses an incident in Garfield County, Colorado where an increase in chloride concentrations in drinking water wells was linked to elevated thermogenic methane associated with oil and gas wells. It is possible that this rise in salinity and thermogenic methane could be caused by fluid migration from oil and gas wells (Vengosh et al., 2014).

Llewellyn et al. (2015) evaluated a groundwater supply contamination incident attributed to shale gas development after a commercial laboratory reported no compounds other than methane concentrations below regulatory action levels (e.g. 10 mg/L). Using 2D gas chromatography coupled with time of flight mass spectrometry, Llewellyn et al. (2015) identified a complex mixture of organic compounds in aquifer water samples that were also present in flowback water from Marcellus Shale gas wells. The compound 2-n-Butoxyethanol which is present in flowback water, was identified in a foaming drinking water well. The incident was attributed to the migration of drilling fluid compounds were transported along shallow and intermediate depth fractures to an aquifer that served as a potable water source.

Other researchers have suggested that natural migration of formation brine to shallow aquifers is a possibility. For example, Warner et al. (2014) demonstrated using geochemical evidence, that there are possible natural migration pathways unrelated to hydraulic fracturing, of Marcellus Formation brine to shallow aquifers in Pennsylvania. Using 426 shallow groundwater samples, Warner et al. (2014) suggest that mixing relationships between shallow groundwater ad deep formation brine causes groundwater salinization in some areas. Groundwater samples containing >20 mg/L Cl from several aquifers that did not correlate with shale gas wells suggests the migration of brine through natural pathways, which could in the future serve as pathways for fracturing fluids.

Conversely, Engelder et al. (2014) evaluated whether residual treatment water (e.g. the hydraulic fracturing fluids that remain underground) could flow out of the gas shale and contaminate overlying groundwater aquifers. It was demonstrated that the concern raised by other researchers over leakage of brines and residual treatment water into upper groundwater was ill-founded due to several reasons. For example, Engelder et al. (2014) suggested that the residual treatment water that remains underground after hydraulic fracturing is drawn into the gas shale where it is retained retained, and that production further reduces gas and brine pressures in the shale below local hydrostatic levels, reducing the risk of leakage.

Although there are contradictory research findings regarding the upward migration of hydraulic fracturing fluids and produced waters into shallow aquifers, a lack of baseline data hinders the ability to gauge the likelihood and extent of this potential contamination pathway.

3.1.2.2 Surface and Drinking Water Quality

The main surface water contamination pathways associated with hydraulic fracturing are leaks and spills of flowback and produced waters, direct discharge of untreated water from shale gas operations, and through the insufficient treatment and discharge of hydraulic fracturing wastewater to surface water (Vengosh et al., 2014). According to Vengosh et al. (2014), the occurrence of spills and leaks coincides with the density of shale gas drilling indicating the rapid growth and intensity of unconventional shale gas exploration could lead to a higher probability of spills or leaks causing potential contamination of water resources. According to the USEPA (2015), estimated for spill frequencies at hydraulic fracturing sites in Colorado and Pennsylvania ranged from 0.4 to 12.2 spills for every 100 wells, and average spill volumes for 11 states were characterized at 3,750 L for produced water.

Entrekin et al. (2011) describes the threats to surface waters associated with the rapid expansion of natural gas development and several realistic threats including sediment runoff into streams, reductions in stream flow, accidental spills resulting in contamination of surface waters, and poor treatment performance.

A 2007 study conducted by the U.S. Geological Survey and U.S. Fish and Wildlife Service showed that the unauthorized discharge of untreated hydraulic fracturing wastewater to a surface water in Kentucky was likely the cause of widespread death and/or distress of aquatic species. (USGS, 2013).

Rozell and Reaven (2011) evaluated water pollution risk associated with natural gas extraction from the Marcellus Shale using probability analysis and found that the highest uncertainty was for wastewater disposal and discharge. The uncertainty of fracture fluid migration was small compared to the risk associated with wastewater disposal and therefore it was suggested that research efforts be focused on wastewater treatment and disposal and specifically on contaminant removal efficacy by industrial and municipal treatment facilities.

Current treatment and handling facilities for hydraulic fracturing wastewater include publicly owned treatment works (POTW), municipal wastewater treatment plants (WWTP), and commercially operated industrial wastewater treatment plants (Vengosh et al., 2014). In several cases across Pennsylvania, hydraulic fracturing wastewater effluent from treatment facilities had Marcellus-like geochemical footprints and were characterized by high levels of chloride, TDS, and bromide, suggesting that these treatment facilities are not designed to handle such wastewaters (Vengosh et al., 2014).

Olmstead et al. (2013) considered the impact of shale gas development on surface water quality in Pennsylvania by estimating the effect of shale gas wells and treated discharge by permitted treatment facilities on downstream concentrations of chloride and TSS. Elevated chloride concentrations were observed downstream from treatment facilities and an increase in TSS was observed in watersheds near unconventional shale gas extraction activities, which were attributed to hydraulic fracturing wastewater spills.

Warner et al. (2013) considered the impacts of shale gas wastewater disposal on water quality in Western Pennsylvania by measuring major constituents (e.g. Cl, Br, SO_4, Ca, Na, Mg, Ba, Sr) and isotopic compositions of discharged effluents, surface waters, and stream sediments associated with a treatment facility in western Pennsylvania. Chloride concentrations were between 2 and 10 times higher than background levels downstream of the treatment facility, and even a dilution factor of 500 to 3000 times was not enough to reduce bromide concentrations in treated effluent to background levels. These elevated bromide concentrations have the potential to negatively impact downstream drinking water treatment facilities (e.g. brominated THM formation). Furthermore, geochemical signature of Marcellus wastewater remained apparent in treated effluents, downstream water, and in sediments.

According to Brantley et al. (2014), between 2008 and 2012 approximately 1000 complains were made to Pennsylvania state regulators regarding the impacts to water supplies in regions of oil and gas development. However, only 17% of the complains were actually linked to oil and gas development, and according to data from the Pennsylvania Department of Environmental Protection (PADEP), between 2005 and 2013 only 3.4% of unconventional gas wells received notices of violation for well integrity, less than 1% were cited for groundwater contamination (Brantley et al., 2014).

Abualfaraj et al. (2014) characterized Marcellus shale flowback water and found that the following constituents were found to have mean concentrations over 10 times greater than the MCL for drinking water: 1,2-dichloroethane, antimony, barium, benzene, benzo (a)pyrene, chloride, dibromochloromethane, gross alpha, iron, manganese, pentachlorophenol, radium, thallium, and vinyl chloride. Concentrations of anthropogenic chemicals were tightly correlated with each other, but not with chloride concentrations, and not with naturally occurring inorganics and radionuclides. However, Abualfaraj et al. (204) also noted that comparing the results geographically by county did not yield any readily interpretable results due to variability in concentration.

Parker et al. (2014) estimated the minimum contribution of diluted hydraulic fracturing wastewater that would result in significant alternations in surface water quality in terms of disinfection by product formation upon disinfection (e.g. chlorination, chloramination, ozonation). Results demonstrated that volumes as low as 0.01 to 0.1% of hydraulic fracturing wastewater could contribute to the formation of both regulated disinfection by products (e.g. iodo-trihalomethanes, NDMA, bromate).

3.1.2.3 Discussion

Many researchers (Osborn et al., 2011; Vidic et al., 2013) have stressed the importance of establishing baseline water quality in order to gauge the likelihood and extent of contamination from hydraulic fracturing activity. Such baseline water quality data is necessary for comparison with future water quality in order to recognize possible changes resulting from unconventional natural gas production.

The USEPA's 2015 assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources highlighted key data limitations associated with hydraulic fracturing and water resources, noting that "data that could be used to characterize the presence, migration, or transformation of chemicals in the subsurface before, during, and after hydraulic fracturing were found to be scarce relative to the number of hydraulically fractured oil and gas production wells" (USEPA, 2015a). The USEPA assessment also observed that local water quality is not consistently collected or made readily available and therefore reduced the ability to determine whether hydraulic fracturing affects drinking water sources in suspected contamination cases (USEPA, 2015a).

In northeastern Pennsylvania, several homeowners participated in a study to have their well water tested to establish baseline quality as a result of legal recommendation prior to drilling. However, recommendations on how to document pre-drill water quality conditions were not provided to homeowners, nor are there specific parameters outlined by a regulatory body, leaving the homeowner or gas company to decide what, when, and how often to measure (Rhodes and Horton, 2015). The high cost of a multi-parameter test, and short time frame between homeowner notification and drilling may prevent homeowners from having repeated measurements. Rhodes and Horton (2015) evaluated the robustness of one single certified multi-parameter water test for establishing baseline water quality given possible variations in hydrogeological conditions in northeastern Pennsylvania. Rhodes and Horton (2015) determined that overall the single certified water test was representative of the baseline water chemistry as compared to repeated measurements taken over a 2.5 year period, and that groundwater characteristics vary more spatially than temporally due to road salt runoff and variations in bedrock aquifer minerals. To distinguish between road salt and formation brine, Cl/Br ratios were used, highlighting the importance of including Br as a baseline water quality parameter (Rhodes and Horton, 2015).

3.1.3 Management of Hydraulic Fracturing Wastewater

3.1.3.1 Characteristics

Wastewater from the hydraulic fracturing process typically consists of flowback, produced and water used during the drilling process (Rahm et al., 2013; Jackson et al., 2014), however the characteristics of hydraulic fracturing are highly variable depending on geographical location and additives used.

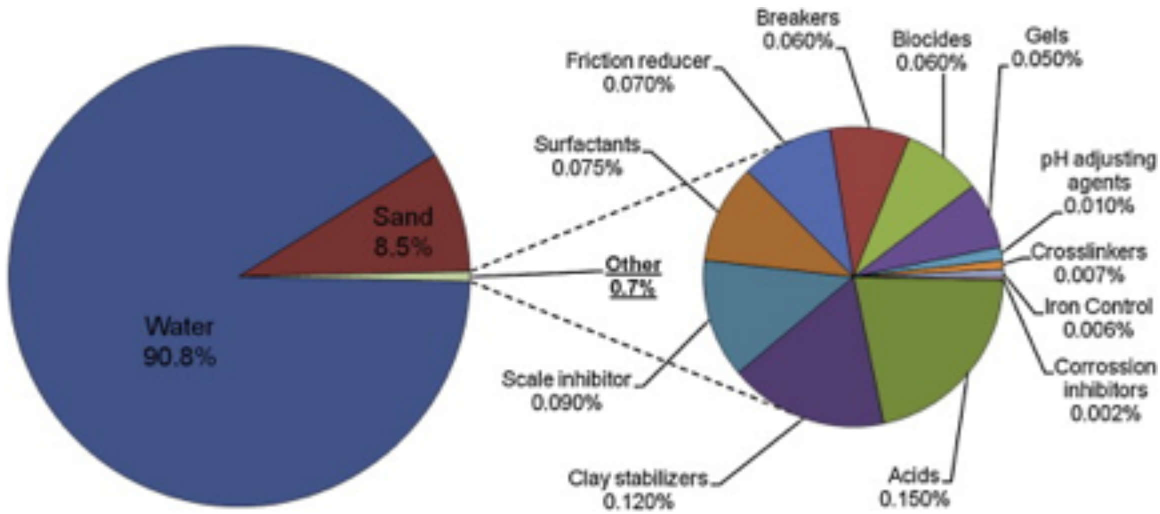

Figure 1. Chemical constituents of hydraulic fracturing water (from Ferrer and Thurman, 2015).

Hydraulic fracturing fluid for shale gas largely consists of water and sand (e.g. proppant), while the remainder consists of chemical modifiers. The proportions of each depend on the individual site characteristics, however, common chemicals used in hydraulic fracturing fluids include acid, friction reducers, surfactants, salt, scale inhibitors, pH adjusting agents, iron control and corrosion inhibitor, and biocides (Gregory et al., 2011). Figure 1 below portrays the chemical constituents of hydraulic fracturing water.

Produced water is defined as "all water that returns to the surface through the wellbore" (Chesapeake Energy, 2011). The volume of produced water has been reported to be between 1 and 8 m^3/day (Gregory et al., 2011; Rahm et al., 2013). Produced water flows over the lifetime of the well.

Flowback water is often refered to as the early water production from a well following hydraulic fracturing (Engle and Rowan, 2014). It flows from the wellbore for days to several weeks after the initial hydraulic fracturing stage. The flow rate of flowback water is highest on the first day (e.g. up to 1000 m^3/day) and decreases with time (Gregory et al., 2011). Flowback water typically consists of fracturing fluids and formation water. It's characteristics depend on local geology and company, however, it is commonly characterized as containing high concentrations of salt, TSS and TDS, elements including iron and manganese, strontium, barium, as well as oil and grease and naturally occurring radioactive material (NORM) (Gregory et al., 2011).

The waters from oil and gas shale in the Marcellus and Bakken regions were evaluated in terms of microbial composition and aqueous chemistry by Strong et al. (2013). Water samples were characterized as having near neutral pH, high salinity (0.5 to 3.5 mol/L), and an organic load from 1 to 4.5 g/L. Thiel and Lienhard (2014) found that produced water can contain salt concentrations up to 9 times that of seawater.

Lester et al. (2015) characterized hydraulic fracturing flowback water in Colorado in terms of general bulk water quality parameters as well as organic and inorganic matter. The flowback water contained high TDS (~22,000 mg/L), metals (iron at >80 mg/L) and dissolved organic carbon (nearly 600 mg/L). Chloride concentrations were >13,000 mg/L.

3.1.3.2 Disposal

Deep well injection of hydraulic fracturing wastewater into a deep saline aquifer of has been the primary method of disposal in the United States, with more than 95% being disposal into class II injection wells (Jackson et al., 2014). Deep well disposal is also a common practice for the oil and gas industry in British Columbia and Alberta (Rivard et al., 2014). In eastern Canada, the deep-well injection of flowback water has not been tested, largely due to a lack of understanding of potential deep-seated geological storage capacity or due to permeability issues causing concerns over leaks (Rivard et al., 2014).

In regions where deep well injection is not possible, hydraulic fracturing wastewater is typically treated and reused or discharged to surface water.

3.1.3.3 Treatment

Until recent years, the most common method of treatment for flowback water was disposal via deep well injection, however, this technology has become less viable due limited access to disposal wells, increased pressure for a more sustainable solution (Lester et al., 2015), as well as concern over seismic activity. Therefore, the treatment of hydraulic fracturing wastewater is becoming increasingly popular especially in areas of water scarcity. The composition of hydraulic fracturing wastewater (e.g. salinity and chemical characteristics), in addition to the receiving environment, direct the suitability of treatment options.

Treatment facilities for flowback water have been established in Pennsylvania as deep-well injection is not viable and trucking to neighboring states (e.g. Ohio) for disposal is costly (Mauter and Palmer, 2014), and in Texas where treatment for reuse is common due to limited water availability.

Until recently, permits for discharging hydraulic fracturing wastewater to publicly owned treatment works (POTWs) for treatment have been issued, although these facilities are not designed to handle the volumes and chemical constituents associated with the waste stream. In 2010, the USEPA urged Pennsylvania to strengthen their regulations regarding the acceptance of hydraulic fracturing wastewater by POTWs. In November 2011, the PADEP established monthly average limits for TDS, chloride, and barium of 500, 250 and 10 mg/L respectively, for discharging hydraulic fracturing wastewaters to POTWs (PADEP, 2011).

Due to the variability in quality and quantity from site to site, there is no one size fits all treatment solution for hydraulic fracturing wastewater (Bluefield Research, 2014). Therefore, the oil and gas industry currently relies on traditional treatment technologies to meet individual operator and drill-site needs. Reverse osmosis, filtration, and evaporation are common treatment technologies used in industry (Bluefield Research, 2014). Lester et al. (2015) identified the removal of suspended solids and iron by aeration, precipitation and filtration followed by disinfection was the most appropriate treatment process for flowback recycling for future hydraulic fracturing operations. Unconventional treatment technologies for the treatment of hydraulic wastewater have also been explored. For example, forward osmosis, deionization, and ion exchange (Gregory et al., 2011), as well as biological (sequencing batch reactors) and advanced oxidation treatment (UV/H2O2, O3/H2O2, photo-Fenton) have all proven to be effective treatment technologies (Lester et al., 2015).

3.1.3.4 Reuse

Hydraulic fracturing wastewater is often treated or diluted then reused during further hydraulic fracturing operations or is treated reused outside of the oil and gas industry (e.g. for crop irrigation) (Gregory et al., 2011; Lester et al., 2015).

According to Rahm et al. (2013), Marcellus wastewater management has trended towards reuse as well as a reliance on industrial on-site wastewater treatment facilities which was likely a result of more stringent legislation pertaining to prohibiting the discharge of high TDS hydraulic fracturing wastewater to POTWs in Pennsylvania (Rahm et al., 2013).

Mauter and Palmer (2014) conducted a survey to assess the current practices and future trends in oil and gas wastewater management. Findings indicated that over 80% of participating operators reported that flowback and produced waters were “often or usually” reused for subsequent hydraulic fracturing jobs. Flowback water was reused more frequently as it has a higher flow rate over a short period of time, compared to produced water which is generated at smaller volumes over a longer time span. Water quality was identified by operators as one of the barriers to reuse and therefore freshwater blending rates were between 20 to 80% (Mauter and Palmer, 2014).

3.2 Summary

The peer reviewed literature points to concern associated with water quality in regions near hydraulic fracturing. While the evidence in the literature presents mixed outcomes, in terms of causal evidence; a consistent theme is to quantify ground water quality. Not surprisingly, industry best practices also recommend groundwater quality assessment before, during, and following hydraulic fracturing activity in areas that are affected by unconventional oil and gas. The literature review also pointed to concerns associated with water use. Indeed in areas where fresh water use is stressed, industry best management practices state that alternative sources of water such as brackish, saline, produced, and third party wastewater should be considered.

3.3 Best Management Practices for Hydraulic Fracturing Operations related to Safeguarding Water Quantity and Quality

This section reviews industry best management practices in both the United States and in Canada in addition to any regulatory frameworks in states or provinces that have well-established hydraulic fracturing operations while demonstrating that water resources are a priority.

3.3.1 Water Use

The increasing water demand for hydraulic fracturing has proven to be challenging for the management of water resources as local and regional water plans become dated as unconventional oil and gas activity rapidly expands (Freyman, 2014). The American Petroleum Institute (API) and the Canadian Association of Petroleum Producers (CAPP) have both released guidelines, or best practices documents related to hydraulic fracturing and water management.

With respect to best management or leading regulatory practices for water use, the state of Pennsylvania is dominant as it has implemented strong disclosure of fresh and recycled water use during hydraulic fracturing operations (Freyman, 2014). Operators must submit a report to the PADEP within 30 days of completion, which includes a stimulation record, as well as a list of water resources used and the respective volumes. The report must also include the volumes of recycled water used during drilling. These reports are reviewed by the PADEP to ensure that water withdrawals do not impact water quality and quantity to other users and to the watershed as a whole (Freyman, 2014). The Susquehanna River Basin Commission (SRBC) regulates and collects data on all surface and groundwater withdrawals as well as collects consumptive water use data for Pennsylvania in order to perform full water lifecycle studies for hydraulic fracturing. The SRBC is also transparent to the public by providing an interactive map demonstrating location and amount of water withdrawal permits.

The American Petroleum Institute (API) guidance document HF2 “water management associated with hydraulic fracturing” suggests that operators conduct a detailed review of the identified water sources available in the area that could be used to support hydraulic fracturing operations (API, 2010). This review should include an evaluation of cumulative water demands considers water requirements for drilling, dust suspension, emergency response, in addition to water required for hydraulic fracturing operations (API, 2010). Water sources need to be appropriate for the forecasted pace and the anticipated level of development. If possible, operators should first consider wastewater from other industrial operations, then resort to non-potable ground and surface water sources. The last resort should be municipal water supplies (API, 2010).

More recently (August 2015), the API released recommended practice 100-2 entitled “Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing”. This new document further outlines recommended practices and considerations for operators sourcing and securing water for hydraulic fracturing purposes.

The API recommended practices document outlines general considerations for source water requirements, for example (API, 2015):

- The potential effect of additional fresh water demand on the local community and region should be considered. Operators should coordinate their operational plans with anticipated water use and available supplies.
  - Important considerations in evaluating surface and ground water sources include – seasonal variability of supply and demand, water rights and permit requirements from regulatory agencies, surface water withdrawal permits, landowner contractual agreements, water withdrawal limitations due to impacts on other users during low flow periods, potential short term and cumulative environmental and community impacts, potential hydrological impacts, and transport and storage requirements.

- Alternative sources of water such as brackish, saline, produced, and third party wastewater should be considered, for example:
  - Municipal and industrial wastewater are other possible water sources to support hydraulic fracturing operations, and in some cases required water quantity can be achieved by combining different water sources
  - Produced water from oil and gas wells may be treated and reused for hydraulic fracturing depending on the water chemistry and logistics of the hydraulic fracturing operations.

- Local water use for agriculture, manufacturing, municipal supply, recreation, and other uses, in addition to seasonal variations in water availability, should be accounted for when evaluating water-sourcing needs for hydraulic fracturing.

- Operators should consult with local agencies (water development board, water use/management districts, city public works departments, etc.) to identify potential competing uses for water.

The API recommended practices also highlight considerations for prioritizing water sources, including (API, 2015):

- Operators should consider securing at least one alternative water source in the event that a primary water source is interrupted or terminated
- If possible, water from other industrial facilities and produced water should be considered first, followed by non-potable, then potable surface and groundwater sources, with municipal being the least sustainable option.

Similarly, in 2012, the CAPP released a best practice document for member companies to reduce impacts and risks from natural gas operations relying on hydraulic fracturing. Member companies are asked to meet or exceed these requirements (CAPP, 2012).

CAPP member companies are strongly encouraged to meet or exceed operational requirements and performance measures outlined in the "Water sourcing, measurement, and reuse operating practice". This includes complying with any withdrawal limits and reporting requirements of water licenses or permits, as well as reporting water use data to the CAPP through the Responsible Canadian Energy Program. (CAPP,2012). Members must also make their process for water sourcing, measurement, and reuse publicly available. CAPP members must also demonstrate the safeguarding of surface and groundwater quantity by monitoring both surface and groundwater, including saline sources, for the appropriate parameters (e.g. pressure, volume, water levels, precipitation data). Members are also required to collect data related to water use for all water sourced, injected and disposed of, and for any flowback or produced water generated.

CAPP member companies must also demonstrate sharing and collaboration of best practices pertaining to water sourcing, measurement, reuse and reporting of data with other operators.

These CAPP and API recommended practices, in combination with other state/provincial best practices (e.g. Pennsylvania) can serve as a baseline, or minimum requirement for regulatory frameworks associated with water sourcing and availability associated with unconventional oil and gas production in Newfoundland.

3.3.2 Water Quality

Several researchers have identified data limitations pertaining to baseline water quality as a major setback to gauging and understanding the risks of hydraulic fracturing on the environment and in particular on water quality (USEPA, 2011; Cooley et al, 2012; Vengosh et al., 2013; Vidic et al., 2013; USEPA, 2015a).

In Ohio, baseline testing of water wells that lie within 300 feet of potential oil and gas well is required by the state for oil and gas companies to perform prior to drilling operations (Precht and Dempster, 2012). Parameters include barium, calcium, iron, magnesium, potassium, chloride, sodium, as well as pH, conductivity, sulfate, alkalinity, and TDS (ALS Global, 2014).

Through the Oil and Gas Conservation Commission (OGCC), the state of Colorado requires the collection of baseline surface water samples directly downhill of the well location in addition to a follow-up surface water sample at the same location 3 months after drilling operations are completed (COGCC, 2014). Furthermore, operators must sample up to four water wells within one half mile of a new gas well before drilling operations and two more samples of each well between 6 and 12 months after drilling and again after 5 to 6 years (COGCC, 2014).

The API guidance document for water management associated with hydraulic fracturing notes that operators should "work with state, local, and regional regulators to ensure that surface and groundwater quality is adequately described" in order to provide a better understanding of regional and local water quality before drilling and hydraulic fracturing are initiated (API, 2010). Furthermore, the guidance document states that:

> *"Site specific baseline water samples should be collected from public and private wells near operations as well as from nearby surface water bodies prior to drilling specific wells if existing information is not adequate. The actual parameters to be tested will depend somewhat on site-specific geology and hydrology. Testing parameters should include, but are not limited to TDS, total suspended solids (TSS), chlorides, carbonates, bicarbonates, sulfate, barium, strontium, arsenic, surfactants, methane, hydrogen sulfide, NORM, and benzene" (API, 2010).*

More recently, in 2015, the API released recommended practices (100-2) for managing environmental aspects associated with exploration and production operations including hydraulic fracturing, which provides technical guidance for baseline groundwater sampling (API, 2015).

The new API recommended practices highlight that "a baseline sampling program can vary from a modest program focused on isolated exploration wells, to a comprehensive, field-wide program suited for a multi-well, multi-location development" (API, 2015).

The API recommends that the operators consider sampling both ground and surface water sources, and that the number of water wells to be sampled be based on the location of oil and gas wells to be drilled and on the local hydrogeological environment (API, 2015). Sampling should be completed prior to and as close to initial operations as practical, and operators should consider taking follow-up samples to assess the nature and extent of potential changes in water quality (API, 2015).

Specifically, the following factors should be considered in the development of a baseline groundwater sampling program (API, 2015):

- Location of water wells relative to the groundwater flow gradient;
- Depth of water wells to be sampled;
- Distance from the proposed well or facility;
- Water well construction;
- Well density within the area of interest;
- Inventory of water users;
- Site-specific hydrogeology;

According to the API, the following laboratory and field parameters should be considered for sampling programs, although some of the parameters may not be (API, 2015).

- Benzene, toluene, ethylbenzene, xylenes (BTEX); total petroleum hydrocarbons (TPH); sodium absorption ratio (SAR); total dissolved solids (TDS); potassium; chloride; bromide; arsenic; barium; calcium; magnesium; sodium; alkalinity; lead; boron; iron; manganese; sulfate; methanol; light hydrocarbons (methane, ethane, propane); and total coliforms.

- pH, conductivity, turbidity, oxidation-reduction potential, and temperature.

Although the API has produced a series of best practices/guidance documents, these are not regulatory documents and therefore operators can use them on a voluntary basis. However, some states including Colorado and Wyoming now require drillers to conduct pre-drilling baseline and post-completion ground water testing to ensure that no contamination has occurred. This is also a requirement in Pennsylvania if a driller desires to exonerate itself from accusations of water contamination (ALS, 2013; Rodriguez and Soeder, 2015).

In the absence of a minimum federal standard for protecting water resources, although state governments may have the ability to design pollution regulations that balance localized regulations and costs, they often fail to account for negative externalities in form of water pollutants that affect persons in other states. Centner and Petetin (2015) have proposed that government employ a permitting program that uses pollutant reduction plans with best management practices to control pollutant releases to acceptable levels. The regulation of water contamination from concentrated animal feeding operations (CAFOs) in the United States under the permitting provisions of the Clean Water Act, have demonstrated how governments could provide increased protection against potential health risks that are linked with shale gas operations. Centner and Petetin (2015) outline a permitting program where individual permits would include fluids emissions reduction plans that contain best management practices to minimize risk and release of contaminants.

In April 2015, the USEPA proposed technology-based pre-treatment standards under the clean Water Act for discharges of pollutants from existing and new unconventional oil and gas operations into publicly owned treatment works (POTWs). As hydraulic fracturing wastewater characteristics are not typical of POTW influents, some contaminants in these waste streams may not be effectively removed by the POTW, can disrupt the operations of a POTW, and can cause disinfection by-products (USEPA, 2015b). The proposed regulations would protect environmental health and the integrity of POTWs by defining pre-treatment standards that would prevent the direct discharge of wastewater discharges from unconventional oil and gas operations directly into POTWs (USEPA, 2015b).

In order to safeguard the quality of groundwater resources, the CAPP has developed hydraulic fracturing operating practices for baseline groundwater testing. Member companies must meet or exceed requirements for domestic well water testing and regional groundwater monitoring (CAPP, 2012). Specifically, CAPP member companies must design and carry out baseline groundwater testing programs under the direction of a qualified groundwater professional. For domestic well water testing, companies must test domestic water wells within 250 meters of the wellhead prior to drilling. Baseline water quality testing for domestic wells and regional groundwater monitoring should include analyses to compare with relevant water quality standards, and at a minimum must include:

- Organic and inorganic constituents identified in the GCDWQ;
- The presence or absence of natural gas in water, including isotopic fingerprinting if applicable (CAPP, 2012).

3.3.3 Wellbore Integrity

As previously described, a common issue associated with wellbore integrity is a faulty seal in the annular space surrounding casings that is used to prevent the transfer of gas from a well into groundwater aquifers.

Some regulators have expressed concern over the potential risk of groundwater contamination associated with the development of oil and gas wells. Some states have revised their cementing, casing, and other well construction requirements to address the high pressures and water volumes associated with hydraulic fracturing operations. There is also API industry best practices that have been developed for well construction and integrity related to hydraulic fracturing.

In the United States, most states regulate the minimum depth to which well casing must extend and be cemented. Some states override these standards or regulations by saying that well casing has to be set and cemented in a manner to protect all fresh water. According to the API best practices, member companies must meet or exceed requirements for the design, installation and quality assurance of wellbores used in hydraulic fracturing operations (API, 2010).

In British Columbia, under the Oil and Gas Commission (BCOGC), a well permit is required for hydraulic fracturing operations at depths of 600 m or less, deemed shallow wells, and applicants must conduct a risk assessment which includes a fracture program design, estimate of maximum fracture propagation, identification, depth, and cement integrity of all water wells within 200 m of hydraulic fracturing operations including pre- and post-hydraulic fracturing sampling of well water and notification to well owner; depth of bedrock, and assessment of the suitability of the well for hydraulic fracturing which includes casing and cement integrity (Precht and Dempster, 2012). Well spacing is also regulated by the OGC and depends on whether the well is an oil or gas well. Wells within 100 m of the natural boundary of a water body or more than 100 m away but in a location such that an uncontrolled flow could reach the water body, surface control features are required to capture any escaping fluids (CCA, 2014b).

The CAPP has developed operating practices for wellbore construction and quality assurance that outline requirements for companies to design, install, and maintain wellbores in order to protect local groundwater resources. In addition to conformation with jurisdictional regulations, the operational requirements highlight that casing must be installed and cemented to surface and the integrity of the wellbore should be confirmed by an appropriately designed pressure test. Companies are expected to make their wellbore construction and quality assurance processes publicly available (CAPP, 2012).

3.3.4 Chemical Use and Disclosure

The API also has recommended practices for managing the environmental aspects associated with exploration and production operations, and provide a list of additives that are used in hydraulic fracturing including polymer gelling agents, friction reducers, crosslinkers, breakers, bactericides, surfactants, and clay stabilizers (API, 2015). The API, however, highlights that the selection of additives is influenced by local geology, source water chemistry, as well as economics and fracture design goals.

The CAPP has developed operating practices for fracturing fluid additive risk assessment and management in order to support the development of fracturing fluid additives with the least environmental risks (CAPP, 2012). According to the CAPP, “The purpose of this practice is to describe the minimum requirements for the risk-based assessment of fracturing fluid additive used in the development of shale gas, tight gas, and tight oil resources”. Under this operating practice, the potential environmental and health risks of each of the additives are assessed by the member or operating company or by a qualified third party (CAPP, 2012). Furthermore, the operational controls and procedures for the additives should be determined in order to manage any potential environmental and health risks identified through the risk assessment. Risk management plans should also be incorporated into the hydraulic fracturing program (CAPP, 2012).

Another CAPP operating practice is related to fracturing fluid additive disclosure and its purpose is to describe the minimum requirements for the disclosure of fracturing fluid additives used in the development of shale gas resources (CAPP, 2012). Under this practice, CAPP member companies must ensure that either on their website or on a third-party website, there is a brief description of the intended use or function of each additive used in the fracturing fluid, and that there is a link to well-by-well disclosure of additives. Member companies must also disclose the type and volume of fluids used, the trade name of the additives and its general purpose, the name of each chemical ingredient from Material Safety Data Sheets, and the concentration of each chemical ingredient within the additive with respect to the total mass of the additive and to the total mass of the fracturing fluid base (CAPP, 2012).

In the United States, there is also a national hydraulic fracturing chemical registry called "FracFocus", which is managed by the Ground Water Protection Council and the Intersate Oil and Gas Compact Commission (Fracfocus, 2015). The purpose of FracFocus is to provide the public with access to the reported chemicals used in their area for hydraulic fracturing. As of April, 2015, 23 states disclose or plan to disclose their additives to the FracFocus database, including Montana, North Dakota, South Dakota, Colorado, Utah, Oklahoma, Texas, Louisiana, Mississippi, Ohio, Pennsylvania, Alaska, West Virginia, Kansas, Alabama, Nebraska, Tennessee, Nevada, North Carolina, Idaho, Michigan, Kentucky, and California (Fracfocus, 2015). The disclosure of chemical information to Fracfocus is mandatory in some states. Some provinces (e.g. British Columbia, Alberta) also disclose to Fracfocus.

3.3.5 Wastewater Treatment and Management

Pennsylvania has some of the most comprehensive regulations pertaining to hydraulic fracturing in the United States. As previously described, the PADEP established more stringent regulations for the direct discharge of hydraulic fracturing wastewater into POTWS. Specifically, new limits of 500, 250, and 10 mg/L for TDS, chloride, and barium, respectively were established (PADEP, 2011). This has resulted in increased discharge to industrial treatment facilities that are designed to treat hydraulic fracturing wastewater, in addition to increased reuse rates in the Marcellus region (Rodriguez and Soeder, 2015).

In Texas, after recent amendments to regulations regarding recycled wastewater streams from hydraulic fracturing by the Texas Railroad Commission, operators are no longer required to obtain permits to recycle water. Furthermore, operators can accept water from other areas or companies as long as it is recycled on the land leased by the operator (Osborne, 2013).

The API guidance document for water management associated with hydraulic fracturing outlines best practices for injection wells, municipal and industrial wastewater treatment facilities, and for recycling and reuse of flowback/produced waters. Injection wells for the disposal of brine associated with oil and gas operations require state or federal permits and are classified under the EPA's UIC program to protect underground sources of drinking water (API, 2010). Publicly owed treatment works (POTWs) must have state approved pre-treatment programs for accepting industrial waste and must be able to certify that their facility is capable of treating contaminants that are in the industrial waste stream without upsetting the process or contaminating the receiving water.

The API released recommended practices (100-2) outline considerations for the management of solid and liquid wastes from exploration, development, and production operations (API, 2015). The API suggest that "operators should develop a waste management plan that starts at the point of material selection and go through the final management after its use, including the management of treatment residuals" (API, 2015).

According to the API (2015) a waste management plan should include, but should not be limited to: source reduction; reuse; storage and containment; incident response and reporting; waste characterization; transportation and custody tracking, and disposal. The scope of a waste management plan can range from a single well location to multiple locations (e.g. states or provinces) (API, 2015).

Additionally, waste management should be based on the following order 1) source reduction, 2) reuse, and 3) disposal in order to reduce the volume of waste at the source and the amount being disposed of (API, 2015). Source reduction can be achieved by using alterative fluids (e.g. nitrogen, carbon dioxide) where they can meet operational needs (API, 2015). For wastewater reuse, operators should consider several factors including but not limited to any regulatory requirements associated with possible reuse options, physical and chemical properties of the reuse material, any necessary pre-treatment prior to reuse, safe storage and transportation, as well as the local/regional impacts of reuse compared to the existing waste management practices (API, 2015). If disposal (e.g. treatment and discharge, deep well injection) is deemed to be the best option for waste management, disposal must be performed in accordance with the appropriate state/provincial or federal regulations (API, 2015).

In Canada, the CAPP's guidelines for Canadian shale gas producers require that member companies practice the safe disposal of fluids that are no longer needed at approved waste management facilities including disposal wells (CAPP, 2012). CAPP member companies must meet or exceed the following requirements related to the handing, storing, and disposing of fracturing fluids, produced and flowback water, and fracturing fluid waste:

- Spent fracturing fluids, produced and flowback water, and fracturing fluid waste will be safely disposed of at approved waste management facilities including disposal wells (CAPP, 2012).
- Disposal design and construction will follow the applicable regulations in the operating jurisdiction (CAPP, 2012).
- Companies must make their processes for fluid transport, handling, storage and disposal publicly available (CAPP, 2012).

3.4 Summary

In recent years, public and regulatory concerns (mainly influenced by development in the Marcellus Shale) have led to increased pressure on operators to adopt environmentally conservative waste management strategies to reduce the impact of hydraulic fracturing on water resources (Rahm et al., 2013). As the potential for shale gas development is contemplated in eastern Canada (i.e., New Brunswick, Nova Scotia) and shale oil development is contemplated in Newfoundland, decision-makers will need to consider the management challenges associated with the volumes of waste generated from resource exploration, and how these wastes potentially impact local water resources including drinking water.

The current approach to managing the water-related risks associated with hydraulic fracturing has been reactive rather than proactive or preventative. Risk-based management tools such as water safety plans (WSP) have been successfully used in a drinking water context (e.g. World Health Organization Guidelines for Drinking Water; Alberta Environment). The WSP approach is a well-recognized method for managing water-related risks, and is a regulatory requirement in several countries (Summerill et al., 2010).

The parallel can be made that the framework for a WSP can be effectively applied to hydraulic fracturing, and used by decision-makers in the development of governance approaches to watersheds. The use of risk management frameworks to protect neighboring water systems from the risks associated with hydraulic fracturing has been previously recommended in the Report of the Nova Scotia Independent Panel on Hydraulic Fracturing (2014). A water safety approach would ensure that chemicals used for hydraulic fracturing processes are known, and that water monitoring and waste-management programs are designed, and that the public is engaged and consulted to provide transparency (Gagnon, 2014). The relevance of water safety frameworks and hydraulic fracturing has also been outlined by Gagnon et al. (2015). Decision-makers in Newfoundland should consider the use of a risk water safety approach for governing water resources in a hydraulic fracturing context. Key principles pertaining to water quality, quantity, and waste management outlined in the API and CAPP best practices could be used as a basis for the development of this approach.

4.0 A REVIEW OF REGULATORY FRAMEWORKS IN NEWFOUNDLAND

While the province does not have specific legislation, regulations, or guidelines focused exclusively on hydraulic fracturing, there are some existing regulatory regimes that address some of the concerns related to hydraulic fracturing including water use, well integrity, and waste disposal. In some jurisdictions, there is a lack of a requirement for public disclosure of fluids used in the hydraulic fracturing process and this would be critical for any future development.

Should the province aim to advance the idea of hydraulic fracturing, it would be critical to build on its existing regulatory regime in the oil and gas sector and evaluate new requirements to ensure operators follow safe industry best practices.

The following Newfoundland legislations have components that address some of the concerns associated with water quality and/or quality, and hydraulic fracturing operations.

- Petroleum and Natural Gas Act
  - Drilling Regulations
  - Petroleum Regulations
- Environmental Protection Act
- Environmental Assessment Regulations
- Water Resources Act
  - Environmental Control Water and Sewage Regulations

The following sections summarize the relevant points within each of the legislation listed above.

4.1 Water Quantity

The Water Resources Act (WRA) was designed to "ensure the fair allocation, proper use and continuing availability of clean water for the environmental, social, and economic well-being of the province of Newfoundland and Labrador (NL House of Assembly, 2002). The WRA provides legal authority to the Minister of Environment (MOE) for permits affecting water, licenses for the allocation of water rights, and enforcement, monitoring, reporting (NL House of Assembly, 2002). Table 3 below highlights the sections of the WRA that are relevant to water use associated with unconventional oil and gas exploration (e.g. hydraulic fracturing) in Newfoundland.

Table 3. Sections of the Water Resources Act relevant to water use associated with hydraulic fracturing (from NL House of Assembly, 2002).

SECTION OF WRA	MAIN PROVISIONS RELATED TO HYDRAULIC FRACTURING
12	Rights to the exclusive use of water (NL House of Assembly, 2002).
14	A person may apply to use, divert or impound water (NL House of Assembly, 2002). The Minister may issue a license with terms and conditions for the diversion of water for municipal, agricultural, institutional, commercial, or industrial use (NL House of Assembly, 2002).
15	Priority of uses if there is more than one application for the same body of water – domestic, municipal, agricultural/industrial, power generation, and other uses as prescribed by regulation (NL House of Assembly, 2002). The Minister can refuse to grant a license, or require additional information, require a modification or alteration, or grant a license subject to modifications or alterations (NL House of Assembly, 2002).
22	The Minister may reduce the licensed quantity of water to the lesser of the amount used or the capacity of works (NL House of Assembly, 2002).
31	The Minister may require a licensee to install and operate stream flow stations and monitor water quality, and to collect data and keep records on flow and quality (NL House of Assembly, 2002).
39	The Minister is authorized to regulate resource development and other activities in a designated public water supply area that may impair the quality of water (NL House of Assembly, 2002).
61	The Minister is authorized to establish a protection one around a groundwater well used for non-domestic purposes in order to protect that well from pollution (NL House of Assembly, 2002).
62	The Minister may order studies and monitoring of groundwater availability, withdrawal rates, flow, water quality, etc. (NL House of Assembly, 2002).

4.2 Water Quality

The Province of Newfoundland legislation does not currently include an explicit requirement for baseline testing of water wells or regional water bodies in areas where oil and gas activity occurs.

The following table outlines current Newfoundland legislation that relates to safeguarding water quality in an oil and gas context. Both direct (e.g. water quality monitoring) and indirect impacts (e.g. well construction and integrity) to water quality are considered.

Table 4. Sections of NL regulations or acts relevant to water quality associated with hydraulic fracturing (from NL House of Assembly).

SECTION OF ACT OR REGULATION	MAIN PROVISIONS
	Water Resources Act
41	Authorizes the Minister to require and direct the owner, operator, or other person responsible for an undertaking to carry tests on water emitted from, surrounding or connected with that undertaking (NL House of Assembly, 2002).
62	The Minister is authorized to order studies, monitoring, and investigations for the purpose of collecting data on… quality of household water supplies, groundwater quality, and other matters that the minister considers necessary in the interest of the conservation, development, control, improvement and proper utilization of groundwater resources (NL House of Assembly, 2002).
	Petroleum and Natural Gas Act
10	A person involved in petroleum exploration, development, or production activities is strictly liable for any loss which may occur as a result of pollution caused and the costs of the clean up and rehabilitation incurred by the province or by another person (NL House of Assembly, 2011).
	Drilling Regulations
31	Where a proposed well is to be located within 100 m of the normal high water mark of a body of water or permanent stream, the operator shall submit evidence that they obtained prior written approval of their plan to prevent pollution of the water from those regulatory bodies that have jurisdiction in respect of the drill site (NL House of Assembly, 2006a)
	Petroleum Regulations
33	Requires an application for a development to include an environmental impact statement under the Environmental Assessment Act, a description of the proposed mitigative measures designed to reduce the impact of the proposed development on the environment (NL House of Assembly, 2006b)
35	The Minister must approve of a development plan that takes into account whether sufficient environmental, social, and economic impact studies have been undertaken by the proponent to provide the basis for the establishment of guidelines for production (NL House of Assembly, 2006b)

	WELL CONSTRUCTION AND INTEGRITY
	Drilling Regulations
11	An operator shall ensure that contingency plans have been formulated and that equipment is available to cope with a foreseeable emergency situation during a drilling program, including the loss of well control (NL House of Assembly, 2006a).
17	An operator shall ensure that the drilling of a well is conducted in a manner that maintains full control of the well at all times (NL House of Assembly, 2006a).
29	An operator shall submit in triplicate to the director an application for an authority to drill a well not less than 21 days before the date he or she plans to spud-in (NL House of Assembly, 2006a). The application required shall be in a form satisfactory to the director and shall include the casing program and the volume of cement estimated to be used (NL House of Assembly, 2006a).
41(2)	An alternative casing design criteria may be applied to casing to be used if the operator submits details of the design criteria that shows that the design criteria submitted, if followed, provides casing, the safety of which is equivalent or superior to the safety of the casing designed in accordance with previous sections (NL House of Assembly, 2006a).
43(2)	The director may where abnormal pressure conditions are known to exist or are anticipated, require the operator to install casing in addition to the casing required by those subsections; and where the operator provides data to show that an equivalent degree of safety to that required by subsection (1) is provided with different casing setting depths, approve casing setting depths other than those required by those subsections (NL House of Assembly, 2006a). An operator may, with the approval of the director, install additional casing in a well, including production casing and liners, below the intermediate casing referred to in paragraph (NL House of Assembly, 2006a). An operator shall not set a casing in a well unless he or she has received approval from the director for the depth at which the casing may be set (NL House of Assembly, 2006a).
47-49	The volume of cement slurry used for the cementation of a casing shall be at least 30% greater than the estimated annular volume to be filled unless that estimate is based on a reliable caliper log in which case the volume shall be at least 10% greater than the estimated annular volume (NL House of Assembly, 2006a). Surface casing unless otherwise approved by the director shall be cemented to surface or to a depth that is not less than 25 metres above the base of a previous casing string. Where possible, a casing liner shall be cemented for its full length Intermediate casing shall be cemented with sufficient cement to rise to a minimum of 300 metres above the casing shoe NL House of Assembly, 2006a).

4.3 Wastewater Management

Newfoundland's Drilling Regulations and Environmental Control Water and Sewage Regulations outline provisions that relate to the management of wastewater, although none are specific to hydraulic fracturing. The following table highlights sections of acts or regulations in Newfoundland related to the management (e.g. treatment, disposal) of wastewater generated during the hydraulic fracturing process.

Table 5. Sections of NL regulations or Acts relevant to wastewater management associated with hydraulic fracturing.

SECTION OF ACT OR REGULATION	MAIN PROVISIONS
	Environmental Control Water and Sewage Regulations
3	A person discharging sewage and other materials into a body of water, public sewer or sewer leading to a public sewer shall comply with the standards, conditions and provisions prescribed in these regulations for the constituents, contents or description of the sewage or other discharged materials (NL House of Assembly, 2003).
4	A person shall not discharge sewage or other effluent into a public sewer or a sewer leading to a public sewer containing materials which would obstruct or impede the flow of sewage within the public sewer or impair or interfere with the public sewer or sewage works of that public sewer. (2) The materials referred to in subsection (1) include oil or by-products of oil, flammable, explosive, toxic, poisonous or corrosive liquids, solids or gases, fats, congealing materials and other substances in quantity which interfere with the free flow within the public sewer (NL House of Assembly, 2003)
5	A person shall not discharge into a public sewer or sewer leading to a public sewer, sewage or effluent containing a constituent specified in Column 1 of Schedule B having a content in milligrams per litre, parts per million, in excess of the maximum specified in Column 2 of that Schedule; having a temperature that is > 65° C or having a pH that is less than 5.5 or greater than 9 (NL House of Assembly, 2003)
6	A person shall not discharge into a body of water any sewage or effluent having a temperature that is greater than 32 ° C, a pH less than 5.5 or greater than 9, or that is a radioactive substance having a gross beta activity of more than 37 Bq/L prior to discharge, with the exception of radium 226 and strontium 90 which shall not exceed 0.37 Bq/L (NL House of Assembly, 2003).
10	A person primarily in the Petroleum Refining Industry shall not discharge sewage or effluent, which does not comply with standards prescribed in Schedule E. A person primarily in the Petroleum Refinery Industry shall comply with sections 4, 7, 8 and 9 and Schedules 1 and 2 of the Petroleum Refinery Liquid Effluent Regulations (NL House of Assembly, 2003).

	Drilling Regulations
82	An operator shall ensure that all waste material, drilling fluid, drill cuttings, formation water and other rig discharges at a drill site are handled and disposed of in a manner that does not create a hazard to safety, health or to the environment; does not create potential for interference with renewable resource activities; and that is approved by the director (NL House of Assembly, 2006a).
83	An operator shall ensure that oil or gas produced during formation flow tests is stored in suitable tanks or flared in a manner approved by the director; where an oil spill occurs, oil spill counter measures of a chemical nature are not used unless, in the opinion of the director, there is a severe threat to the safety of persons, property or the natural environment; waste fuel, oil or lubricant is collected in a closed system that is designed for the purpose; and that stored waste oil or oily material, not burned at the drill site, is transported in a suitable container for disposal at an approved disposal site (NL House of Assembly, 2006a).

4.4 Summary

Although there exist some regulatory frameworks in Newfoundland and Labrador for the oil and gas industry, there is a need to develop regulations for not only unconventional oil and gas operations (e.g. hydraulic fracturing) directly, but for the water quality and quantity aspects associated with hydraulic fracturing.

Regulations for baseline water quality monitoring programs and the use of freshwater for hydraulic fracturing will be necessary in order to safeguard the water resources in Newfoundland and Labrador. Furthermore, chemical disclosure rules and the use of Fracfocus should be considered.

Wastewater management regulations are also required to support the onshore oil and gas industry. Although general wastewater regulations exist in Newfoundland, consideration should be given to develop specific regulations that are more explicit to unconventional oil and gas.

The USEPA (2015) has published proposed pretreatment standards for oil and gas extraction that govern the discharge of hydraulic fracturing wastewater to publicly owned treatment works (POTWs). These standards should be considered when developing regulations for the management of hydraulic fracturing wastewater in Newfoundland.

5.0 ASSESSMENT OF WATER RESOURCES IN PORT AU PORT

As a part of this task, we evaluated local water resources including both ground and surface water quantity and quality. We also examined water use and availability in the Port au Port area.

The Port au Port peninsula is situated on the west coast of Newfoundland and is bound by St. George's Bay on the west, the Gulf of St. Lawrence on the North, and by Port ay Port Bay on the East. The communities included in this study are referred to as the "Port au Port Area" or the "Port au Port region" and include:

- Boswarlos;
- Campbell's Creek;
- Port au Port West-Aguathuna-Felix Cove;
- Abraham's Cove;
- Piccadilly;
- West Bay;
- Lourdes;
- Mainland;
- Three Rock Cove;
- Black Duck Brook;
- Winterhouse;
- Ship Cove-Lower Cove-Jerry's Nose;
- Sheaves Cove;
- Cape St. George;
- Marches Point;
- Red Brook; and

Only the communities with available water quality and quantity data were discussed in the following sections. The communities Point au Mal, Fox Island River, and Port au Port East are also considered as part of the Port au Port region. Figure 2 shows the geographical locations of the communities in the study area.

Figure 2. Communities included in the study area of Port au Port Bay (note some community names are not displayed) (Google Maps, 2015).

5.1 Water resources on the Port au Port Peninsula

5.1.1 Groundwater

In Western Newfoundland, water resources serve as drinking water supplies in addition to supporting other resources and activities. Although dependent on local geological characteristics, large volumes of water are usually required to support long-term hydraulic fracturing operations.

The impact on water extraction is greatest at a local level, therefore it is important to ensure that water used for hydraulic fracturing comes from a sustainable source, and that water usage rates are monitored and compared in a water management plan as a whole.

Hydrological data and published reports were evaluated to understand the water resources in western Newfoundland in order to gain a further understanding of the water availability in the Port au Port Area.

Due to hydrological conditions and consequent low well yields, a portion of Newfoundland relies solely on groundwater. Specifically, ~30% of the population of Newfoundland rely on groundwater, of this 75% are private dug and drilled wells where most of which are located in small, rural communities (DOEC, 2010). Several rural communities in western Newfoundland rely on groundwater for domestic purposes and almost all communities in the Port au Port area are dependent on groundwater. Figure 3 below depicts the distribution of groundwater wells in the Port au Port area.

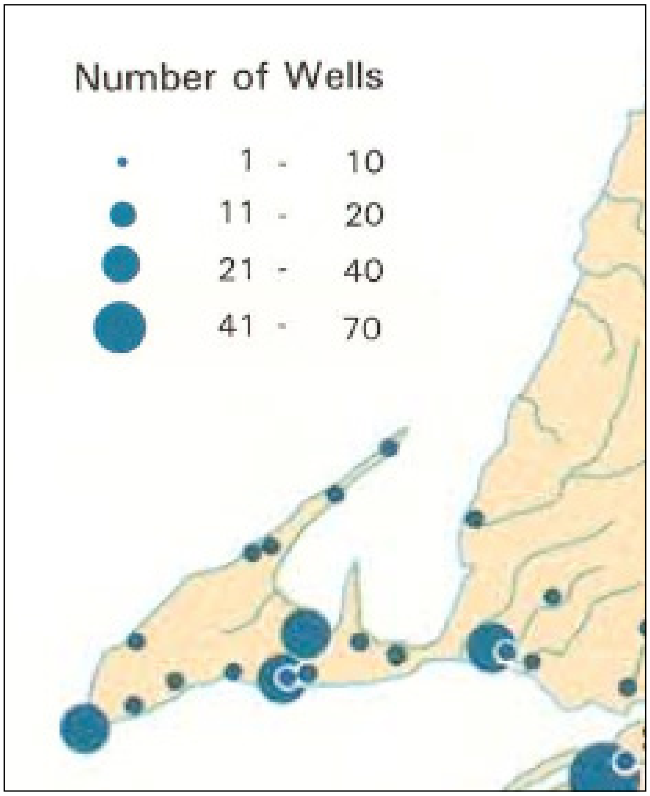

Figure 3. Distribution of groundwater wells in the Port au Port region of western Newfoundland (Government of Newfoundland, 1992).

According to the Water Resources Atlas of Newfoundland (1992), the average groundwater yield from bedrock in the Port au Port Peninsula is 27 L/min, with a range from 1 to 454 L/min. This yield is considered to be sufficient for small communities. This yield approximation is based on the grouping of geologic formations according to their yield characteristics as reported from available well records (Government of Newfoundland, 1992).

The Port au Port peninsula in generally consists of hydrostratigraphic units that are classified as having moderate yield with an average estimate of between 33 and 37 L/min and the potential to meet all domestic needs and limited commercial and municipal needs.

A review of groundwater well yields published by AMEC (2013) for the communities outlined in the study area revealed an average well yield of over 100 L/min, however this value is inclusive of Stephenville and Kippens, both of which have high well yields (e.g. over 500 L/min with some wells over 1000 L/min). A review of well data excluding Stephenville, Stephenville Crossing and Kippens shows an average yield of approximately 40 L/min. This yield represents wells that are currently being used (or are registered) for either domestic or municipal purposes (e.g. may be unavailable for use in unconventional oil and gas operations).

The average well yield in communities on the Port au Port peninsula are considered to be moderate according to the well potential classification outlined by Acres (1992) that defines low yield as 5 to 25 L/min, moderate as 25 to 125 L/min, and high as > 125L/min. According to Acres (1992), low yields are considered to be suitable for single dwelling homes, moderate yields are deemed suitable for domestic and some commercial uses, and high yields (>125 L/min) are considered to be suitable for domestic, industrial, commercial, or municipal needs. Further groundwater assessments and/or studies should be conducted to determine whether the groundwater yields in the area would be able to support industrial activity such as hydraulic fracturing.

According to Lightfoot (2014), lack of groundwater availability in Port au Port has been a hindrance to community growth. It has been estimated that in the past 15 years, there have been 3 to 4 instances of water shortages likely from low rainfall in summer and winter, resulting in implementation of conservation efforts. Some local businesses have suffered and community residential developments have halted due to the lack of water to support growth (Lightfoot, 2014). There have been steps taken to reduce water usage and address the occasional instances of water scarcity that have occurred in recent years. For example, the Port au Port municipality recently conducted testing in order to begin to secure a new artesian well with hopes that it will help prevent future water shortages (Lightfoot, 2014).

A survey of water operators in Newfoundland found that water quantity is an issue for some rural communities (Speed, 2014b). The survey showed that 20% of operators in local service districts, and 13% of operators in municipalities of 1,000 residents or less see low water levels as and drought as a threat to their drinking water systems (Speed, 2014b). In a survey of community administrators (response rate of 28% from western Newfoundland), results indicated that administrators in 62% of local service districts and in 72% of municipalities of 1,000 residents or less have issued a water ban due to water shortages arising from drought (Speed, 2014a).

5.1.2 Surface Water

Although approximately 70% of the population of Newfoundland uses surface water resources for municipal water demands, there are limited surface water resources in the Port au Port Bay area. According to the Water Resources Atlas of Newfoundland, there are no major lakes, streams, or ponds in the area. The total of all ponds accounts for under 1% of the land mass of the Port au Port Peninsula (Government of Newfoundland, 1992).

There are, however, some smaller ponds in the study area. For example, Gravels Pond is a brackish pond situated between Port au Port and Port au Port West-Aguathuna-Felix Cove. There are several ponds in the nearby Kippens and Stephenville area including Ned's Pond, Noel's Pond, Gull Pond and Long Gull Pond.

Although located further away from the study area, there are several larger surface water bodies in the Corner Brook area, for example, George's Lake, Grand Lake, and Deer Lake. Grand Lake is the largest lake on Newfoundland (area 534 km^2) and is dammed to divert water to Deer Lake as it serves as a supply to the Deer Lake Hydro Electric Station where power is generated for Corner Brook Pulp and Paper Mill.

5.2 Water Use on the Port au Port Peninsula

5.2.1 Residential Water Use

The total water use per capita in Newfoundland in 2011 has been estimated at over 800 litres per capita per day (LPCD) (CBCL, 2012), which is substantially higher than other provinces in Canada. The National average consumption for Canada is approximately 500 LPCD (Environment Canada, 2011).

It is broadly accepted that small communities (e.g. less than 2,000 residents) have higher residential water use per capita compared to larger communities in Canada (Environment Canada, 2011).

For many small communities, conservation measures such as water metering are rarely used. Additionally, smaller communities are more likely to have leaking infrastructure, and flush water during the winter months to keep pipes from freezing, all of which contribute to higher water use per capita in these smaller communities (Environment Canada, 2011).

It is difficult to estimate the exact quantities of water used by residents in rural communities in the Port au Port region, however, one case study on the Port au Port region provided daily average water consumption in the community and values ranged from 1,000 to nearly 4,000 litres per day per household (Lightfoot, 2014). It is expected that other communities in the area consume similar volumes of water on a daily basis.

A large fraction of the population relies on groundwater for domestic or household water purposes. Most of these dug or drilled wells are for one or two households (Acres, 1992). Table 6 below outlines the domestic water wells located in the study area as well as their yields. A comparison was drawn between the water consumption rates (1000-4000 L/d/household) to average daily water yields from Table 6. While it is difficult to estimate water stress from these data on a case-by-case basis, it is evident that by comparing the anticipated consumption and yield data, some wells could already be experiencing issues with water availability. With that in mind, a cursory level analysis indicates that wells in Point au Mal, for example, could be under stress.

Table 6. Domestic water wells in the Port au Port Area (1950-2005).

COMMUNITY	NUMBER OF WELLS	AVERAGE YIELD (L/MIN)	WELL CLASSIFICATION
Point au Mal*	4	1	NA
Three Rock Cove*	5	2.34	NA
Ship Cove (PB)*	1	3	NA
De Grau*	3	7.33	Low
Lourdes	11	8.2	Low
Campbells Creek	13	13.2	Low
Boswarlos	10	15.87	Low
Aguathuna*	1	15.9	Low
Ship Cove (NP)	22	16.28	Low
Abrahams Cove	9	19.54	Low
Ship Cove	23	25.1	Moderate
Felix Cove*	4	28.88	Moderate
Marches Point	11	35.42	Moderate
Sheaves Cove*	4	35.75	Moderate
Black Duck Brook*	3	36	Moderate
Mainland*	2	38.65	Moderate
Ship Cove (SGB)	11	39.07	Moderate
Winterbrook*	2	45	Moderate
Cape St. George	47	52.32	Moderate
Port au Port West*	1	67.5	Moderate
Port au Port East*	4	81.5	Moderate
Average	**13.7**	**49.3**	**Moderate**

** Water wells with potential stressed conditions*

Most of the municipal or public water supplies in the Port au Port area also use chlorination as their primary method of treatment and serve less than 1,000 people, however, the Town of Lourdes has a semi-conventional water treatment plant.

There are, however, some communities in the study area that use surface water supplies for municipal drinking water. For example, the communities of Lourdes, Mainland, and Cape St. George all use brook water as drinking water supply.

Table 7 depicts all municipal water supplies and local service districts and their sources within the study area.

Table 7. List of municipal water supplies and local service districts in the Port au Port area.

COMMUNITY NAME	WATER SOURCE	POPULATION SERVICED	PROTECTED OR UNPROTECTED	TREATMENT SYSTEM
Port au Port East	GW	608	Protected	Chlorination
Port au Port West (Aguathuna, Felix Cove)	GW	371	Protected	Chlorination
	GW	86	Protected	Chlorination
Black Duck Brook	GW	25	Unprotected	Chlorination
	GW	29	Unprotected	Chlorination
Piccadilly Slant (Abraham's Cove)	GW	414	Unprotected	Chlorination
		364	Unprotected	Chlorination
Lourdes (West Bay)	SW	1,090	Protected	Coagulation-Filtration Chlorination
Mainland	SW	311	Protected	Chlorination
Cape St. George (Red Brook, De Grau, Marches Point)	SW	427	Protected	Chlorination
Sheaves Cove	GW	59	Protected	Chlorination
	SW	66	Unprotected	Chlorination
Ship Cove (Lower Cove, Jerry's Nose)	GW	34	Protected	Chlorination

5.2.2 Industrial Water Use

Industrial activity in the Port au Port region Newfoundland is generally comprised of fisheries or fish plants, and mining. According to a report on the sustainability of drinking water systems in Newfoundland and Labrador available data on water abstraction for industrial use is outdated (Ramalho et al., 2013). Furthermore, there is no specific data on the industrial use of water in communities of less than 1,000 residents. These industrial users can exert large demands on small water systems however they may be irregular depending on the facility.

In 1992, industrial water use in western Newfoundland was approximately $350x10^6$ m^3/year with the largest users being mining and pulp and paper, which used over 200x106 and 120x106 m^3/year, respectively (Government of Newfoundland, 1992). There are no pulp and paper mills directly in the study area however there is one located in Corner Brook and in Stephenville. There is also one mine in the study area, Atlantic Minerals in Lower Cove on the Port au Port area however there is limited data on water consumption for this particular quarry.
Many municipal water systems in small communities in Newfoundland and Labrador supply fish plants with water, which can cause large, regular demands on water supplies. When fish plants are not operating, water use characteristics are similar to those of small, rural communities (CBCL, 2011).

Commercial fisheries are one of the most important economic bases for small communities in western Newfoundland (DFO, 2009). Fish plants and aquaculture sites exist in several communities within the Port au Port Peninsula. Both fresh and salt water are used for fish plants and aquaculture sites in western Newfoundland. It has been estimated that fish processing plants use on average 10,000 m^3/year during peak production for various processes. The largest water source for fish plants in Newfoundland is surface water (68.6%), followed by groundwater (15.4%) and salt water (12.8%). Specific details on fish plants and aquaculture sites in the Port au Port area are outlined in Table 8 below. According to Acres (1992) the fish plant in Piccadilly relies entirely on groundwater.

Table 8. Fish processing plants in the Port au Port area.

LOCATION	PROCESS
Piccadilly	Shellfish Aquaculture (Blue Mussels)
Piccadilly	Shellfish Aquaculture (Giant Scallop)
Piccadilly	Shellfish Aquaculture (Blue Mussels)

5.3 Summary of Water Quantity in the Port au Port Area

Based on a review of local water resources in the Port au Port area it was found that:

- According to several reports, groundwater resources in the Port au Port area are considered to have moderate yields (e.g. suitable for domestic and some commercial uses), however, a substantial portion of communities on the peninsula rely solely on groundwater for both municipal and private water supplies. It has been estimated that the water use per capita in the area is approximately 800 litres per capita per day. The main industrial users of groundwater are fish plants located in Piccadilly which consume an estimate of 10,000 m^3 of groundwater per year.

- Surface water resources on the Port au Port peninsula are limited and there are no major lakes in the area, although there are several small ponds. There are also larger freshwater lakes and ponds located further from the Port au Port area (e.g. Corner Brook, Stephenville).

- A preliminary analysis of water well data indicate that some groundwater wells in the Port au Port peninsula could be under water stress.

- A detailed review of ground and surface water resources in the Port au Port area is recommended in order to fully understand the water demand, or water budget, exerted by the communities and industries in the region, and to gauge the potential impact of unconventional oil and gas exploration on local water resources.

5.4 Water Quality on the Port au Port Peninsula

As described in Task 1, a review of literature demonstrates that baseline water quality data is essential for gauging any changes in water chemistry as a result of unconventional oil and gas operations. Therefore, we evaluated publicly available water quality data and government reports on water quality in western Newfoundland, specifically in the Port au Port region in order to gain a further understanding of the baseline water quality in the study area.

5.4.1 Municipal

As previously mentioned, many communities in the Port au Port area rely on groundwater as primary source for drinking water, so it is crucial to understand in detail the baseline water quality in order to gauge the impacts of unconventional oil and gas operations on drinking water resources.

Turbidity, color, and disinfection by-products are prevalent water quality issues in Newfoundland. For example, high turbidity levels exist in 48% of Newfoundland drinking water supplies (CRA, 2010). This is attributed to a lack of infrastructure for removing colloidal matter and dissolved matter (e.g. filtration) that cause high turbidity and color (CRA, 2010). As most communities in the Port au Port area do not have advanced water treatment systems, and therefore rely on chlorination only for treatment.

As previously described, the communities in the Port au Port area generally have fewer than 500 residents and rely on groundwater systems. Other studies have noted that communities in Newfoundland with fewer than 500 residents are more susceptible to poor water quality (CRA, 2010).

Water quality for public water supplies in Newfoundland is generally summarized based on the Water Quality Index (WQI), which was developed by the Canadian Council of the Ministers of the Environment (CCME). The WQI is calculated by comparing the frequency, scope, and amplitude of water quality exceedances to Health Canada's Guidelines for Canadian Drinking Water Quality, which then generates a score between 0 and 100 (higher score indicates better water quality) which are categorized by poor (WQI 0-44), marginal (45-64), fair (65-79), good (80-88), very good (89-94), and excellent (95-100) (NLDOE, 2015).

If a public water supply system is on a boil water order, has a current contaminant exceedance above the drinking water quality guideline as defined by Health Canada, a WQI score is not computed.

The WQI for public water supplies in the Port au Port area were reviewed in order to gain a better understanding of the overall water quality in the study area and are outlined in Table 9.

Table 9. Water quality indices for public water supplies in the Port au Port area (NLDOE, 2015).

COMMUNITY NAME	WATER SOURCE	POPULATION SERVICED	PROTECTED OR UNPROTECTED	LATEST WQI RANKING
Port au Port East	GW	608	Protected	Excellent
Port au Port West (Aguathuna, Felix Cove)	GW	371	Protected	Excellent
	GW	86	Protected	Excellent
Black Duck Brook	GW	25	Unprotected	Not Ranked
	GW	29	Unprotected	Not Ranked
Piccadilly Slant (Abraham's Cove)	GW	414	Unprotected	Not Ranked
	GW	364	Unprotected	Not Ranked
Lourdes (West Bay)	SW	1,090	Protected	Not Ranked
Mainland	SW	311	Protected	Not Ranked
Cape St. George (Red Brook, De Grau, Marches Point)	SW	427	Protected	Excellent
Sheaves Cove	GW	59	Protected	Not Ranked
	SW	66	Unprotected	Excellent
Ship Cove (Lower Cove, Jerry's Nose)	GW	34	Protected	Not Available

Several communities in the study area were not ranked in terms of the WQI due to water quality exceedances. Therefore, we also evaluated boil water advisories for public water supplies in the Port au Port area to provide more information on the quality of groundwater resources in the Port au Port area.

Boil water advisories are issued by local governments to protect public health when there exists a reason for contaminants to be in their water supply, or if water quality is threatened by operational deficiencies including inadequate or lack of chlorine residual, no disinfection system, or the presence of bacteriological indicators such as total coliform and/or E.Coli (Minnes and Vodden, 2014).

In western Newfoundland, 88 boil water advisories have been issued for public water supplies since 1990 and many of them have not been lifted (Government of Newfoundland and Labrador, 2015). Boil water advisories in western Newfoundland are typically issued due to a lack of chlorination system, a lack of chlorine residual detected in the water distribution system, or a lack of sufficient contact time in distribution system. Furthermore, the majority of boil water advisories were issued for surface water sources (e.g. lake, pond, river, stream).

The communities Black Duck Brook, Piccadilly Slant (Abraham's Cove), Lourdes (West Bay), and Cape St. George, including Red Brook, De Grau, Marches Point, and Sheaves Cove, were not ranked on their last WQI report due to water quality issues.

Black Duck Brook has been under boil water advisory since the year 2000 as the water supply does not have a proper disinfection as the chlorination system was turned off by the operator due to taste. Piccadilly Slant and Abraham's Cove are currently under boil water advisory because the chlorination system was turned off due to lack of funds to operate, which is concerning since the groundwater source is not protected. In addition to having THMs well over the MAC of 100 ug/L in the Guidelines for Canadian Drinking Water Quality, the community of Lourdes has recently been under boil water advisory due to mechanical failure of the disinfection system. Mainland has been under boil water advisory since March of 2015 due to the repeated presence of total coliforms in their water. Mainland has also had issues with elevated THM and HAA concentrations in their treated water for several years. Sheaves Cove has also been under boil water advisory dating back to 2006 due to the presence of total coliforms and E.Coli in their drinking water, and more recently due to having a lack of minimum free chlorine residual of at least 0.3 mg/L in the distribution system.

According to a study on operation and maintenance of drinking water infrastructure in Newfoundland and Labrador by Conestoga-Rovers & Associates, there is a tendency for boil water advisories to occur in regions of western Newfoundland with populations less than 500 people (CRA, 2010). This study also reveals that the percentage of communities under boil water advisories in western Newfoundland (45%) is higher than central and eastern regions (21 and 38%, respectively), which is likely attributed to the high proportion of local service districts in the area.

Figure 4 highlights boil water advisories in the Port au Port region of western Newfoundland as of November, 2015.

A recent study of rural Newfound and Labrador drinking water systems considered aspects of public perception, awareness, and demand of drinking water (Minnes and Vodden, 2014). As a result of consultations with municipalities, it was revealed that residents dislike the taste of chlorine, and combined with the discoloured surface water in many communities, residents were drinking form roadside spring water sources. Additionally, a survey of community administrators also showed that municipalities of 1,000 people or less receive complaints about their water systems every 1-7 days (Speed, 2014). Overall, these findings point to distrust in publicly supplied water in rural Newfoundland (Minnes and Vodden, 2014).

One of the primary concerns with hydraulic fracturing is the risk of methane contamination in groundwater resources. Aside from the relevant drinking water quality indicators as outlined in the Guidelines for Canadian Drinking Water Quality, the CAPP recommends monitoring for the absence or presence of free natural gas in groundwater wells as a part of a baseline water quality monitoring program as outlined in their "hydraulic fracturing operating best practices for baseline groundwater testing". During this review, it was found that methane is not included as a parameter in the current water quality monitoring programs of the communities studied.

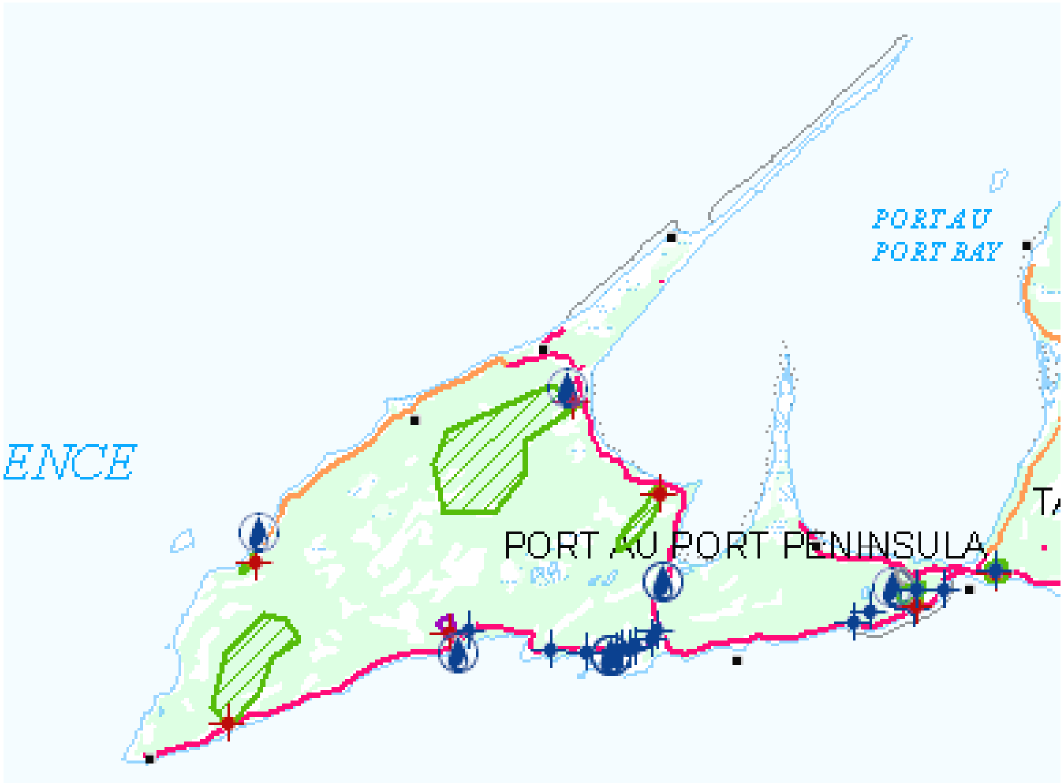

Figure 4. Boil water advisories in the Port au Port Region as of November, 2015 (NLDOE, 2015).

5.4.2 Private Wells

In Newfoundland, private water testing is the responsibility of the homeowner, and therefore published data on private well water quality is limited.

One study on the quality of private drilled and dug wells in several small communities of western Newfoundland was conducted by Sarkar et al. (2012). In samples collected during the summer, 23% of drilled and 63% of dug wells were contaminated with total coliforms, and 10% of dug well water samples had fecal coliforms present. In samples collected during the fall, 38% of drilled wells had total coliforms and for dug wells, 80% and 10% of total and fecal coliforms were present respectively. Several private well owners did not have filtration systems.

Two well water samples had high arsenic; one had fluoride, all of which were from dug wells. Ten samples exceeded guidelines for turbidity and five of those samples had total coliform presence. Six of the wells sampled had high iron and manganese concentrations. Furthermore, according to Sarkar et al. (2012), at least four major giardia outbreaks have occurred in the western region of Newfoundland over the past 20 years.

According to this study, 89% of participating communities drank their well water, however there was some mixed response from participants with respect to the quality of their well water. For example, communities appeared to be very confident in their water sources, even though some wells were untested for more than 30 years. Interviews showed that 87% of drilled well owners had faith in the quality of their water, although laboratory analysis showed that 55% of them had both contaminant and aesthetic parameters that were higher than the guideline values. Similarly, 94% of dug well owners had perceived that their wells were free from contamination, however 67% had issues with contaminants or aesthetic parameters (Sarkar et al., 2012). Owners of wells contaminated with arsenic and/or fluoride had no complaints about the quality of their water and were surprised by reports of contamination.

5.5 Summary of Water Quality in the Port au Port Area

A review of publicly available water quality data and reports on water quality in western Newfoundland was conducted in order to gain a further understanding of the baseline water quality in the Port au Port area. Through this review, it was determined that:

- Publicly available water reports showed that many communities in the Port au Port area are facing significant challenges associated with water quality. Aside from Port au Port East and West-Aguathuna-Felix Cove, substantial portion of the communities in the Port au Port area studied were not ranked on the Water Quality Index due to various water quality concerns. For example, a lack of chlorination system and/or lack of adequate residual caused many communities to be under boil water advisory. Some communities had repeated occurences of total coliforms and E. Coli in their water systems. Evidence of public distrust in water systems was also reported, which caused some residents to consume untreated water from roadside sources.

- Private well water quality is limited although in the Port au Port area as it is the responsibility of home owners to have their water tested. One study revealed that the presence of both fecal and total coliforms were prevalent in many private wells in western Newfoundland, although the majority of these residents consumed their well water and had minimal concerns over the quality of their water even though some wells were untested for over 30 years.

- The overall quality of water in the Port au Port area is considered to be poor in a drinking water context.

- Methane is not included as a parameter in the current water quality monitoring regime of the communities studied in this review. In the current state it would be extremely difficult to gauge the potential impacts to water quality from unconventional oil and gas exploration in the Port au Port area.

6.0 CONCEPTUALIZATION OF POTENTIAL WATER AND WASTEWATER MANAGEMENT OPTIONS IN PORT AU PORT

The information from Task 2 was used to conceptualize and discuss the possible scenarios for managing the various aspects of water and wastewater related to unconventional oil and gas exploration in a hypothetical context in the Port au Port area.

6.1 Water Use

Water use for hydraulic fracturing varies by geographic location as it is based on local geology. According to a review of the water demands exerted by hydraulic fracturing in North America range from ~7,500 to 75,000 m^3/well, with a median of approximately 20,000 m^3/well. One report noted that the Green Point Shale of western Newfoundland is primarily comprised of Illite clay, which is also the main clay in the Barnett Shale of Texas. According to the review in Task 1, the Barnett requires between 10,600 and 15,000 m^3/well for hydraulic fracturing. Based on this information, a conservative estimate of 20,000 m^3/well was used to represent an estimate for water use on a per well basis in western Newfoundland.

The Panel considered one drilling scenario in the Port au Port area to have 480 producer wells, drilled at a rate of 80 wells per year, recovering approximately 150 million barrels of oil in addition to 75 billion cubic feet of natural gas. Based on the conservative water demand estimate of 20,000 m^3/well, 80 wells drilled per year for 6 years would equate to approximately 16,000,000 m^3 of water required per year.

Three potential water use scenarios were considered of a) high, b) medium, and c) low risk in the context of water availability in the Port au Port area.

a) High Risk – 100% Freshwater

As previously described, the majority of communities in the Port au Port area are entirely reliant on groundwater resources for daily use, in addition to any industries (e.g. fish plants) in the area that currently rely on groundwater for their daily operations.

Therefore the use of 100% freshwater was considered from ground and surface water resources to meet the 20,000 m^3/well water demand estimate for hydraulic fracturing operations in the Port au Port area.

Given the information on groundwater resources that are currently available it would be considered high risk to communities in the Port au Port area to rely on groundwater resources to support hydraulic fracturing activity. Based on a population estimate of ~4,900 residents in the Port au Port area and a water demand of 0.8 m^3 per capita per day equates to a water demand of nearly 4,000 m^3/day and more than 1,430,000 m^3/year to meet residential needs. The water demand to support hydraulic fracturing of 80 wells per year was approximately 16,000,000 m^3/year. A comparison of the two demonstrates that the water demand for hydraulic fracturing significantly outweighs the residential water demand, which is met through mainly groundwater resources.

The review of groundwater resources revealed that the current well yields are classified as moderate yield, sufficient for meeting the domestic and some commercial needs in the communities of the Port au Port area. Other reports have noted that a lack of groundwater availability in the Port au Port area has been a hindrance to community growth. In addition, according to Freyman (2014), communities with small water supplies or those that rely primarily on groundwater resources are particularly vulnerable to the impacts on water resources from shale gas industry since as these communities often do not have the financial resources to build infrastructure to import water.

Therefore, a more detailed hydrological assessment is necessary to further understand the groundwater resources in the Port au Port area. This review should consider the estimated water demand for residents in small communities in western Newfoundland, in addition to any demands on freshwater resources exerted by commercial entities (e.g. schools, restaurants, hotels, hospitals) and industry (e.g. fish processing plants).

Our review of surface water resources in western Newfoundland revealed that there are limited fresh surface water resources in the Port au Port area. There are, however, large surface water bodies located further from the study area, such as Grand Lake, George's Lake, and Deer Lake.

The use of these surface water resources to support unconventional oil and gas activity would involve trucking of freshwater from surface water bodies surrounding the Port au Port area on main roads, which would need to be updated in order to withstand the induced heavy truck traffic. An alternative to this would be to construct pipelines to transport freshwater from lakes surrounding the study area, which would also require infrastructure demands.

b) Medium Risk – 25% Freshwater, 75% Reuse

A medium risk scenario where only 25% freshwater was used (e.g. 5,000 m^3/well, or 400,000 m^3/year). This water demand for hydraulic fracturing could potentially be met by the existing freshwater resources in the Port au Port area, as it is much less than the annual residential water demand. However, detailed hydrogeological assessments would still be necessary to confirm the available freshwater resources in the Port au Port area.

The remaining 75% of the water demand for hydraulic fracturing could be met by reusing the wastewater generated during the hydraulic fracturing process (e.g. flowback and produced water). This is common practice in other regions with intense hydraulic fracturing such as Pennsylvania. Depending on the characteristics of the wastewater, additional treatment may be required prior to reuse and therefore this would need to be further investigated during bench and pilot-scale treatability studies.

This scenario could potentially reduce the need for upgrading or constructing infrastructure to transport water to and from well sites.

c) Low Risk – 75% Reuse with 25% Use of Seawater

The final scenario evaluated was to use 75% recycled wastewater from hydraulic fracturing operations and 25% use of seawater. This scenario is considered to be the lowest risk because it would involve minimal use of freshwater resources and therefore would have the lowest impact on the communities in the Port au Port area as it is surrounded by abundant seawater resources including St. George's Bay and Port au Port Bay.

The use of saltwater for hydraulic fracturing operations has become more viable due to advances in technology. It is common in places such as British Columbia, where water that is not fit for human consumption (e.g. flowback reuse, saline groundwater, and recycled municipal wastewater) is used to support 30% of the water used in hydraulic fracturing operations.

Several researchers have demonstrated how sea water can be used for hydraulic fracturing operations, resulting in a reduced freshwater demand. According to Bonapace et al. (2012) 412 of 760 fracturing treatments in Argentina in 2010 used various types of produced water as a base fluid in hydraulic fracturing operations, resulting in a 54.8% reduction in freshwater.

Li et al. (2014) found that based on laboratory-scale experiments, untreated produced water with extremely high TDS (over 300,000 mg/L) and hardness (up to 90,000 mg/L) were compatible with certain fracturing fluids (e.g. organometallic-crosslinked deviated polysaccharide). Similarly, Sareen et al. (2014) used a saltwater and TDS tolerant friction reducer (water-based polyacrylamide) in a slickwater fracturing operation in the Delaware basin with produced containing over 250,000 mg/L TDS and 60,000 mg/L hardness. A comparison with conventional crosslinked fluids and friction reducers showed that the new friction reducer was compatible with additives commonly used in slickwater fracturing applications including scale inhibotrs, bacteria control additives, clay stabilizers, surfactants, and brines, offering a cost-effective solution of reducing produced water disposal and fres water demands.)

6.2 Water Quality

One of the most common concerns associated with hydraulic fracturing is the potential risk to water quality, especially drinking water resources. In order to effectively evaluate the impacts of hydraulic fracturing on water quality, there is a need for detailed baseline water quality evaluations prior to exploration.

We evaluated three risk scenarios for considering the potential impacts to water quality from hydraulic fracturing – a) Hydraulic fracturing proceeds without baseline water quality monitoring program, b) baseline water quality is monitored but drinking water wells are left in their current state, and c) baseline water quality is monitored and drinking water wells are upgraded.

a) High Risk – Hydraulic Fracturing Proceeds without Baseline Water Quality Monitoring Program

The primary contaminant of concern associated with hydraulic fracturing is methane. Currently in western Newfoundland there is no publicly available data on baseline methane concentrations in groundwater resources. Furthermore, methane is not included as a parameter in the current water quality monitoring regime of the communities studied as part of this review. Without this information it is challenging to consider the potential impact that hydraulic fracturing operations could have on local water resources.

A review of Drinking Water quality in the Port au Port area revealed that many communities have been issued boil water advisories due to inadequate drinking water infrastructure (e.g. lack of disinfection system), and some communities have shown indications of contamination (e.g. total coliforms and E. coli). This demonstrates that the there is likely aging infrastructure that is in need of replacement. Any hydraulic fracturing activity in these areas could pose a high risk to these drinking water systems, especially with respect to migration of hydraulic fracturing fluid and fugitive methane. The same risk would be posed on domestic/private water wells.

A proper baseline water quality monitoring program should characterize the ambient water quality (including methane) surrounding natural gas exploration area, the chemicals and additives used in hydraulic fracturing, flowback fluids, as well as the water quality after hydraulic fracturing activities occur.

It would be considered high risk if unconventional oil and gas operations were to proceed in the Port au Port area without a proper baseline water quality monitoring program. The experiences taken from Pennsylvania and other similar jurisdictions, where hydraulic fracturing activity has been occurring for nearly a decade, and where over 30% of residents in counties rely on shallow groundwater wells for drinking water and many of which are living within close proximity to wells (e.g. 1 km) should be used as a learning tool by decision-makers in Newfoundland.

b) Medium Risk – Baseline Water Quality Is Monitored but Drinking Water Wells Are Left in Their Current State

A lower risk, medium risk scenario to consider would be if baseline water quality were monitored in the Port au Port area prior to, and after hydraulic fracturing activity.

A regional water quality monitoring program should involve the characterization of water quality characteristics at various stages. First, prior to any natural gas drilling activity, water quality should be characterized to understand all background chemical parameters associated with the water resource and well location. Chemical additives in fracturing fluids as well as flowback water should be characterized in order to establish the proper indicator parameters to track potential contamination.

More specifically, a proper baseline water quality monitoring program should:

- Develop sampling protocols that include sampling location, sampling frequency, and duration for baseline data and ambient water quality after hydraulic fracturing activity has ceased.
- Define a geographical area of interest
- Establish an understanding of baseline water quality monitoring criteria (e.g. how long before hydraulic fracturing activity does baseline monitoring have to occur, how many samples should be collected?).
- Identify potential contaminants and possible chemical tracer or indicator parameters for the said contaminants
- Establish a list of water quality analytes that should be measured (e.g. general water quality indicators and parameters that are specific to hydraulic fracturing activity)
- Understand the chemical composition and fate of potential contaminants

There is however, a level of risk associated with the vulnerability of the drinking water infrastructure (e.g. groundwater wells) in Port au Port that would remain whether a baseline monitoring program were in place or not. By monitoring the baseline water quality in the Port au Port area it would become possible to identify incidences of groundwater contamination after they have already occurred, however with poor infrastructure the risk of contamination remains through subsurface migration of fracturing fluids including methane into drinking water wells.

c) Low Risk – Baseline Water Quality Is Monitored and Drinking Water Wells Are Upgraded

The lowest level of risk to the Port au Port area would be if a detailed baseline water quality monitoring program were implemented and the current drinking water infrastructure were upgraded to reduce the likelihood of groundwater contamination through subsurface pathways (e.g. fracturing fluid migration, fugitive methane). In this scenario, the likelihood of contamination of public or municipal water supplies would be reduced while the likelihood of capturing any groundwater contamination events would increase.

6.3 Wastewater Management

One of the greatest challenges faced by the oil and gas industry is the management of wastewater generated during unconventional oil and gas operations. As previously mentioned, wastewater produced during hydraulic fracturing operations is comprised of flowback water, produced water, and water used during the drilling process.
For this review, the rate of water flowback was conservatively estimated to be 50% of the water used for each well. Based on a water use rate of 20,000 m^3 per well equates to 10,000 m^3 of combined flowback and produced water generated per well. At an estimated 80 wells drilled per year, approximately 800,000 m^3 of wastewater will be generated per year for six years. The rate of wastewater generation will likely be highest at the beginning of operations when wells are being drilled, and will decrease over the six year period once all of the wells have been drilled.

In the Panel report, two options for the disposal of hydraulic fracturing wastewater were considered a) High risk - the construction and operation of 8 Class II disposal wells, and b) Medium to Low Risk – Construction and operation of a water treatment facility with ocean discharge.

a) High Risk – Construction and Operation of Class II Disposal Wells

Many researchers have identified the optimum means for disposal of wastewater generated during hydraulic fracturing operations to be deep well disposal. Disposal in Class II injection wells has been the primary disposal option in the United States. Disposal wells are commonly used in western Canada (e.g. British Columbia and Alberta), however the deep-well injection of hydraulic fracturing wastewater may not be possible on the east coast of Canada (e.g. New Brunswick and Nova Scotia) due to geological conditions.

The primary concerns with the use of disposal wells for hydraulic fracturing wastewater are groundwater contamination and the risk of seismicity. Therefore, the construction and operation of 8 Class II disposal wells was considered to be the highest risk scenario primarily due to the reliance of small communities on groundwater resources for drinking water purposes.

A detailed investigation on the geological conditions in the Port au Port area is necessary in order to further understand the potential risks of using disposal wells for the management of wastewater during the hydraulic fracturing operations.

b) Medium to Low Risk – Treatment and Discharge

The second scenario evaluated was the treatment of hydraulic fracturing wastewater to a level where it could be discharged to the ocean.

It would be beneficial for the Newfoundland to consider USEPA's newly (Summer 2015) proposed treatment standards that address the discharges of wastewater generation from unconventional oil and gas extraction to publicly owned wastewater treatment facilities. In addition, treatment conditions will be established through the level of reuse. Finally, treatment options will need to be consistent with the environmental risk being placed on the receiving body (e.g. ocean, freshwater).

7.0 CONCLUSIONS AND RECOMMENDATIONS FOR THE PROVINCE OF NEWFOUNDLAND

7.1 Literature Review

The peer reviewed literature points to concern associated with water quality in regions near hydraulic fracturing. While the evidence in the literature presents mixed outcomes, in terms of causal evidence; a consistent theme is to quantify ground water quality. Not surprisingly, industry best practices also recommend groundwater quality assessment before, during, and following hydraulic fracturing activity in areas that are affected by unconventional oil and gas. The literature review also pointed to concerns associated with water use. Indeed in areas where fresh water use is stressed, industry best management practices state that alternative sources of water such as brackish, saline, produced, and third party wastewater should be considered.

7.2 Regulatory Review

A review of existing regulatory frameworks in Newfoundland and Labrador for the oil and gas industry demonstrates that there is a need to develop regulations for not only unconventional oil and gas operations (e.g. hydraulic fracturing) directly, but for the water quality and quantity aspects associated with hydraulic fracturing.

Regulations for baseline water quality monitoring programs and the use of freshwater for hydraulic fracturing will be necessary in order to safeguard the water resources in Newfoundland and Labrador. Furthermore, chemical disclosure rules and the use of Fracfocus should be considered.

Wastewater management regulations are also required to support the onshore oil and gas industry. Although general wastewater regulations exist in Newfoundland, consideration should be given to develop specific regulations that are more explicit to unconventional oil and gas.

The USEPA (2015) has published proposed pretreatment standards for oil and gas extraction that govern the discharge of hydraulic fracturing wastewater to publicly owned treatment works (POTWs). These standards should be considered when developing regulations for the management of hydraulic fracturing wastewater in Newfoundland.

7.3 Assessment of Water Quantity in Port au Port

Based on a review of local water resources in the Port au Port area it was found that the quantity of freshwater resources in the immediate Port au Port area are considered to be limited relative to the quantities required for unconventional oil and gas operations. Specifically:

According to several reports, groundwater resources in the Port au Port area are considered to have moderate yields (e.g. suitable for domestic and some commercial uses), however, a substantial portion of communities on the peninsula rely solely on groundwater for both municipal and private water supplies. It has been estimated that the water use per capita in the area is approximately 800 litres per capita per day. The main industrial users of groundwater are fish plants located in Piccadilly which consume an estimate of 10,000 m^3 of groundwater per year.

Surface water resources on the Port au Port peninsula are limited and there are no major lakes in the area, although there are several small ponds. There are also larger freshwater lakes and ponds located further from the Port au Port area (e.g. Corner Brook, Stephenville).

A preliminary analysis of water well data indicate that some groundwater wells in the Port au Port peninsula could be under water stress.

A detailed review of ground and surface water resources in the Port au Port area is recommended in order to fully understand the water demand, or water budget, exerted by the communities and industries in the region, and to gauge the potential impact of unconventional oil and gas exploration on local water resources.

7.4 Assessment of Water Quality in Port au Port

A review of publicly available water quality data and reports in western Newfoundland was conducted in order to gain a further understanding of the baseline water quality in the Port au Port area. Through this review, it was determined that the overall quality of drinking water in the Port au Port area is suspected to be poor. Specifically,

- A substantial portion of the communities in the Port au Port area have substantial water quality issues. Many communities are under boil water advisory and some communities have had repeated occurrences of total coliforms and E. coli in their water systems.
- Private well water quality is limited although in the Port au Port area as it is the responsibility of homeowners to have their water tested. One study revealed that the presence of both fecal and total coliforms were prevalent in many private wells in western Newfoundland, although the majority of these residents consumed their well water and had minimal concerns over the quality of their water even though some wells were untested for over 30 years.

7.5 Recommendations

Based on the conceptualization of potential water and wastewater management options for hydraulic fracturing in Port au Port, the following recommendations have been made:

- A detailed analysis of freshwater resources and availability should be conducted on Port au Port peninsula. With the information available, it would be considered high risk to rely solely on the freshwater resources in Port au Port to support the water requirements for hydraulic fracturing operations outlined in the Panel report. It is recommended that the reuse of wastewater during hydraulic fracturing operations be considered.
- The use of alternative water sources such as saltwater or utilizing freshwater sources closer to Corner Brook should also be considered. Should the province consider the use of saltwater sources regulatory requirements for using seawater will be required. Should the province consider using freshwater sources closer to Corner Brook consideration will be required for infrastructure requirements (e.g., roads or water pipelines) needed to obtain freshwater.
- A proper baseline water quality monitoring program is recommended prior to any unconventional oil and gas exploration.
  - A baseline water quality monitoring program should consider water quality (including methane concentrations) prior to oil and after oil and gas activity. It should also characterize chemical additives in fracturing fluids and flowback water to establish proper indicator parameters to track potential contamination from hydraulic fracturing operations.
- A detailed investigation of local geology in the Port au Port area should be conducted in order to understand the potential risks associated with using Class II Disposal wells for the management of wastewater associated with hydraulic fracturing operations. At this time, it Class II Disposal wells do not appear to be an option for the Port au Port area.
- Wastewater treatment plan would therefore be required in the event Class II disposal wells are not available. The wastewater management plan would include wastewater discharge regulations, required treatment technologies and appropriate receiving body monitoring requirements.

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