Abridged Report

Development of a Water Safety Framework for Watershed and Water Demand Governance and Management Approaches Related to Hydraulic Fracturing

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1.0 Introduction

The growth of hydraulic fracturing in Canada has led to increased public interest in ensuring that decisions surrounding its application and management are informed by the best available science. A majority of the issues of top concern involve water – including water use, wastewater management, and the impact of hydraulic fracturing activities on surrounding water resources. With the recent rapid expansion of the industry, the need for scientific knowledge to form a solid basis for decision-making has become a common theme. Within the context of the Canadian Water Network, this project addressed watershed governance and management approaches for resource development, including First Nations, Inuit, and Metis Issues, and integrating issues relating to water use and demand management. In particular, this project included the following primary objectives:

- Summarize current research approaches and knowledge relevant to the issue area
- Identify key knowledge gaps in the issue area that are clearly articulated as priorities for decision makers
- Present the range of practical research approaches that could be used to address these priority knowledge gaps

This document represents an abridged version of the final report submitted to the CWN.

2.0 Project Team

The core project team consists of the following Researchers:

- Dr. Graham Gagnon, Ph.D., P.Eng. – Dalhousie University, Principal Investigator
- Dr. Ed McBean, Ph.D., P. Eng. – University of Guelph
- Dr. Madjid Mohseni, Ph.D., P. Eng. – University of British Columbia
- Dr. Ian Mauro, Ph. D. – University of Winnipeg

Project Management:

- Dr. Wendy Krkosek, Ph.D., P. Eng. – Dalhousie University
- Lindsay Anderson, M.A.Sc., EIT – Dalhousie University

Collaborators:

- Dr. Karl Linden, Ph.D. – University of Colorado Boulder
- Noel Milliea, Wisdom Keeper for Elsipogtog First Nation, NB
- Andy Nichols, First Energy First Nation, Tobique, NB.

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- Elliott Corston-Pine – University of Guelph, and Garden River First Nation
- Kaitlynn Livingstone, MASc Candidate – University of British Columbia
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3.0 Technical Approach

A risk-based approach, which informs the public of choices and governance models, has great potential to have significant and real value, providing a logical structure of issues, potential resolutions thereof, and the identification of key knowledge gaps. To allow this to take place, and better characterize the information needs, the team followed a structure of assessment that is utilized in drinking water system assessment, called the Water Safety Plan (WSP). This approach involves:

1. Collecting the array of information about the water system;
2. Analyzing and understanding the risks that are present that can threaten the safety of water users;
3. Identifying and assessing the necessary tasks that need to be employed in order to mitigate or reduce the risks to acceptable levels;
4. Determining strategies to prioritize and audit the tasks that have been identified, and
5. How to deliver the actions within a specified timescale.

Figure 1 below depicts a typical cycle for a water safety plan. The focus for this report was to evaluate steps 1 through 4 of a WSP in the hydraulic fracturing context. Steps 5 through 8 should be evaluated by government representatives, decision and policy makers when developing a water-related framework for hydraulic fracturing.

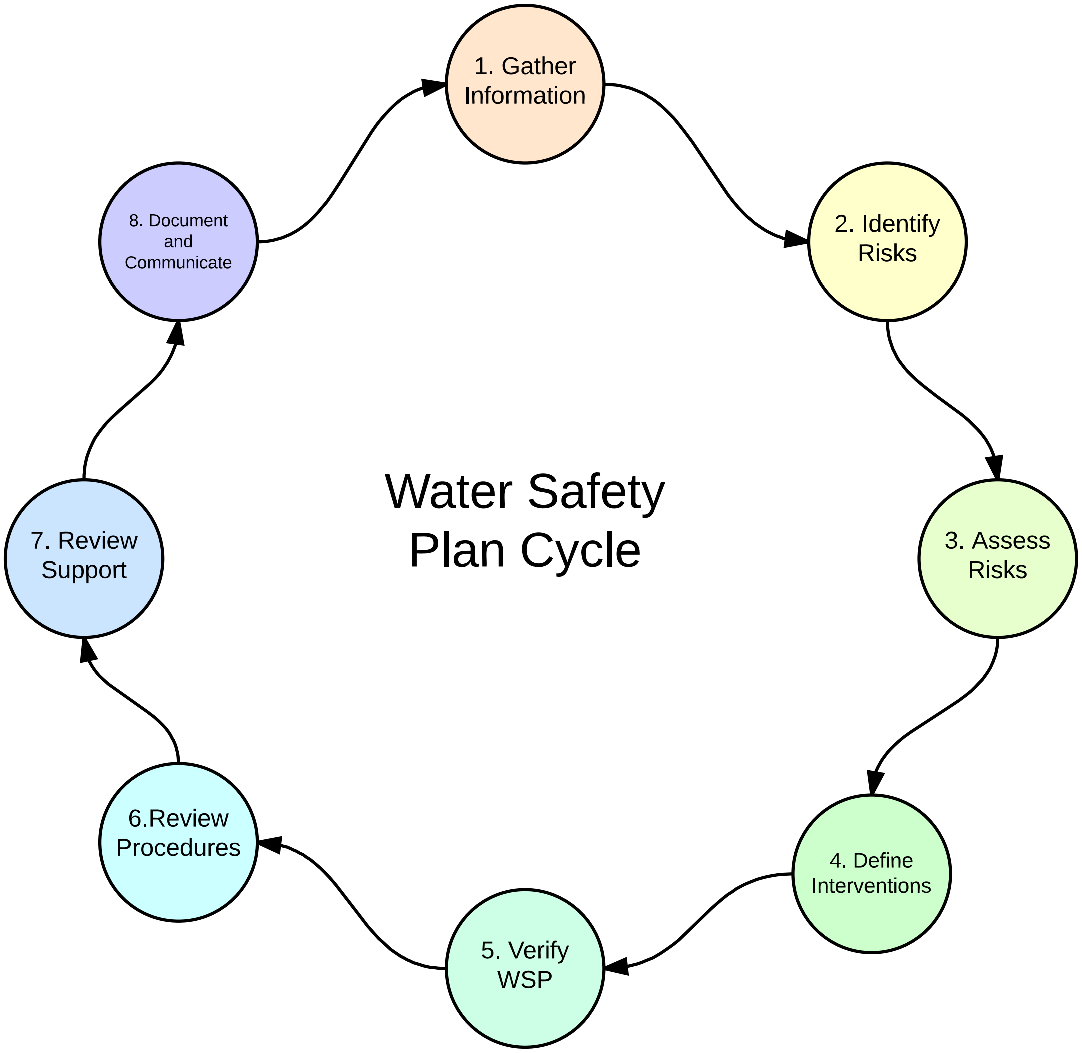

Figure 1. The Water Safety Plan Cycle (Reproduced from Alberta Environment, 2015).

A water safety plan has a series of components similar to a "catchment to consumer" model used in drinking water treatment. The parallels to issues in hydraulic fracturing are embodied in the themes of the student research papers. Six themes related to watershed governance surrounding hydraulic fracturing were developed based on a "cradle to grave" model. The themes identified were water use and demand, impacts to water quality, wastewater treatment and management, community consent, water conflict and negotiation strategies/barriers to engagement and governance approaches to watersheds. Literature reviews included peer-reviewed literature and relevant technical papers, regulatory-based literature, and other relevant documents including information on policy and governance instruments and frameworks related to their topics among federal, provincial and First Nations governments.

Student research papers included the following components:

- **Desktop Literature and Jurisdictional Reviews (April to June, 2014):** Students were asked to provide a review of relevant technical papers, including peer-reviewed literature, regulatory-based literature, and other documents related to their topics. Students were also asked to include a jurisdictional review containing information on policy and governance instruments and frameworks related to their topics.
- **Science and Research Directions (August to September, 2014):** After reviewing relevant literature and attending a state-of-science workshop in Boulder, Colorado, students were asked to identify knowledge gaps within their research topics.
- **First Nations Perspectives (October to November, 2014):** Following the workshop in Elsipogtog, New Brunswick, students were asked to incorporate a section on First Nations perspectives related to their topics.
- **Research Approaches and Risk Assessment (August to November, 2014):** Students were asked to provide research approaches to address the knowledge gaps identified throughout their research. The goal of this section was to provide a risk mitigation approach to resource development.

Draft student reports were submitted to the decision-making peer review advisory panel to provide comments and feedback on the direction of student research. The final report is based on the sections (e.g. literature and jurisdictional review, state of science, First Nations perspectives, and research approaches) from student papers with input from the Core Research Group and the Advisory Panel.

After reviewing literature, the project team attended a state-of-science workshop in Boulder, Colorado. During this workshop the team went on-site to hydraulic fracturing sites, met with the industry and with leading research groups that are addressing water challenges in the hydraulic fracturing industry. Following the state-of-science workshop, the project team reviewed the literature reviews and were asked to identify key knowledge gaps within the research topics.

Given the challenges associated with hydraulic fracturing in First Nation communities a cultural sensitivity workshop was held in Elsipogtog First Nation, New Brunswick. The goal of this workshop was to understand views and perspectives of water and the resource sector from Elders in Elispogtog First Nation. As well, the project team held discussions and meetings with Elders from Tobique Frist Nation. During this process, aspects of the cultural sensitivity workshop were documented using videography. Consistent with the project team's iterative process, the team was asked to reflect on ideas and concepts from First Nations people and assess the gaps and approaches from the current state of science.

As a result of the project team's risk-based approach, a series of priority questions for decision-makers associated with key knowledge gaps were identified and were transformed into research questions to guide future knowledge development. Research questions related to some of the following topics: risk-based regulatory frameworks for wastewater management; appropriate assessment of First Nation dialogue and inclusiveness; and appropriate water monitoring strategies to ensure water safety.

For each research question, possible research approaches were discussed by the project team. By addressing these areas it is anticipated that a risk-based, or even a water safety plan approach could be further enabled. During the preparation of this report, it was observed that other international agencies have established regulatory approaches (e.g., United States - USEPA 2015; United Kingdom - UKOOG, 2015) that incorporate risk- based frameworks into regulatory structures.

Within a Canadian context, risk-based approaches will likely reflect provincial and territorial regulatory principles. The key knowledge gaps and their subsequent research approaches identified in this project along with the existing regulatory principles will enable specific regional water safety frameworks to understand the implications of potential (if any) unconventional gas development.

The following sections describe the project findings in terms of key research questions and approaches identified by the project team.

4.0 Water Demand and Use

During the extraction of unconventional natural gas, water use occurs during drilling, hydraulic fracturing, extraction and processing of proppant sands, testing of gas transportation pipelines, processing at gas plants, and other processes (KPMG, 2012; Energy Institute at the University of Texas at Austin, 2012). The average water use related to hydraulic fracturing of shale gas in the United States is approximately 19,000 m^3 per well (CCA, 2014a). Water use is a much more complex issue that varies significantly from site to site. The impacts of water use on each region are also highly variable, and are dependent on a number of factors, such as the timing of withdrawal, climate change issues, ecosystem sensitivities, water allocations, and water use changes in a region.

4.1 Summary of Key Research Questions for Decision-Makers Related to Water Demand and Use

Water use for hydraulic fracturing has been highly controversial and under public scrutiny. Literature has shown that water use for unconventional shale gas development can be relatively low compared to other water users (e.g. agricultural, industrial) when examined at a larger scale (e.g. state or province wide, nationally). Additionally, studies have shown that water use for oil and gas development generally represents a small percentage of total water budgets for a given state or province. For example, the annual amount of water used for hydraulic fracturing in Texas is less than 1% of total water use (Jackson et al., 2014). In Alberta, the oil and gas industry is allocated approximately 8.5% of the province's available surface and ground water, while agriculture and municipal account for 11.3 and 44.3% (Alberta Environment, 2009).

Conversely, the impacts of the water demand exerted by hydraulic fracturing operations have been shown to be more significant when examined at a local, or regional scale. These impacts can also be more extreme in areas that are under water stress. For example, according to Bluefield Research (2014), the largest volume of hydraulic fracturing has occurred in water-stressed Texas where water requirements for hydraulic fracturing represented 57% of the total water demand for hydraulic fracturing in 2014. Jackson et al. (2014) states that unconventional energy extraction in counties in the Barnett, Eagle Ford, and Haynesville shale plays accounted for 18, 38, and 11% of total groundwater use. Freyman (2014) stated that the projected water demand in the Eagle Ford is expected to reach levels comparable to the total water used by all of the residents in the county. Scanlon et al. (2014a) suggest that through innovation, water demand should not constrain hydraulic fracturing processes even in semi-arid regions and in fact be lower than other regulated sectors of the economy.

Given this information and clear concerns associated with water demand, the project team has identified the following research gaps:

- There is a need for greater understanding of the quantity of water used for hydraulic fracturing, the timing and frequency of withdrawals, the water sources used, and the extent of reuse. This need is primarily attributable to the limited nature of existing water use data, which may be caused by insufficient monitoring, a lack of reporting; or the inaccessibility of reported data.
- There is a need for greater understanding of short and long-term availability and vulnerability of water sources used for hydraulic fracturing in order to examine and manage water use at the local and regional scale.

4.2 Identified Research Approaches

Understanding and evaluating the water demands associated with hydraulic fracturing are crucial in supporting the development of water management strategies. In order to gauge the significance of the impact of the water demand exerted by hydraulic fracturing, decision-makers must also be aware of the available water supply in a region. Given this information, the project team has identified the key research question for decision-makers "Can water budgets for hydraulic fracturing be managed?".

In order to evaluate whether water budgets for hydraulic fracturing can be managed, the project team identified the sub-questions "Can water demand for hydraulic fracturing be predicted?" and "Can available water supply be predicted?".

4.2.1 Can water demand for hydraulic fracturing be predicted?

To address this question, the project team has suggested the following approaches:

- Select a range of factors that impact water demand to be evaluated in order to analyze whether future water demand for hydraulic fracturing can be forecast at a local scale. The factors that influence water demand may include but are not limited to:
    - Oil and Gas Reserves: Estimates of potential future water use can be based on assessments of oil and gas resources and on drilling projections.
    - Flowback percentage and extent of reuse, and alternative water sources: As flowback water can be and is often reused in further hydraulic fracturing operations, it should be considered in terms of extent of reuse by operators in the location being considered. Alternative water sources (e.g. saline or brackish water, treated municipal wastewater) should also be considered.
    - Geology: As described in the literature review, the water demand for hydraulic fracturing varies significantly by play therefore geological characteristics of shale should be considered when estimating the potential future water demand for hydraulic fracturing.
- Develop a model to predict water use for hydraulic fracturing in a particular region
    - Compile and perform statistical analysis on factors (e.g. regression analysis).

4.2.2 Can water supply be predicted?

In order to gauge the impacts of water demand exerted by the shale gas industry at a local scale, an estimate of future water availability is needed for comparison. The project team suggests an approach that includes:

- Surveying the water availability under normal and stress conditions over short and long term and using this information to make a projection of future water supply.

Although projecting the available water supply may not be a research gap in itself, the key that is highlighted by the project team is that the water availability predictions need to consider water stress conditions (e.g. extreme drought, climate change) as well as short and long term time scales in order to capture the potential for managing water budgets for hydraulic fracturing at a local scale over a long time span.

5.0 Wastewater Treatment and Management

Since a by-product of the hydraulic fracturing process is wastewater, it is important to understand the wastewater characteristics, as well as the storage, treatment, disposal, and recycling methods currently used to manage it.

5.1 Summary of Key Research Questions for Decision-Makers Related to Wastewater Treatment and Management

The U.S. based hydraulic fracturing industry produces between 450 and 500 million barrels of wastewater annually (Bluefield Research, 2014). Although the volumes may not be as large in Canada, the rapid increase in unconventional gas development will likely result in the generation of significant volumes of wastewater. Currently, there are variations in policies and regulatory requirements related to the management of wastewater generated during unconventional oil and gas development in both Canada and the U.S. This information has resulted in the identification of the following research gap:

- There is a lack of uniform design, monitoring, and management standards/requirements for hydraulic fracturing waste storage facilities (e.g. tanks, ponds, etc.)

Hydraulic fracturing operators typically look to storage and disposal via deep well injection (if available), then treatment and/or reuse for management of the wastewater generated. Operators who are unable to dispose of hydraulic fracturing wastewater via underground injection are forced to find alternative methods to manage their wastewater such as discharge to publicly owned treatment works (POTWs) or privately owned centralized waste treatment facilities (CWTs). There an expected increase of 158% in treatment of hydraulic fracturing wastewater is expected by the year 2020 in the United States (Bluefield Research, 2014). As hydraulic fracturing wastewater is not typical or comparable to wastewater that are normally handled by POTWs, constituents that are common to unconventional oil and gas extraction (e.g. high salinity/TDS, organic and inorganic chemicals, heavy metals, NORM) can be discharged into receiving waters without treatment, can disrupt treatment plant operation, and can result in the formation of harmful disinfection by-products (USEPA, 2015).

In the United States, the *Clean Water Act* (CWA) has established an Effluent Guidelines Program, which sets national standards for industrial wastewater discharges based on best the available technologies that are economically achievable. However, currently no complete set of national treatment standards for wastewater from natural gas extraction activities exists in Canada or the United States. With this information, the project team has identified the following research gap:

- There is a lack of understanding of what the operating and/or performance requirements specific to hydraulic fracturing wastewater treatment facilities should be with intent to discharge to the environment.

Reuse of hydraulic fracturing wastewater has increased in popularity to due to more stringent regulatory standards, as well as a lack of deep-well injection sites resulting in high transport and disposal costs. In the Canadian context, up to 40% of produced water is reused in further hydraulic fracturing operations in British Columbia (BCOGC, 2014) and in Alberta, the industry recommends treating and reusing hydraulic fracturing wastewater, although fresh water is sometimes needed for blending purposes. In both Canada and the United States, the use of injection wells for disposal is under pressure from environmental groups and regulators due to rising concerns over earthquakes, contamination, and water use.

Furthermore, according to Bluefield Research (2014), only 14% of wastewater is treated and reused in further hydraulic fracturing operations (with exception to Pennsylvania, who has high reuse rates (up to 68%) due to heavier frameworks and a lack of access to deep well injection for disposal). In Texas and North Dakota shale plays, reuse is as low 2% (Bluefield Research, 2014). As of 2012, approximately 5% of hydraulic fracturing wastewater was reused for hydraulic further fracturing operations in Western Canada (CAPP, 2012). The project team views the increasing pressure on industry as an opportunity to further promote the reuse of hydraulic fracturing wastewater in further operations, resulting in the following research gap:

- There is a lack of promotion of the need for treatment and reuse of hydraulic fracturing wastewater to industry.

5.2 Identified Research Approaches

The current regulatory framework for hydraulic fracturing wastewater is complex as some areas are well equipped to manage hydraulic fracturing and others are not. There is no over-arching standard that encompasses all aspects of hydraulic fracturing wastewater management. Establishing a regulatory framework that is unique to hydraulic fracturing wastewater would allow for a common baseline across all provinces. Given this information, the project team has identified the following key research question for decision-makers "Should hydraulic fracturing wastewater management have a unique regulatory framework?"

Currently, wastewater is collected and stored in enclosed tanks with secondary confinement to avoid potential infiltration of slickwater or saline flowback water into the soil in British Columbia and Alberta (Rivard et al., 2014). Unlined surface ponds are not currently being used in Canada. In Eastern Canada, deep well injection of flowback water has not been tested or performed because of lack of understanding of potential deep-seated geological storage capacity or is simply not authorized because of potential leaks resulting from assumed permeability issues of cap rock units (Rivard et al., 2014).

There is potential for the unconventional shale gas industry to expand in Canada in the upcoming years, which will require decision-makers to address many of the issues and concerns with the storage, treatment, disposal, and reuse of hydraulic fracturing wastewater. Increasing pressure on and limited access to disposal wells, in addition to concerns over seismic activity (CCA, 2014a), more stringent regulations on water use, and concerns over surface water quality in areas where hydraulic fracturing wastewater is treated and discharged are all valid reasons for government regulators and decision-makers to evaluate the development of a unique regulatory framework for the management of hydraulic fracturing wastewater in Canada.

In order to assess whether hydraulic fracturing wastewater management should have a unique regulatory framework, the project team has identified more specific knowledge gaps, or sub questions, that relate to the storage, treatment, and reuse of hydraulic fracturing wastewater.

5.2.1 In the absence of disposal wells, what should be the design, monitoring, and management requirements of waste storage facilities?

To address this question the research team has suggested a phased approach that includes:

- A detailed literature review that considers the state of current wastewater monitoring requirements storage of hydraulic fracturing fluids and comparatively evaluates them against the monitoring requirements for landfills (e.g. spatially and temporally) and other industrial waste facilities.

- An assessment of the current design options, and monitoring requirements for storage tanks and ponds used in the oil and gas industry, and the identification of improvements that could be made.
- Perform pilot-scale and field trials that evaluate the improvements to the design and monitoring requirements identified through literature reviews and design assessments.

This approach essentially assesses the "best management practices" for the design storage and monitoring requirements of waste fluids that could be used towards the development of nation wide standards, specific to the storage of hydraulic fracturing waste.

5.2.2 What should be the design and operating/performance requirements for treating hydraulic fracturing wastewater with intent to discharge to the environment?

To address this the team has suggested a phased approach that includes:

- A thorough evaluation of the performance of current treatment processes for hydraulic fracturing wastewater to highlight any gaps in treatment processes.
- The establishment of minimum water quality requirements to set a treatment objective –What parameters are of greatest concern and what concentrations are acceptable?
- Evaluate the treatment objectives at bench and pilot-scale: is it feasible to achieve these treatment standards, are they achievable?

This approach can be used to evaluate whether a risk assessment approach would be a reasonable strategy for individual components of hydraulic fracturing fluid. It would be particularly beneficial for the development of treatment standards for hydraulic fracturing wastewater in areas across Canada in regions where deep well injection is not an option, and where the treatment using municipal wastewater treatment facilities is unacceptable. Canadian decision-makers could follow the groundwork laid by the USEPA (2015) in the development of pretreatment standards for wastewater generated during unconventional oil and gas development that is discharged to publicly owned treatment facilities as this form of wastewater management could become increasingly popular as disposal options (e.g. deep-well injection) may become more limited in the future as regulatory requirements become more stringent.

5.2.3 Can wastewater reuse be promoted?

The following approaches have been addressed by the project team in order to begin evaluating the promotion of hydraulic fracturing wastewater reuse:

- Evaluate the current reuse criteria (e.g. which characteristics, if any, of hydraulic fracturing wastewater are currently limiting reuse).
- Perform a survey of operators to determine any additional barriers to reuse (if any)
- Investigate methods for promoting reuse (e.g. new technologies, such as high TDS tolerant friction reducers, or establishing a reuse market for hydraulic fracturing wastewater between operators in a region where hydraulic fracturing occurs).

6.0 Impacts to Water Quality

Hydraulic fracturing fluid has potential to impact surface water and groundwater through the spilling of chemicals and/or hydraulic fracturing fluid during transportation, storage or use, accidental release of flowback water from the well, leakage of methane gas into groundwater due to deteriorating wellbore seals, and from inadequate storage, treatment, or disposal of flowback and/or produced waters (CCA, 2014b).

6.1 Summary of Key Research Questions for Decision-Makers Related to Impacts to Water Quality

Some of the most common criticisms related to hydraulic fracturing are the potential impacts to water quality and the lack of available baseline data. In order to safeguard surface and ground water quality in areas surrounding hydraulic fracturing operations some jurisdictions have implemented baseline and post-operation water quality monitoring requirements. However, there are large variations in water quality monitoring requirements across Canada and within the United States. The absence of "credible and comprehensive" data has been a major setback to properly study and monitor hydraulic fracturing activities and their pertinent risk on environment in particular water quality (Cooley et al., 2012; US EPA, 2011; Vengosh et al., 2013; Vidic et al., 2013).

There is also an absence of detailed information of the common chemicals used in hydraulic fracturing processes, and their potential impacts to water quality (including drinking water). Although many operators voluntarily submit their chemical information to the FracFocus Chemical Disclosure Registry website, Stringfellow et al. (2014) noted that out of the 81 evaluated common chemicals used in hydraulic fracturing, that there were major gaps in the availability of toxicity information as nearly 1/3 of the chemicals were missing toxicological information. Understanding which chemicals are of concern would allow help decision-makers in the improvement and/or formation of regulatory standards related to water quality surrounding hydraulic fracturing operations (e.g. water quality monitoring programs). In essence, decision-makers need to know which chemicals are of greatest concern in order to develop appropriate regulatory regimes. Given this information, the project team has identified a need for more detailed water quality monitoring program specific to hydraulic fracturing operations, and suggest that the following research gaps are addressed:

- There is need for a more detailed water quality monitoring program specific to hydraulic fracturing operations. More specifically, there is a need for information on where samples should be collected (e.g. sampling locations), the sampling frequency, and the duration of sampling (e.g. 6 months, 1 year, 5 years, etc.).
    - How frequently should samples be collected, and for what duration?
    - From where should samples be collected?

6.2 Identified Research Approaches

The shortage of available baseline data makes gauging the impacts of hydraulic fracturing on water quality challenging to government regulators and decision-makers. Given this information, the project team has identified a need to evaluate "what is the appropriate monitoring strategy created specifically to assess the impacts of hydraulic fracturing on the environment – including drinking water resources?"

In order to evaluate the appropriate monitoring strategy for assessing the impacts of hydraulic fracturing on the environment (including drinking water resources), the project team has identified more specific knowledge gaps, or research questions, that need to be answered including "What parameters should be measured?", "How often should samples be collected and for how long?", and "Where should samples be collected?".

6.2.1 What parameters should be measured, how frequently should samples be collected and for how long, and from where should samples be collected?

In light of recent work by Rabinowitz et al. (2015), who called for further study to examine the associations between public health and water exposure in areas associated with shale gas development, the project team believes that decision-makers should further investigate which parameters should be considered/measured, where samples should collected from, and how often they should be taken in the water quality monitoring strategy for assessing the impacts of hydraulic fracturing on the environment. Furthermore, our literature review highlighted of the contrasting results between studies by Jackson et al. (2013) and Siegel et al. (2015). Thus the project team recognizes that there is an on-going need to further enhance and refine our understanding of water quality in plays associated with unconventional gas development. That said water quality monitoring program should characterize: the ambient water quality surrounding natural gas exploration activity, the chemicals and additives used in hydraulic fracturing, flowback fluids, as well as the water quality after hydraulic fracturing activities occur.

The following approaches should be considered to begin the development of the water quality monitoring program.
Extensive literature reviews to:

- 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?). The landfill industry has well established guidelines that govern the permitting and operation of landfills that should be reviewed.
- Identify potential contaminants
- Understand the chemical composition and fate of potential contaminants,
- Identify 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)
- Develop sampling protocols that include sampling location, sampling frequency, and duration (e.g. where should samples be collected from, how often should they be collected, and for how long?) for baseline data and ambient water quality after hydraulic fracturing activity has ceased.
- Define a geographical area of interest (e.g. radius of 1 km, 5 km, or more?)

This information could be gathered to develop a preliminary water quality monitoring program that could be tested during pilot-trials in multiple locations. In order to conduct pilot trials, regulators and decision makers would need more information on future hydraulic fracturing activity well in advance of actual exploration in order to capture a baseline water quality data set that is large enough and that considers chemical parameters specific to hydraulic fracturing.

7.0 Community Engagement and Public Perception

As hydraulic fracturing is generally a controversial topic to the public, it is important to understand how the process impacts the public in all dimensions - environmentally, socially, culturally, and economically, in order to move forward in policymaking and regulation.

It is equally important to understand public perception, including First Nations, in terms risks and barriers to engagement related to hydraulic fracturing. Canada's First Nations, Metis, and Inuit (FNMI) peoples have differences in cultural values that vary from community to community; however, one aspect that resonates across all groups is the connection they have to nature and their care for water.

7.1 Summary of Key Research Questions for Decision-Makers Related to Community Engagement and Public Perception

Much of the public concern around hydraulic fracturing is related to the potential environmental impacts of hydraulic fracturing and the subsequent impacts that these could have on human health. Generally, the main concerns are the possibility of groundwater contamination, and regarding water use and the threat on public water supplies. At a local level (e.g. regional, municipal, county) water supply and management plans must deal with a new and sometimes significant demand on their water supplies.

Public concerns with hydraulic fracturing are further compounded by a lack of scientific consensus on the impacts, creating an environment where stakeholders feel they do not have reliable evidence to assess potential impacts of hydraulic fracturing. Furthermore, non-industry stakeholders often do not feel they are being heard, or have an equal voice in the decision-making process. This results in a lack of trust and legitimacy, where stakeholders do not hear that they are being heard.

Therefore, the project team has identified the following research gap:

- There is need to further understand how the industry engages with the public and how the public perceives this process.

There has also been concern related to the potential impacts of hydraulic fracturing on culture, especially in First Nations communities. First Nations perspectives on resource development are impacted not just by science but also by cultural and traditional values. For example, to First Nation communities, water is regarded as sacred as a giver and sustainer of life and is very important to their cultural traditions. In many First Nations, there is a strong desire to ensure that water-related matters are not made worse. Additionally, First Nation communities typically consider impacts on a long-term scale. For instance, they consider the benefits a proposed project would have as well as the risks not just at the present time but also over many generations. Considering the information presented in literature and through experiences gained during the cultural sensitivity workshop in Elsipogtog, First Nation, the project team has identified the following research gap:

- There is a lack of understanding on how First Nations' traditional and cultural values influence the community engagement process.

Unconventional shale gas development often occurs in small, rural areas, including First Nations communities that often have limited infrastructure capacity. The Not In My Backyard (NIMBY) opposition is a common phenomenon where the proximity with respect to resource development projects (e.g. wind farms, radioactive waste management facilities) is associated with strong opposition. However, researchers have suggested that NIMBY is an inaccurate portrayal of the public reactions to proposals for development projects (Devine-Wright, 2005; Jacquet, 2012; Cotton, 2013).

- There is need to understand how the remoteness of a community influences their opinion on hydraulic fracturing.

The media plays an important role in how the public perceptions on hydraulic fracturing are formed. The newspaper coverage on hydraulic fracturing is often negative and focused on issues such a water quality. Social media often serves as a platform for the public to express opinions on contentious issues. With the recent growth and popularity of social media platforms such as Facebook and Twitter, many more people identify as affected stakeholders to oil and gas development. These platforms allow the public to get involved, share their concerns, and voice their opinions on topics like hydraulic fracturing.

Researchers have shown that the potential for support on the Internet is greater compared to conventional media channels due to its speed of information flow and accessibility (Kimsky, 2007). Researchers have also evaluated whether hydraulic fracturing support or opposition differs, depending on media use, but researchers have not looked at specifically using social media (e.g. Twitter, Facebook) to assess community opinion on hydraulic fracturing. Due to the general lack of empirical data on the impact of media on the perceptions of hydraulic fracturing, further evaluation is recommended. Considering this information, the project team has identified the following research gap:

- There is need for an evaluation of the potential for social media to assess community opinion, or social license to operate on hydraulic fracturing.

7.2 Identified Research Approaches

Considering that the risks and potential impacts of hydraulic fracturing vary regionally, it is important to engage with the public at regional and local levels. Focused outreach programs will lead to an improved understanding and assessments of the public perception and the potential social risks surrounding hydraulic fracturing. In Canada, increasing controversy and pushback on hydraulic fracturing indicates there is a need for a better understanding on how to effectively communicate with and engage the public.

As a result, a key research question decision makers need to identify is “What constitutes appropriate community, including First Nations, engagement and dialogue around the subject of hydraulic fracturing?” Four priority knowledge gaps were identified in order to further evaluate this key research question: “What are the best practices for community engagement?", "How do First Nations' traditional and cultural values influence community engagement?", "How does the remoteness of a community influence their opinion of hydraulic fracturing?", and "How can media (conventional and social) be used to assess community opinion on hydraulic fracturing?".

7.2.1 What are the best practices for community engagement?

Public engagement is necessary to inform local residents of development activity, to gather their input and to allow them to reflect their concerns and earn their trust. Understanding how to better engage communities on the topic of hydraulic fracturing will be important for decision-makers and industry operators in order to achieve a social license to operate.

To further understand the question "What are the best practices for community engagement?", the project team suggests the following approaches:

- A literature review of community engagement methods and a review of various situations (case studies) where community engagement has been both effective and ineffective in small communities and within First Nations.
- Surveys and interviews with experts on community engagement, and in regions or communities, including First Nations, to determine which community engagement practices are preferable in the eyes of community members.

In order to assess this gap, there is a need for further engagement with the Canadian public. There is value in assessing public opinion of hydraulic fracturing through a survey. However, there is also a need to engage on a deeper level with the public in order to understand not only how people feel about hydraulic fracturing, but to understand where their views come from and how they are formed. In order to have this deeper level of engagement interviews with the public would be an important source of information. Considering that the risks and potential impacts of hydraulic fracturing vary regionally, it is important to engage with the public regionally as well in order to accurately assess the public perception and the potential social risks that hydraulic fracturing may have on an area. As there is value to both survey and field based work, a combination of these two methods is recommended in order to accurately assess both public perception of hydraulic fracturing as well as understanding how people form their perceptions.

A recent study entitled "Identifying Health Concerns relating to oil and gas development in northeastern BC – human health risk assessment Phase 1 report" was performed by the Fraser Basin Council for the British Columbia Ministry of Health. This study was developed in response to a number of concerns related to oil and gas development, as raised by the public, First Nations, government and non-government organizations. The study outlined community engagement processes that involve First Nation and other small communities with residents who live and work in areas where oil and gas development is taking place. For example, engagement practices (e.g. meetings, in-person conversations, media releases, website, advertisements in local media outlets, email broadcasts, and print copy distribution to rural areas) and consultation methods (one-on-one interviews, group meetings, on-line feedback submissions, toll-free call-in numbers, and email) were all used to effectively engage stakeholders on the topic of hydraulic fracturing.

In the UK Onshore Shale Gas Well Guidelines, (United Kingdom Onshore Oil and Gas, 2015), recommends that operators engage with local communities, residents, and stakeholders at the beginning, before any operations or application for planning permission occurs. Furthermore, operators should listen to concerns and respond promptly, in addition to allowing for sufficient time for comments on plans, operations, and performance (UKOOG, 2015b). An emphasis should be placed on recognizing relations with the community, and while having specific opportunities for consultation is important, operators should engage more broadly with the various stakeholders involved (UKOOG, 2015b).

7.2.2 How do First Nations' traditional and cultural values influence community engagement?

Greater community engagement is needed in order to maintain a social license to operate. The shale gas industry must show communities who are affected by hydraulic fracturing, that their values and concerns are important. If communities feel neglected or excluded, the public engagement process will be hindered. This is especially true with First Nations communities, who often feel that the consultation process regarding hydraulic fracturing is not adequate and does not address First Nations' concerns and values. This was highlighted through the project team's cultural meeting with Elsipogtog First Nation and its associated videography.

To evaluate how First Nations traditional and cultural values influence community engagement, the project team suggests the following approaches:

- A review of literature on the various traditional and cultural values that are held by First Nations, and a review of media to evaluate how traditional values have influenced community engagement in the past. This will help decision-makers to further understand the aspects of First Nations culture that may not be considered in conventional public engagement methods.
- Perform surveys, interviews, and expert consultations within First Nations communities to determine the traditional values that are considered highly important to move forward in community engagement processes.

Although there is no “one size fits all” formula for engaging with First Nations communities, common characteristics that can be regarded as effective in forming long term relationships trust, respect, transparency, commitment, and goodwill. For instance, the government of British Columbia’s “Building relationships with First Nations – Respecting rights and doing good business” highlights several principles for building relationships that should be considered by decision-makers when consulting with First Nations. It notes that companies and decision-makers should be respectful, engage early, be open and transparent, act with honour, listen, and be willing to adapt (Government of British Columbia, n.d.). It is also crucial to understand the importance of lands to First Nations and to demonstrate respect for First Nation knowledge and uses of lands (Government of British Columbia, n.d.).

There is a need for decision-makers to determine ways to better engage with communities that are impacted by hydraulic fracturing, especially First Nations. Decision-makers should understand how First Nations values influence engagement in First Nations communities and should incorporate them into future engagements and decision-making.

7.2.3 How does the remoteness of a community influence their opinion of hydraulic fracturing?

The project team also believes that there is benefit in understanding “how the remoteness of a community influence their opinion on hydraulic fracturing?”. The approaches suggested to address this knowledge gap are:

- Perform literature and media reviews to understand how remoteness of a community, or proximity to resource development, has impacted public opinion in the past.
- Conduct surveys and interviews in the remote communities to understand at first-hand how remote communities perceive hydraulic fracturing.

7.2.4 How can social media be used to assess community opinion on hydraulic fracturing?

Media coverage can have an impact on perception of risk and the acceptance of new technologies. However, the idea of evaluating community opinion on hydraulic fracturing using social media has not directly been assessed in literature. The project team believes that there is benefit in understanding if media can be used to assess public opinions on hydraulic fracturing. To further evaluate the question "How can social media be used to assess community opinion on hydraulic fracturing?", the following approaches have been suggested:

- Data mining to determine whether the data generated on social media can be transformed and used to assess a community's social license to operate.

8.0 Conclusions

The overall objective of this project was to integrate leading international research into a Water Safety Framework for hydraulic fracturing to address knowledge gaps within watershed and water use governance and demand management approaches. To address this objective, our team utilized the water safety plan approach, which consists of the following four components that parallel the objectives of this project:

- Collecting the array of information
- Analyzing and understanding the risks that are present that can threaten the safety of water users
- Identifying and assessing the necessary tasks that need to be employed in order to mitigate or reduce the risks to acceptable levels
- Determine strategies to prioritize and audit the tasks that have been identified

The project team took a risk-analytic based approach, similar to that of a water safety plan, to indicate the importance of various issues influencing the development potential of unconventional shale gas in Canada with respect to watershed governance. The benefit of the water safety framework for this type of issue is that the key gaps, or risks, always evolve based on existing data and conditions. In essence, the framework evolves to be a living document as processes and outcomes become informed. Thus, it would be anticipated that as these research gaps and questions are answered, a re-evaluation would provide a range of new or evolving gaps/risks to be managed.

Six themes were developed based on the "catchment to consumer" model for watershed governance issues surrounding hydraulic fracturing as mirrored in the water safety plan approach. The themes identified were water use and demand, impacts to water quality, wastewater treatment and management, community consent, water conflict and negotiation strategies/barriers to engagement and governance approaches to watersheds. Technical reports based on activities such as literature reviews, a state of science workshop and a cultural sensitivity workshop, were prepared by the project team and its students to identify and analyze key knowledge gaps for decision-makers in each of the theme areas. These reports served as a basis for this final report.
As a result of the technical review and technical approach, the key questions for decision-makers associated with key knowledge gaps were identified. The knowledge gaps were transformed into research questions to guide future knowledge development as shown below. For each research question, the strengths and weaknesses of possible research approaches were discussed by the project team and presented in this report.

- **Can water budgets for hydraulic fracturing be managed?**
    - Can water demand for hydraulic fracturing be predicted?

    - Can water supply be predicted (i.e. how much water will be available over time in a particular region)?

- **Does hydraulic fracturing wastewater management require a unique regulatory framework?**
    - In the absence of disposal wells, what should be the design, monitoring, and management requirements of waste storage facilities?
    - What should be the design and operating/performance requirements for HF wastewater treatment with intent to discharge to the environment?
    - How can HF wastewater reuse be promoted?

- **What is the appropriate monitoring strategy to assess impacts on the environment—including drinking water resources?**
    - What parameters should be measured?
    - How frequently should samples be collected, and for how long?
    - From where should samples be collected?

- **What constitutes appropriate community, including First Nations, engagement and dialogue around the subject of hydraulic fracturing?**
    - What are the best practices for community engagement?
    - How do First Nation's traditional and cultural values influence community engagement?
    - How does the remoteness of a community influence their opinion on hydraulic fracturing?
    - How can social media be used to assess community opinion on hydraulic fracturing?

By addressing these areas it is anticipated that a risk-based, or water safety approach could be further enabled. Outside of Canada, the project team has identified how new regulatory frameworks from USEPA (2015) and from United Kingdom (UKOOG, 2015) are incorporating risk frameworks into regulatory structures.

Within a Canadian context, a risk-based approach will likely reflect provincial and territorial regulatory principles. The knowledge gaps identified in this report along with the specific regulatory principles will enable specific regional water safety frameworks to support unconventional gas development.

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