This is an accepted manuscript version of the article "Ensuring health and environmental protection in hydraulic fracturing: A focus on British Columbia and Alberta, Canada" published in The Extractive Industries and Society, Volume 5, Issue 4, November 2018, Pages 581-595. DOI: 10.1016/j.exis.2018.07.006

Title

Ensuring health and environmental protection in hydraulic fracturing: a focus on British Columbia and Alberta, Canada

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Funding

This research was supported by the Natural Sciences and Engineering Research Council of Canada (NSERC) [strategic project grant 447474]. RG also acknowledges research funding from an Early Researcher Award (Ontario Ministry of Innovation) and a Discovery Grant from NSERC.

Declaration of interest

MD has served as an unpaid consultant on technical issues related to hydraulic fracturing to Terralog Technologies (http://www.terralog.com/). DK is the NSERC Industrial Research Chair in Risk Science at the University of Ottawa (http://www.nserc-crsng.gc.ca/Chairholders-TitulairesDeChaire/Index_eng.asp).

Abstract

Unconventional natural gas resources recovered using hydraulic fracturing (HF) is contributing to national energy self-sufficiency and could be a significant factor in the global transition to a low carbon economy. Using an integrated risk management framework, we conduct a comparative analysis of practices and review recommendations of a regulatory, economic, advisory, community-based, or technological nature for British Columbia and Alberta, Canada. Lessons learned from international assessments of risk issues are also considered. Overall, there is much less emphasis on potential impacts on human health than on the environment. The analysis also identifies a need for a strong and adequately resourced regulatory framework that works in concert with enhanced technological requirements; evidence-based emissions standards; regulated and/or community-based setbacks and buffer zones; operational surveillance, reporting, and disclosure of value-chain activities in an accessible and transparent way; community participation in the development of these mechanisms; and provision for legacy sites. Economic options such as performance-based taxes and fees, industry-funded studies, the role of carbon taxes, and cost allocations to protect or improve determinants of health are the

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least advanced option. This analysis provides support for the development of a risk management policy agenda with respect to broad and persistent HF risk management issues.

Key words
Hydraulic fracturing, human health, environment, technological risk, risk management, Canada

1. Introduction

Fossil energy production remains an important component of overall economic development in Canada with respect to both domestic and export markets (Natural Resources Canada, 2016). Oil, natural gas liquids (NGLs), and natural gas are co-produced from unconventional tight reservoir formations classified as shales, mudstones, and tight sands. Natural gas, including that derived from unconventional gas development (UGD), is often viewed positively as a transition fuel to a low carbon global economy because it contains lower carbon dioxide (CO_2) concentrations than oil or coal.[2]

While eight Canadian provinces and territories produce natural gas (Council of Canadian Academies, 2014, Rivard et al., 2014), hydraulic fracturing (HF) in UGD is the fastest growing method of underground resource extraction, particularly in western Canada. Internationally, the United States is the largest producer, with China ranking third - just behind Canada - in commercial extraction. Countries in South America and Europe, as well as Australia and Russia, are exploring UGD (Orcutt, 2015, US Energy Information Administration, 2015).

HF activities in UGD, that also apply to unconventional oil development, include construction and drilling at well pads; high pressure injection of a mix of fluids, chemicals, and proppants (often sand) in a series of parallel horizontal wells to enhance the permeability of the target formation; and flowback of the petroleum resources and water. Production requirements include land development and infrastructure to gain access to suitable sites and for delivery of water, chemicals, proppants, and energy. Wastes include flowback wastewater, air emissions including greenhouse gases (GHGs), and solid waste generated at development sites (Council of Canadian Academies, 2014).

UGD using HF is approved under oil and gas policy and regulatory contexts, including legislation, regulations, and directives that vary among Canadian provinces. Provisions could reflect energy strategies focused on historic or emerging assets, such as hydro development and HF (in Quebec), coal and legislated renewable energy targets (in Nova Scotia), nuclear and renewables (in Ontario), and oil and gas (in British Columbia, Alberta, and Saskatchewan). In jurisdictions with less experience in oil and gas development, or where activities may occur in more densely populated regions, outstanding questions and public concern towards the impacts of HF compared with the potential economic benefits have been important drivers in opposition to HF activities.

Local environmental and human health hazards associated with HF have been identified for both the short and long term (Broomfield, 2012, Council of Canadian Academies, 2014, Coussens and

[2] Currently, producers target development that yields the most oil and NGLs since the price of these is currently higher than that of gas.

Martinez, 2014, Ewen et al., 2012, Jackson et al., 2014, Krupnick et al., 2013, Maryland Institute for Applied Environmental Health, 2014, New York State Department of Health, 2014, Rabinowitz et al., 2015, Shonkoff et al., 2014, Small et al., 2014, United Kingdom Environment Agency, 2013, Werner et al., 2015). Potential direct and indirect effects include: reduced surface and groundwater quality and quantity; reduced ambient air quality; induced seismicity; waste generation; habitat destruction and fragmentation; wildlife morbidity and mortality; the introduction of invasive species; altered land use patterns and increased development, including increased road/truck traffic, noise, and visual pollution; boom and bust local economic cycles and pressures on infrastructure; occupational health and safety; general impacts on mental health and wellbeing in local communities; and overall cumulative environmental unsustainability. Fugitive methane emissions from UGD, a potent GHG, has also been identified as contributing to climate change, and may thus have further wide-ranging implications for the environment and human health at the global scale. Pipeline activity, an important component of the distribution of natural gas recovered using HF, may also cause significant residual adverse effects in western Canada for caribou, caribou habitat and grizzly bear (Vypovska and Johnson, 2016). From a population health perspective, diverse potential direct and indirect impacts of HF activities on upstream social, economic and environmental circumstances and factors could therefore influence health and wellbeing.

The Government of Nova Scotia suspended unconventional shale gas test well activities in 2007 pending completion of the *Report of the Independent Review Panel on Hydraulic Fracturing* (Wheeler et al., 2014). The Panel concluded that none of the potential negative impacts of the identified hazards could be defined as catastrophic, but that outstanding questions about the potential risks of HF require further research to better understand possible effects of HF on populations and ecosystems. In November 2014, the Nova Scotia legislature "extended a moratorium on 'high-volume hydraulic fracturing' in shale formations until the government can develop regulations and an onshore atlas of available natural gas resources" (The Chronicle Herald, 2014). The law includes an exemption that allows HF for the purpose of research and testing. In Quebec, a 5-year UGD moratorium was lifted in 2016, but the associated regulatory framework is under development (Quebec, 2016).

On the other hand, British Columbia (BC) and Alberta energy policy or plans describe UGD as integral to energy development and/or a way to reach the goal for sustained economic prosperity (Alberta Government, 2009, British Columbia Ministry of Energy and Mines, 2012, Government of British Columbia, 2007, Government of British Columbia, 2013). Indeed, the vast majority of HF activity in Canada is located in the Western Canadian Sedimentary Basin that spans these provinces.

In this paper, we examine the current HF policy and regulatory contexts with respect to environmental and human health protection in two active UGD jurisdictions: BC and Alberta, Canada. Similarities and differences are discussed with reference to risk management guidance proposed in Canadian and international investigations, with risk management options categorized as regulatory, economic, advisory, community-based and technological (REACT) that we have discussed previously (Krewski et al., 2007, Krewski et al., 2014). The federal government context for HF is first presented as a backdrop to our discussion of BC and Alberta.

1.1 Canadian federal government role in HF

Although the Canadian federal government has a limited role in the risk management of HF activities, it is involved in this issue in a number of ways.

Canada is a signatory to the Paris Agreement, a global initiative to limit average global warming to 2°C through 2100, with an aspirational goal of 1.5°C (United Framework Convention on Climate Change [UNFCCC], 2015). In conjunction with most provinces, including BC and Alberta, the federal government is implementing a Pan-Canadian Framework on Clean Growth and Climate Change (PCF) (Governments of Canada, 2016). The intended nationally determined contribution (INDC) to GHG reductions is 30% below 2005 levels by 2030 (Government of Canada, 2016a). This is relevant to HF because GHGs from well completions, particularly methane emissions, are not currently included in the UNFCCC annual GHG Inventory Report for large facilities (e.g., stationary combustion sources of upstream oil and gas production) as they do not meet the reporting threshold for emissions or size of facility (Environment Canada, 2016). However, a developing federal regulation for upstream oil and gas facilities is intended to limit methane emissions by 40-45% over 2012 levels by 2025 (Government of Canada, 2016b).

Health Canada and Environment Canada administer the *Canadian Environmental Protection Act, 1999* [CEPA] (Government of Canada, 1999), legislation that enables assessment and management of potential risks associated with environmental pollutants and substances found to meet the definition of toxic under the *Act*, including those related to HF activities. While some substances used in the HF industry have been deemed toxic (such as benzene and naphthalene), exploration and drilling using HF is currently exempt from reporting under the National Pollutant Release Inventory (NPRI) (Government of Canada, 2014); moreover, other substances injected underground have not yet been assessed (Boothe, 2011).

Federal authority for environmental assessment of HF projects is delineated in the *Canadian Environmental Assessment Act*[3] (CEAA). This is limited to jurisdiction for federal lands, the North, where interprovincial matters exist within the federation, and where effects cross international boundaries (Canadian Environmental Assessment Agency, 2016). For example, HF activities could require federal intervention if they occur in a wildlife area or migratory bird sanctuary, or if they could affect Aboriginal peoples or fish and fish habitat. Provincial environmental assessment legislation may be substituted for the CEAA. The National Energy Board[4] (NEB) is responsible for CEAA on federal lands and offshore areas not covered by federal/provincial management agreements, and for interprovincial and international oil and gas pipelines and additions to existing federally regulated pipelines (Government of Canada, 2012). The NEB's risk management system, especially for risks caused by accidents and errors, includes *Filing Requirements for Onshore Drilling Operations Involving Hydraulic Fracturing* (National Energy Board, 2013). A safety plan, risk assessment and risk management plan, environmental protection plan, waste management plan, and spill contingency plan are required. The NEB also developed *Procedures for the Public Disclosure of Hydraulic Fracturing Fluid Composition Information* (National Energy Board, 2016). Operators regulated under the *Canada*

[3] A recently proposed Canada *Impact Assessment Act* and associated regulations are currently under public consultation.

[4] Replacement of the National Energy Board by the proposed Canadian Energy Regulator is currently under public consultation.

Oil and Gas Operations Act are requested to submit information on HF fluid composition 30 days after the HF operation has ceased. This information is posted for disclosure on the FracFocus.ca website.

In addition to this policy and regulatory context, Environment Canada commissioned the Council of Canadian Academies (CCA) to assess the state of knowledge of potential environmental impacts from the exploration, extraction, and development of Canada's shale gas resources, as well as the state of knowledge of mitigation options for environmental impacts (Council of Canadian Academies, 2014). The overarching CCA recommendation was a "Go Slow" approach. Ongoing federal research is evaluating exploration or production techniques that may prevent or minimize the risks of contamination, emissions, land impacts, and induced seismicity associated with shale and tight resource development (Natural Resources Canada, 2016).

2. BC and Alberta's broad policy contexts

Energy exploration and extraction is primarily a provincial responsibility, where governments sell exploration and production sub-surface tenure rights to industry which then produces and markets the oil or gas in exchange for royalty payments. Shale gas resources may be extracted from under Crown land, private property, or First Nations communities. In the latter case, where title has been established, a 2014 Supreme Court of Canada ruling requires project consent of the First Nation(s) or, failing that, that the government demonstrate that the development is pressing and substantial, and that the fiduciary duty to consult with the Aboriginal group has been met (Supreme Court of Canada, 2014). Provincially delegated municipal government jurisdiction may apply policies and by-laws for private property, but this is generally limited to roads, municipal infrastructure, and noise.

In BC, approximately 90% of oil and gas resources are owned by the Province. Over 85% of drilled wells targeted UGD in 2012/13 (BC Oil and Gas Commission, 2013b), particularly in the Montney (40%), Horn River Basin (10%), Liard Basin, and Cordova Embayment. In Alberta, HF production is at an earlier stage, with approximately fifteen identified prospective shale gas formations (Rokosh et al., 2012), with most activity occurring in the Duvernay Region.

Environmental and human health protection associated with HF is generally administered by the provincial Ministry of Environment. This section details the goals of broad policy frameworks in each province related to land, water, air, biodiversity, and consultation, with a comparison provided in tabular format (Table 1). The provincial regulatory frameworks are discussed in section 3.

Both BC and Alberta are implementing integrated resource management decision making frameworks. In BC, the *Natural Resource Sector (NRS) Transformation and Integrated Decision Making Initiative* includes six provincial ministries and several agencies: Aboriginal Relations and Reconciliation; Agriculture; Energy and Mines; Environment, including the Environmental Assessment Office; Forests, Lands and Natural Resource Operations; Natural Gas Development, the BC Oil and Gas Commission, and others. Coordinated action aims to manage the land base through land and resource planning, resource objectives, integrated resource monitoring, policy for mitigating impacts on environmental values, and climate change adaptation. In Alberta, the *Integrated Resource Management System* (IRMS) is "based on cumulative effects management

of energy, mineral, forest, agriculture, land, air, water and biodiversity resources" (Alberta Government, 2015, p. 1). The Policy Management Office (PMO) was established as an interface between natural resource policy development and policy assurance. Priorities include independent environmental monitoring through the Alberta Environmental Monitoring, Evaluation and Reporting Agency (AEMERA); non-energy regulation under the Land-use Framework; energy policy; integrated regulatory systems through the Alberta Energy Regulator (AER); and strong relationships with partners and stakeholders, including First Nations (Alberta Government, 2015).

Table 1: British Columbia and Alberta provincial or regional policy context for human health and environmental protection in unconventional shale gas development (General Crown Land policies are excluded).

UGD issue areas	British Columbia	Alberta
Cross government resource management	Natural Resource Sector Transformation and Integrated Decision Making Ministries and Agencies: • Aboriginal Relations & Reconciliation, Agriculture, Energy and Mines, Environment, Environmental Assessment Office, Forests, Lands and Natural Resource Operations, Natural Gas Development, Oil and Gas Commission	Integrated Resource Management System Based on cumulative effects management • Single Alberta Energy Regulator • Land-use Framework Regional Plans • Energy policy • Independent monitoring • Relationships with partners and stakeholders, including First Nations
Water	*Water Sustainability Act* Living Water Smart Northeast Water Strategy	Water for Life Strategy and Action Plan Watershed Planning and Advisory Councils Targeted issues: • Water Used for Oilfield Injection Purposes • Expanded Groundwater Observation Well Network • FracFocus Chemical Disclosure Registry
Air	Canadian Council Ministers of Environment - Air Quality Management System Ministry of Environment • Air Zone Management	Ministry of Environment • Clean Air Strategy and Action Plan
Integrated land management	Municipal government - Integrated Sustainable Community Plan Ministry of Forests, Lands and Natural Resources • Cumulative Effects Framework • Land-use Reports, Land and Resource Management Plans, State of Play Reports	*Alberta Land Stewardship Act* • Land-use Framework - 7 land-use regional planning districts • Cumulative Effects Management - air, water, land, and biodiversity
Biodiversity	Conservation Framework Boreal Caribou Management Plan	Draft Biodiversity Policy Caribou Range Plan
Consultation	"New Relationship" with Aboriginal Peoples BC Oil and Gas Commission consultation framework	Alberta Energy Regulator Participant Involvement Initiative

BC's environment and sustainable development policy context for Crown land and resources includes three components: an overarching cumulative effects framework (CEF) (Government of British Columbia, 2014a), a Land Use Operational Policy for Oil and Gas (applied to surface tenures approved by the Ministry of Agriculture and Lands) (British Columbia Ministry of Agriculture and Lands, 2005), and Area-based Analysis initiated by the BC Oil and Gas Commission (BCOGC) (BC Oil and Gas Commission, 2013a, BC Oil and Gas Commission, 2015) (section 3). The CEF includes policies, procedures and decision-support tools to guide risk assessment and management of values such as forest ecosystem biodiversity, riparian ecosystems, water quantity and quality, air quality, priority fish and wildlife species, visual quality, cultural heritage resources, resource capability, and economic and social wellbeing.

Alberta's sustainability-related objectives for environmental, economic, and social outcomes of land use are enacted through the authority of the *Alberta Land Stewardship Act* (Alberta Environment and Parks, 2011). Seven regional land use plans are being developed under the associated Land Use Framework (LUF) (Alberta Environment and Parks, 2016). These plans are meant to guide land-use decisions to reflect local objectives, conditions, and priorities within the wide-ranging provincial policy context. Broadly, desired outcomes include a healthy economy supported by land and natural resources; a healthy ecosystem and environment; and people-friendly communities with ample recreational and cultural opportunities. The LUF districts attempt to match the province's major watersheds, with adjustment to municipal boundaries.

LUF planning considers conservation areas, air quality, surface water quality, groundwater, recreation and tourism, and monitoring and reporting. The LUF process identifies indicators and how they are to be assessed where region-specific or issue-specific strategies and policies can be developed. When approved, municipalities and provincial ministries and agencies are required to comply with the LUF in decision-making. With respect to energy, Alberta's LUF outcomes are meant to promote responsible development, including a smaller environmental footprint based on limits or thresholds that guide development decisions.

Living Water Smart is BC's overall plan for sustainable water stewardship (Government of British Columbia, 2017b). NRS action includes implementation of the *Northeast Water Strategy* (Government of British Columbia, 2015), which seeks to enhance information requirements within a coordinated process in support of decision-making; strengthen monitoring and reporting; and establish a water stewardship ethic that helps to ensure water demands can continue to be met (Government of British Columbia, 2016, Holding et al., 2015). This also supports a priority on transparency (Government of British Columbia, 2016). Actions and targets with implications for HF include a strengthened regulatory regime through the *Water Sustainability Act* and regulations (Government of British Columbia, 2014b), particularly with respect to groundwater management and withdrawals, which were previously unregulated.

In Alberta, the *Water for Life* strategy (Alberta Government, 2008) was renewed in 2014, including an action plan for HF targeted issues (Alberta Government, 2014a): water conservation through an update of the Oilfield Injection policy to conserve the allocation of fresh water for hydraulic fracturing operations; groundwater quality and quantity monitoring and knowledge through additional wells within the Groundwater Observation Well Network; and access to

information and transparency on fracturing operations including fracturing fluid composition and water quantity.

With respect to clean air, all provincial governments agreed to implement the Canadian Council of Ministers of the Environment *Air Quality Management System* in 2014 in order to provide a comprehensive approach for improving air quality in Canada (Canadian Council of Ministers of the Environment, 2017). Air zone management includes base-level industrial emission requirements for major industry, new ambient air quality standards, and actions to keep clean areas clean (BC Ministry of Environment, 2014). Specified actions with potential effects for HF will be implemented over a one to ten year timeframe, such as: coordination of regional air quality management of point and non-point emission sources; shared responsibility and partnerships, including integration; monitoring, evaluation and reporting; and enhanced knowledge in the private and public sectors, including updated regulations.

Regarding biodiversity, BC has a five-year plan to protect species and ecosystems at risk (British Columbia Ministry of Environment, 2014). Boreal Woodland Caribou recovery plans were also approved, with implications for the petroleum and natural gas sector (British Columbia Ministry of Environment, 2016). In designated areas, the government's environmental objectives for wildlife and habitat are now considered in the decision making process to issue a permit or develop conditions for associated activities. In Alberta, a draft policy for biodiversity protection is intended to support Alberta's LUF (Alberta Ministry of Environment and Parks, 2014), protection that could affect HF through energy sector planning and development. Proposed outcomes are "to conserve the diversity of Alberta's ecosystems, species, and genetics; to value the province's biodiversity and contribute to its conservation, stewardship, and sustainable use; and to use biological resources in a sustainable manner that reflects underlying ecological processes as well as population and ecosystem renewal capacities" (Alberta Ministry of Environment and Parks, 2014, p. 12).

Whereas HF is done primarily on Crown land, broad provincial policy implemented at the municipal level includes sustainable municipal development. Both provinces encourage *Integrated Community Sustainability Planning* (ICSP). Using a holistic, collaborative, and coordinated approach, municipal plans attempt to address social, cultural, environmental, and economic goals for the longer term. Goals in individual ICSPs may be a factor in future UGD.

The duty to consult with Indigenous Peoples rests with the Crown; however, this may be delegated to the HF proponent. BC and Alberta have published guidelines for these activities for different project scopes (Government of Alberta, 2014, Government of British Columbia, 2017a). For example, after the BCOGC conducts an initial environmental impact assessment of an application, if it determines that the project could potentially impact Indigenous communities the regulator sends the communities an information package that includes a description and maps of the proposed project. The communities then have 20 days to respond with a request to consult; engagement processes are then initiated. In BC, together with the applicable First Nation(s) and the BCOGC, the provincial government has also embarked on a "New Relationship with Aboriginal peoples" and is negotiating economic benefits agreements, long term oil and gas agreements, consultation process agreements, and strategic land-use planning agreements in some regions.

3. BC and Alberta's regulatory frameworks

The BCOGC and AER act as single window energy regulators for the review and approval of oil and gas project proposals. Key components of the regulatory frameworks for HF are included in Table 2.

In BC, environmental protection during oil and gas surface-based operations on Crown Land is regulated through the *Oil and Gas Activities Act* [OGAA] Environmental Protection and Management Regulation (EPMR) (Government of British Columbia, 2008, 2010). The associated Environmental Protection and Management Guideline explains the regulatory requirements associated with water-, riparian-, wildlife and wildlife habitat-, and old growth management area-values, for both industry and those potentially impacted by activities (BC Oil and Gas Commission, 2016a).

The BC HF regulatory framework includes area-based analysis (ABA), an evolving regional planning approach incorporated in project review and approval (BC Oil and Gas Commission, 2013a, 2015). ABA requires a baseline calculation of the surface area used to support oil and gas development and a standardized methodology for the measurement of surface area disturbances. This then begins to operationalize BC's CEF (section 2) for ecological, social, and cultural values for oil and gas sector activities. The goal is to achieve a "routine review" and maintain "standard operating conditions" in ecological assessment units (such as Water Management Basins or Natural Disturbance Units). Where generic objectives and management options surpass thresholds within an assessment unit, the area is assigned an ABA status of "Enhanced Management" or "Regulatory Policy" (BC Oil and Gas Commission, 2015). Further, if an environmental or cultural value is regulated by a single agency and/or affected by a single sector, then the likelihood of unintended cumulative effects is considered low and are then not considered in ABA (BC Oil and Gas Commission, 2013a).

ABA is expected to be completed for the full Western Canadian Sedimentary Basin and is intended to contribute to other plans published by the BCOGC: Land and Resource Management Plans (LRMPs), Sustainable Resource Management Plans, and the Muskwa-Kechika Management Area Plan. These Plans provide information on the surface area used by oil and gas activities, including wellsites, pipelines, roads, geophysical exploration programs, facilities, and associated activities (BC Oil and Gas Commission, 2013b). Moreover, regional strategic environmental assessment is being informed by and will inform the Northeast cumulative effects program, particularly to recommend responses that "optimize the practice of Treaty rights and the development of interests of the [First Nations] parties" with respect to effects of natural resource development (Austin and Pokorny, 2016, p. 15).

A proof of concept ABA was piloted in the Liard Unconventional Gas Basin, where a rationale, indicators, triggers, and nested values were developed for two ecological values, the riparian reserve zone and old forest, in 69 watersheds (BC Oil and Gas Commission, 2014a, BC Oil and Gas Commission, 2014b, BC Oil and Gas Commission, 2016b). ABA for high priority wildlife (such as the Boreal caribou), agricultural land, private land values, cultural heritage resources, ground water, water quality, and air quality are planned, but no timeline is provided (BC Oil and Gas Commission, 2016b).

Table 2: British Columbia and Alberta regulatory frameworks with a potential effect on human health and environmental protection in unconventional shale gas development (General environmental assessment and oil and gas extraction legislation are excluded).

UGD issue areas	**British Columbia**	**Alberta**
Decision Maker	BC Oil and Gas Commission (BCOGC)	Alberta Energy Regulator (AER)
Environmental Protection, Cumulative Effects Framework	*Oil and Gas Activities Act*, Environmental Protection and Management Regulation (EPMR) • Area-based Analysis (ABA) • Proof of concept - Liard Unconventional Gas Basin	*Responsible Energy Development Act* (REDA) • Risk-based regulation; Play-based performance • Play-based pilot project - Duvernay Region
Legacy sites	*Oil and Gas Commission Act* Orphan Site Reclamation Fund	*Oil and Gas Conservation Act* Orphan Fund Levy
Water	*Water Sustainability Act* Surface and groundwater resources	AER Directives including 083 Hydraulic Fracturing Subsurface Integrity
Air	EPMR - Drilling operations Flaring and Venting Reduction Guideline	AER Directive 060 • Upstream Petroleum Industry Flaring, Incinerating, and Venting
Waste	*Environmental Management Act* Oil and Gas Waste Regulation	AER Directives • Water, waste, wells, storage
Seismicity	*OGAA* Drilling and Production Regulation 4.0M suspension wellbore operations	*Oil and Gas Conservation Act* Fox Creek area within Duvernay Zone subject to Subsurface Order No. 2 (2015) – Seismic Monitoring
Non-Crown land	*Local Government Act* Integrated Sustainable Community Plan Community Charter	*Municipal Government Act* Integrated Sustainable Community Plan AER Directives • Infrastructure and Municipal Development - well abandonment, noise control

Communication and Outreach	• *OGAA* Consultation and Notification Regulation • Aspects of ABA, CEF, Integrated Decision Making processes • Economic, consultation, and planning agreements with First Nations	• AER Public Notice of Development • Play-based performance pilot - Stakeholder engagement • Regulatory approvals framework
Transparency	*OGAA* General Regulation	FracFocus public registry
Special Reports	2012-2015 Northeast BC Human Health Risk Assessment 2012 Horn River Seismicity 2014 Montney Trend Seismicity	

In Alberta, a play-based regulation (PBR) pilot project was completed under the *Responsible Energy Development Act* (Province of Alberta, 2012) to test UGD application, review, and approval processes on a landscape level (Alberta Energy Regulator, 2014, Alberta Energy Regulator, 2016a). PBR was initiated because of the potential size of shale gas plays, covering large continuous areas thousands to tens of thousands of square kilometres (Energy Resources Conservation Board, 2011). The play represents a three-dimensional unit, which may require variable regulatory responses depending on the specific risk profile defined by geology, geographic area and corresponding land use, technology, fluids produced, and other reservoir properties. The AER also practices risk-informed decision-making, with risk management options for compliance and enforcement proportional to the risk posed by the energy development.

In the Duvernay Region, a 2015 pilot tested a single application process under multiple Acts, regulations, rules, and directives applied to environmental and human health risk issues (Alberta Energy Regulator, 2016b) (i.e., the *Oil and Gas Conservation Act*, *Pipeline Act*, *Public Lands Act*, *Water Act*, and *Environmental Protection and Enhancement Act*). Applicants could apply for "multiple project activities over multiple years … as well as flexibility in the timing of construction and the specific location of an activity" (Alberta Energy Regulator, 2014, Hill, 2015, pp. 1-2). Objectives and performance measures were identified for five issue categories (Alberta Energy Regulator, 2014): water management, surface impacts/infrastructure, reservoir management, life-cycle wellbore integrity, and stakeholder engagement. Pilot applications were to identify and analyze hazards, evaluate risks, and provide preventive and mitigation measures in order to achieve the pilot objectives and other Government of Alberta outcomes (Alberta Energy Regulator, 2014, p. 16). Elements of the single play-based application included project information, and plans for stakeholder engagement, comprehensive risk management, and reporting. The evaluation of the pilot found that progress was made toward reducing the cumulative effects of surface disturbances and water management but that greater operator collaboration is necessary to support and enable PBR (Alberta Energy Regulator, 2016a).

BC and Alberta have additional regulatory requirements with respect to air, water, waste, infrastructure and municipal development, Crown lands, ecological conservation, public safety, access to information, and monitoring. BC's EPMR, for example, applies to air quality discharges of drilling operations (with air quality also included in ABA in 2015) and AER Directive 060, *Upstream Petroleum Industry Flaring, Incinerating, and Venting*, requires an air quality plan.

BCs *Water Sustainability Act* (Government of British Columbia, 2014b) applies to both surface and groundwater resources during sequential shale gas phases of development: site identification and preparation; well design, drilling, casing, cementing; fracturing; well completion; production; and well abandonment. The BCOGC's water allocation policy aims to limit withdrawals to 15% of the average surface flow in each river for all permits and licences, a trigger that is consistent with the BC Ministry of Environment's environmental flow policy to maintain 85% natural flow. Groundwater use greater than 75 L/s requires an assessment under the *Environmental Assessment Act*, however there is no distinction between saline or non-saline water resources. In Alberta, the aforementioned broad policy *Water for Life* action plan includes a goal to develop a new regulatory framework for HF that aligns with the provincial water

management approach and desired outcomes (Alberta Government, 2014a). Currently, four AER directives attempt to protect drinking water, including a specific Directive 083, *Hydraulic Fracturing – Subsurface Integrity*, focused on well development and the protection of water resources (Alberta Energy Regulator, 2013).

With respect to waste, BC's *Environmental Management Act* Oil and Gas Waste Regulation (Government of British Columbia, 2003b, 2005) addresses potential contamination from HF development: spilled fuel oil; drill cuttings or drilling mud; leaked gas or fracturing fluid; and blowouts. In Alberta, the AER regulates the management of oilfield wastes at the site, in transportation, treatment, and disposal.

BC's regulatory provisions for communications and outreach include the *OGAA* Consultation and Notification Regulation as well as aspects of the ABA, CEF, and Integrated Decision Making processes. Engagement with stakeholders is to occur prior to the approval of any petroleum and natural gas rights (sub-surface tenure). Consultation and notification requirements vary for processing plant, facilities of different sizes, wells, pipeline, road, or geophysical activities (BC Oil & Gas Commission, 2017a, 2017b), with provisions for a complaint process. Furthermore, the BC *Natural Gas Strategy* (British Columbia Ministry of Energy and Mines, 2012) identified consultations with First Nations as an important component of land and resource decision making. Economic, consultation, and planning agreements are being negotiated. In Alberta, communications and outreach were one of five requirements within the PBR pilot.

Regarding infrastructure, BC *OGAA* Drilling and Production Regulation applies to well permits, spacing, operations, abandonment, data collection, safety, pollution prevention, and production operations. Since 2014, BCOGC Well Permit conditions regulate induced seismicity, including reporting and requirements to cease operations. The Oil and Gas Road Regulation is under re-development as the *Natural Resource Road Act.* Where UGD may occur on non-Crown land, the BC Ministry of Community and Rural Development may create a Community Charter (Government of British Columbia, 2003a) under the *Local Government Act* (Government of British Columbia, 1996). These Charters could affect HF with respect to their goals for municipal services, health and safety protection, and protection and enhancement of wellbeing. Additional matters described in a Charter may complement other areas of provincial jurisdiction, such as public health, protection of the natural environment, animals, buildings and other structures. In Alberta, the PBR pilot included objectives for surface impacts and infrastructure, but did not include measures or indicators for other community impacts. Applicants were expected to develop performance measures and reporting for air quality, odours, noise, dust, and traffic (Alberta Energy Regulator, 2014) but consideration of these issues by applicants was not part of the pilot evaluation (Alberta Energy Regulator, 2016a).

A working group of Canada's New West Partnership (including BC, Alberta, and Saskatchewan) (2016) focused on shared best practices related to water use in the interests of ensuring public access to information and transparency in HF. Mandatory disclosure of hydraulic fracturing fluids, including additives, is now required through the FracFocus public registry within 30 days of the end of operations. Release of information is also included in BC's *OGAA* General Regulation. This was found by Lucas and Lilles (2016) to be a positive development, but that

other compulsory requirements for public notification and consultation in Alberta have not yet been developed, notwithstanding regulatory initiatives that could be moving in this direction (Lucas and Lilles, 2016). The AER has since undertaken a widespread consultative process, the *Participant Involvement Initiative* within the industry-wide Integrated Decision Approach (Alberta Energy Regulator, 2017). The AER continues to implement recommendations made by Coglianese (2015) in support of regulatory excellence that may be recognized in Canada and abroad.

4. Risk management options for human health and environmental protection

Regulatory and policy frameworks applied to hydraulic fracturing in British Columbia and Alberta, Canada (described in sections 2 and 3, respectively) attempt to protect human health and the environment in the short and long term. These undertakings are examined here within the REACT (regulatory, economic, advisory, community-based, and technological) taxonomy of risk management actions (Krewski et al., 2007, Krewski et al., 2014), with additional consideration of risk management recommendations emanating from previous national and international initiatives. Key national reports include the work of the Council of Canadian Academies (2014), the Nova Scotia *Report of the Independent Review Panel on Hydraulic Fracturing* (Wheeler et al., 2014), Holding et al. (2015), New Brunswick Commission on Hydraulic Fracturing (2016), and results from the human health risk assessment (HHRA) in northeastern BC (BC Ministry of Health, 2017). Selected international assessments include the International Risk Governance Council (2014), Maryland Institute for Applied Environmental Health (2014), Royal Society and Royal Academy of Engineering (2012), Gamper-Rabindran (2014), and Small et al. (2014).

While not having undertaken a systematic review, we advance these initiatives by identifying repeated suggestions within the REACT framework as a policy agenda within eleven HF issue areas (Table 3). In this analysis, regulatory, economic, advisory, community-based, and technological approaches are discussed in turn, also respecting interrelationships between the five domains (i.e., a regulatory approach may require action in one or more of the other four categories of action). Each of these risk management approaches are defined below, with a discussion of provincial, national or international perspectives for each approach presented. This is followed by a comparative analysis of the use of the risk management option within our study provinces. Examples of where the provincial context is implementing or attempting to implement a suggestion in Table 3 are highlighted. Given the early stages of some of the provincial initiatives it was not possible to evaluate their effectiveness at this time.

Table 3: Human health and environmental risk management options for shale gas hydraulic fracturing hazards using the REACT framework[1]

Risk Management Option				
Regulatory	**Economic**	**Advisory**	**Community-based**	**Technological**
Approvals and approach				
• Single body lead for regulatory responsibilities • Comprehensive regulatory protections with performance monitoring, inspection, enforcement • Life cycle environmental risk assessment • Comprehensive gas development plans; regional planning • Industry best practices • Combined federal/state risk governance and land management • Associated enforcement resources	• Bond and insurance protections (people and environment) • Royalty/benefit sharing with communities • Aboriginal support	• Industry codes of conduct or centres of excellence • Full and transparent access to information by all stakeholders	• Joined-up engagement of local communities (including First Nations) in work of single body lead for regulatory responsibilities • Community participation in environmental risk assessment • Develop criteria for community permission to proceed/consent • Regional, potentially inter-provincial review committee on watershed basis • Risk reduction and benefit sharing, including equity lens for when, where and to whom benefits and harms may accrue	• Baseline (environmental, socio-economic, socio-ecological) data • Early risk assessment and risk management process (health, social, environmental) • Re-assessment of risk management options • Enhanced monitoring systems • Equipment design, use, maintenance • Safety management of equipment and processes
Environmental monitoring				
• Follow principles of Framework for BC Air Monitoring Network • RA enforced through monitoring and inspections		• Consider goals of monitoring programs • Make publicly available - ambient data for air, water, soil, vegetation, food	• Add locations	• Expand mapping - ambient (baseline monitoring) data for air quality, water, soil, vegetation, food, chemicals of potential concern

				• Study groundwater and surface water interactions within shallow aquifers • Monitor methane leakage
Air quality • Ambient air quality objectives - NO_2 and SO_2 • Link venting, flaring, and fugitive emissions to air quality objectives • Reporting • Risk management audit		• Learn from operational and regulatory best practice internationally - WHO, Health Canada	• Community panel for air quality monitoring and objectives • Determination of "safety hazard"	
Water quality • Baseline, integrity test data provided to regulators and used to inform (evidence-based) policy and regulatory requirements • Establish wellhead protection areas • Well integrity tests and inspections • Setbacks • Regulator disclosure – public e-database	• Industry fees or payments for analysis and public consultation • Fines for under-reporting	• Baseline, monitoring data publicly available • Online access to investigative reports of contamination	• Water safety planning	• Baseline groundwater and surface water tests and surveys • Regional groundwater monitoring • Pre- and post-drilling water samples
Fracture fluid composition • Well stimulation materials disclosure • Flow-back chemical disclosure		• Full disclosure on emergency basis	•	•

• Duty to inform • Use of most benign fluids and/or prohibition				
Seismicity				
• Suspend operations at 4.0M or greater event • Establish induced seismicity monitoring and reporting at magnitude 2.0M • Require submission of micro-seismic reporting • Implement regulatory scrutiny for disposal wells including permit conditions • Cradle to grave measurement, characterization and tracking of waste		• Research relationship between HF parameters and seismicity • Data sharing, publication, awareness • Traffic light system	• Determine buffer zones near subsurface disposal or storage facilities	• Collect baseline data • Identify pre-existing faulting • Establish induced seismicity monitoring and reporting at magnitude 2.0M • Enhance Canadian National Seismograph Network • Install ground motion sensors • Use portable, high resolution dense seismograph array
Human health surveillance				
• Make publicly available - ambient data for chemicals of potential concern • Review, revise, standards for exposure	• Funding for public health studies	• Public access to ambient data	• Coordinated research agenda for human health • Health care forum	• Baseline assessments (those living, working, at school, recreation, playing) • Disease rate and birth outcome surveillance • Monitor standards for exposure
Worker and public safety[2]				
• NIOSH and OSHA controls for operation • Management of NORMs	• Workplace inspection resources • Employers provide employee assistance		• Emergency planning • Community outreach to transient workers	• Safety management of equipment and processes • Emergency shut down • Setback calculation tools

• Setbacks	programs			
Information management				
• Government and industry accessible data sharing • Reporting of well failures • Disclosure - post inspections, cases of contamination, violations, impacts		• Objectives and use of databases reviewed to make systems more accessible and user-friendly; including access by researchers • Federal role for information collection and dissemination (industrial, regulatory, public)	• Improve public engagement and transparency	
Legacy sites				
• Standards and rules for permitting and liability	• Performance-based taxes and fees • Liability coverage • Well closure and environmental restoration bond • Impact fee, distributed to community	• Use of site classification tool and framework for management of contaminated sites		• Monitor abandoned wells

[1] Based on BC Oil and Gas Commission (2012); BC Oil and Gas Commission (2014c); Broomfield (2012); Council of Canadian Academies (2014); Gamper-Rabindran (2014); Holding et al. (2015); Intrinsik Environmental Sciences (2014a); Maryland Institute for Applied Environmental Health (2014); Royal Society and Royal Academy of Engineering (2012); Small et al. (2014); Wheeler et al. (2014)
[2] Acronyms: NIOSH - US National Institute for Occupational Safety and Health; OSHA - US Occupational Safety and Health Administration; NORM - Naturally Occurring Radioactive Material

4.1. Regulatory approaches

Regulatory-based risk management options include government policies, legislation, guidelines, permits, or approvals for required action (three categories of statutes include products, emissions, and protection of the natural environment). The CCA suggested an effective framework for risk management would include an effective regulatory system, where "rules to govern the development of shale gas must be based on sound science, and compliance with these rules must be monitored and enforced" (2014, p. xix).

In other jurisdictions, Precht and Dempster (2012) completed a regulatory review for the Nova Scotia Hydraulic Fracturing Review Committee and Becklumb et al. (2015) describe the Canadian regulatory framework for selected HF effects on water resources, air, and land. Gagnon et al. (2016) report on potential impacts of HF on ground and surface waters, as well as related governance approaches in the US and Canada. Gaps in the literature and suggested regulatory-based risk management options specific to protecting water quality were also identified (Gagnon et al., 2016). In examining wastewater disposal management across four North American shale gas basins, Goss et al. (2015, p. v) found that the extent to which regulatory regimes "are sufficient to protect the environment over the long term remains unknown", with knowledge gaps in regulatory outcomes and compliance with best management practices. More broadly, Krupnick et al. (2013) investigated viewpoints of what type of US organization should be held responsible for pathways of contamination: 264 risk pathways were identified with experts reaching consensus on 12 priority pathways for regulatory intervention.

Comparative analysis

Given the federal-provincial division of powers within the Canadian constitution, this analysis finds BC and Alberta both have policy and regulatory jurisdiction over energy, land, water, air, biodiversity, and community development, including their interactions (sections 2 and 3). Indeed, both provinces have established cross-government resource management initiatives (Table 2). Both provinces have also established a single window energy regulator, the BCOGC and AER, that administer a myriad of oil and gas related laws and regulations (Tables 2, 3). Project consent by Aboriginal communities is sought in conjunction with a fiduciary duty to consult (Supreme Court of Canada, 2014). Local municipal jurisdiction is generally limited to roads, municipal infrastructure, and noise, but possibly with options to manage HF within the development of integrated sustainable community plans.

In BC, a regulatory framework review was completed during the HHRA (Intrinsik Environmental Sciences, 2014b) and an interjurisdictional regulatory comparison considered water use and protection (water lifecycle), induced seismicity, quality of life disturbances, and issues such as cooperation and standardization (Ernst & Young, 2015). While the study found HF to be well-regulated, some opportunities for improvement were identified, particularly for data collection and monitoring, new areas for regulatory authority and oversight, and enhanced regulatory instrument coverage. With a focus on water security, Holding et al. (2015) also reviewed the BC regulatory framework, as well as the potential roles of strategic partnerships and stakeholder collaborations (the Northeast Water Strategy), data collection, and distribution.

The HF regulatory framework was reviewed in Alberta, with challenges identified for well spacing, water management, landowner/public concerns, environmental issues, the regulatory process, and information collection and dissemination (Energy Resources Conservation Board, 2011). A discussion paper (Energy Resources Conservation Board, 2012) and decision on regulating unconventional resources resulted in the play-based pilot (section 3) as well as Directive 083, *Hydraulic Fracturing – Subsurface Integrity* (Alberta Energy Regulator, 2013).

Both provinces also have emerging regulatory requirements with an emphasis on regional planning to manage environmental risks related to HF activities. BC is linking CEF with a number of current and emerging initiatives across the natural resource sector, with BCOGC collaborating to ensure consistency between broad policy CEF and regulatory ABA. As noted in section 3, the CEF includes a values list that is longer than those to be assessed under the ABA (Government of British Columbia, 2014a). ABA was first applied to desired outcomes and expectations for old forest and riparian reserve zones with respect to impacts from well pads and facilities, roads, geophysical activities, pipelines, and ancillary activities and temporary workspaces (BC Oil and Gas Commission, 2015). Stakeholder-identified outcomes and expectations for other environmental and cultural values are planned but have not yet been initiated. As noted in section 3, ABA using the CEF, land-use, and State of the Play Reports will eventually cover the entire Western Canadian Sedimentary Basin.

In Alberta, the PBR pilot was implemented as a trial to improve the project application process. The pilot evaluation found that more needs to be done to provide guidance to proponents on the range and depth of information required (Alberta Energy Regulator, 2016a). Indeed, specific environmental, economic, and social outcomes were not easily identified, although "meeting government policy outcomes" was mentioned thirty-four times in the guidance document, but without elaboration (Alberta Energy Regulator, 2014). The PBR approach could be layered with other environmental policy such as LUF, yet it is unclear how these are integrated. Since promulgation of the enabling legislation, only two LUF have been approved in Alberta: the Lower Athabasca (Alberta Government, 2012c) and South Saskatchewan (Alberta Government, 2014b). A third LUF is in consultation and four have yet to begin, including the Upper Athabasca and Upper Peace planning regions where the PBR Duvernay Pilot occurred. Furthermore, only regulatory-based plans within a regional plan have binding legal effect (Alberta Government, 2012c, Alberta Government, 2014b). Complicating matters, the LUF geographical districts do not necessarily overlap eleven formally recognized watershed planning districts under the *Water for Life* strategy (Alberta Government, 2008) and Action Plan (Alberta Government, 2014a), where actions are to be integrated into policies and plans such as LUF. For example, the Duvernay Formation is located within the Mighty Peace Watershed Alliance and Athabasca Watershed Council watershed planning districts.

With respect to air quality, both provinces are implementing a pan-Canadian airshed monitoring approach (Table 3). Alberta's *Renewed Clean Air Strategy* and Action Plan (Alberta Government, 2012a, Alberta Government, 2012b) could affect HF operations if goals for known issues are included within LUF plans. Regarding other issue areas (Table 3), water well setbacks are required in BC; while both provinces and the NEB have implemented requirements for FracFocus public disclosure (also see section 4.3, Advisory approach). Both provinces have also

established induced seismicity thresholds, discussed further as a technological risk management approach (section 4.5).

4.2. Economic approaches

Economic risk management options include incentives or disincentives such as insurance, levies, and other cost structures designed to have the proponent take. These could include performance bonds, public liability insurance, and contributions to technology or emissions funds. While Small et al. (2014) found that performance-based instruments for safe and responsible operations related to air emissions and water quality were beginning to be considered, it appears that compensation as a risk management option for various HF activities that may result in deleterious effects on the environment or human health is not well developed. Table 3 illustrates this approach has had the least proposed application across the eleven HF issue areas, being limited to human health surveillance, workplace health and safety, cost allocations for increased health care services in the community, and as a mechanism to risk manage potential legacy sites.

Where UGD is not on Crown Land, risk management could include municipal compensation through development fees. The *Report of the Nova Scotia Independent Panel on Hydraulic Fracturing* recommended that a policy be developed regarding "benefit allocation from the activities of the unconventional gas and oil industry through, for example, royalty sharing to ensure that communities affected by development receive adequate compensation for risks and costs and tangible benefits in terms of community health and social investments for hosting the activity" (Wheeler et al., 2014, p. 330). An example from the province of New Brunswick suggested royalties be divided between the provincial government, local government (to cover roads and repairs, for example), and landowners (National Research Council, 2014). In Canada's North, loss of harvesting opportunities caused by energy development may be compensated if there is damage to wildlife and habitat (National Energy Board, 2013).

Internationally, the UK government and industry considered how compensation might be provided directly to local communities (International Risk Governance Council, 2014). In the European Union, insurance coverage and compensation for potential damage from seepage or leakage was recommended (World Resources Institute, 2010 in Broomfield (2012)).

Comparative analysis

A provincial review of the tenure fee structure is underway within our two study provinces, potentially enhancing protective features within UGD operations. Occupational health and safety and emergency management regulations may also include compensation provisions for adverse events. Instances of landowner compensation for access or harm were not identified except in BC where compensation to landowners is required if the operator fails to reclaim a site properly (Precht and Dempster, 2012). BC is also negotiating economic benefits agreements and long term oil and gas agreements with some Indigenous communities.

As a combined regulatory and economic risk management option to reduce potential GHGs associated with HF operations (fugitive, planned and unplanned emissions), natural gas production, including HF, has been exempt from both BC's carbon tax (established in 2008) and Alberta's Specified Gas Emitters Regulation (established in 2007 and now replaced by the Carbon Competitiveness Incentive Regulation under Alberta's carbon levy program) (Alberta

Treasury Board and Finance, 2018, Government of Canada, 2018). Implementation of the PCF carbon tax discussed in section 1.1, however, could result in reduced emissions over time.

4.3. Advisory approaches

Advisory programs are developed to encourage action, including communications, education, and awareness activities such that stakeholders may make informed decisions to reduce or avoid risks. These programs should occur with all HF stakeholders, because similar to a myriad of industrial land use activities, HF comprises multi-sectoral interests including industry, government, non-government, and the general public, sometimes represented at sub-regional levels. For HF, North et al. (2014, p. 8388) identified "strong value conflicts, [the] need to make decisions urgently, and mistrust across the decision-making environment".

Moreover, advisory approaches may meld with regulatory, community-based or technological risk management activities. For example, the Council of Canadian Academies (2014) recommended regional planning as a way to address cumulative impacts, with resultant drilling and development plans that reflect local and regional environmental conditions, including existing land uses and environmental risks (see section 4.1). In this way, advice could be seen as bi-lateral: industry with non-industry stakeholders.

Within government, Canadian advisory programs include interjurisdictional collaboration between provincial Ministers of Energy and Mines. A shale and tight resources web portal https://www.nrcan.gc.ca/energy/sources/shale-tight-resources/17669 has been created; and Natural Resources Canada and the Governments of BC, Alberta, Saskatchewan, Newfoundland and Labrador, Yukon, and Northwest Territories established a Shale Cluster Action Plan to consider collaborative action on wellbore integrity, geoscience and geo-engineering R&D gaps, environmental baseline data collection, and participation in a flaring and venting regulators forum (Energy and Mines Ministers' Conference, 2015).

Advisory initiatives such as standards and voluntary codes have also been developed by industry and non-government organizations (ALL Consulting LLC, 2012, Council of Canadian Academies, 2014, Interfaith Center on Corporate Responsiblity, 2011, International Association of Oil & Gas Producers, 2013, International Energy Agency, 2012). As implementing a recommended approach (Table 3), the Canadian Association of Petroleum Producers published a set of guiding principles and operating practices for seven HF issue areas (Canadian Association of Petroleum Producers, 2017): fracturing fluid additive disclosure; fracturing fluid additive risk assessment and management; baseline groundwater testing; wellbore construction and quality assurance; water sourcing, measurement, and reuse; fluid transport, handling, storage, and disposal; and anomalous induced seismicity — assessment, monitoring, mitigation, and response. Evidently, these are mostly technological risk management options.

Comparative analysis

Overall, disclosure policies have been identified as both a gap and necessity (Gamper-Rabindran, 2014), and Table 3 includes recommendations for improved public access and disclosure of data and information for many HF issue areas.

The BC, Alberta, and Saskatchewan *New West Partnership* arrived at an agreement for fracturing chemical disclosure on www.FracFocus.com. In both study provinces, as well as through the National Energy Board, mandatory disclosure through the FracFocus registry is underway although reporting is done within 30 days following operations, rather than in real time. In Alberta, the *Water for Life* strategy includes requirements for access to information and transparency on fracturing operations including fluid composition and water quantity.

On a project basis, both our study provinces have published guidance for notification and consultation with Indigenous Peoples and the general public. Regulatory-based ABA in BC and PBR in Alberta begin to enhance the advisory risk management option. However, an evaluation of the Liard Basin pilot project suggested further action to share documentation transparently with all users and directly with First Nations Communities, to incorporate additional values, and to review analysis methodologies (BC Oil and Gas Commission, 2014b). The evaluation of the PBR in Alberta found that insufficient information was provided to stakeholders, leading to a limited understanding about PBR and its outcomes (Alberta Energy Regulator, 2016a). An enhanced effort in Alberta could result from the *Participant Involvement Initiative* (section 2).

4.4. Community-based approaches

Community-based risk management interventions are grounded in public inception, support, and commitment to take action. For example, the CCA suggested that engagement of local citizens and stakeholders is important because "public engagement is necessary not only to inform local residents of development, but to receive their input on what values need to be protected, to reflect their concerns, and to earn their trust. Environmental data should be transparent and available to all stakeholders" (2014, p. xix). This further underlines the linkage between community-based and advisory options.

Combined community-based and advisory risk management options for HF have been identified (Royal Society and Royal Academy of Engineering, 2012, Small et al., 2014, Wheeler et al., 2014), including participation in risk assessment, developing criteria for permission/consent, and joined-up engagement, including First Nations, in the work of the single body regulator (Table 3). Communities may also organize a health care forum, provide input to buffer zone determination, and control local truck traffic.

Comparative analysis

Emerging issues in both provinces include HF activities closer to populated areas and the fiduciary duty to consult and obtain consent of Aboriginal communities. Community-based approaches are being implemented within the regulatory domain, albeit for different purposes: BC's LUF/ABA is focused on identifying regional environmental and socio-economic values while Alberta's PBR was a trial for a regional play-based approval process. At the municipal level in both provinces, broad policy enables the creation of Integrated Sustainable Community Plans, with the added Community Charters only in British Columbia (section 3), and these may describe risk management of HF activities close to populated areas.

Specifically with respect to Indigenous communities in BC, Vypovska and Johnson (2016, p. 95) suggested (for natural gas related projects and not HF in particular) that "effective consultation and engagement with Indigenous Groups is one of the most critical factors for the success of the

project". In BC, together with the applicable First Nation(s) and the BCOGC, the provincial government has or is currently negotiating a variety of agreements (section 2), including economic benefits agreements. Austin and Pokorny (2016) outline the goals of regional strategic environmental assessment for northeast BC in the Montney gas play especially for Treaty 8 First Nations.

In Alberta, guidance included recognition of shared responsibilities and the importance of partnerships, with operators asked to plan for stakeholder engagement, including with First Nations and Métis, that will continue throughout the life cycle of the project (Alberta Energy Regulator, 2014). Nevertheless, there was early concern in the PBR pilot for stakeholder capacity to review regulatory applications that cover every aspect of project within one comment period at the beginning of the process. Further, stakeholder outreach during the pilot was deemed insufficient (Alberta Energy Regulator, 2016a). Lucas and Lilles (2016) found that opportunities for public review engaged a narrow range of stakeholders with no legal right to participate at the PBR rule-making stage or compulsory public notification or consultation requirements for HF. However, this approach is currently under review (Alberta Energy Regulator, 2017).

4.5. Technological approaches

Technological risk management options focus on advances in technological abatement, including monitoring, and these remain an oft-recommended risk management approach for HF (Table 3), sometimes in conjunction with regulatory initiatives. The CCA (2014, p. xix) suggested "equipment and products must be adequately designed, installed in compliance with specifications, and tested and maintained for reliability." Monitoring is a critical component: the CCA (2014) suggested that HF has continued in the past decade without sufficient environmental baseline data (e.g., baseline water quality, ecosystem and wildlife, social impact on aboriginals, natural seismic activity to the region, and other environmental impacts) (See also Table 3). It is important to note, however, that a monitoring activity is not risk management in and of itself, but that the use of the information could support better risk management practices.

Holding et al. (2015) described management tools available to industry, the public, and decision makers in NE BC, including a review of their deficiencies which largely focused on data availability from poor monitoring regimes. Also in BC, Lapp et al. (2015) found concerns that monitoring, research data, and results should be easily accessible to water managers and industry. Our view is that these should also be made available to a broader range of stakeholders, including the general public, as an advisory intervention.

In addition to enhanced monitoring, innovative technological solutions provide an alternative to traditional HF hydrocarbon production and wastewater disposal techniques that are the source of much public concern. For example, HF technologies have been developed that require a smaller footprint, less traffic and noise; fewer chemicals, less fresh water, lower injection pressures that can improve wellbore integrity, reduce waste streams, and overall reduced health and environmental risks (Terralog Technologies Inc., 2017a). In terms of the disposal wells, dedicated facilities have been developed that not only dispose of waste water, but also other exploration and production waste streams, including contaminated soils and naturally occurring radioactive material (NORM) would further reduce risks (Terralog Technologies Inc., 2017b).

Such examples are a combined technological and regulatory risk management approach, with attendant monitoring regimes.

Comparative analysis

In our study provinces, results of BC's HHRA noted a limited air quality monitoring framework (Intrinsik Environmental Sciences, 2014a). Since then, as a combined regulatory and technological approach, both provinces have started to implement the cross-Canada Air Quality Management System.

BC enacted a broad water management strategy through the *Water Sustainability Act* (Government of British Columbia, 2014b). This review of policy and legislation suggests, however, that only Alberta has a regulatory requirement for baseline water sampling prior to development. This is also an example where regulatory, advisory, community-based, and technological risk management options may intersect, with a regulatory requirement for monitoring, as well as sufficient resources for implementation, transparency, and enforcement.

Both provinces have responded to seismic events. An investigation in BC's Horn River Basin (April 2009 through December 2011) concluded seismicity was "caused by fluid injection during hydraulic fracturing in proximity to pre-existing faults" (BC Oil and Gas Commission, 2012, p. 3). Seven recommendations were made to enhance seismic monitoring, industry best practices, and regulations. In 2014, five additional recommendations were made following an investigation in the Montney Trend (BC Oil and Gas Commission, 2014c): to increase regulatory scrutiny for disposal wells; encourage deployment of high-resolution dense (monitoring) arrays; improve regulations to address induced seismicity; increase public availability of data necessary to study induced seismicity; and assess the use of hydraulic fracturing buffer zones to protect sensitive infrastructure and subsurface projects. BCOGC regulations now require ground motion monitoring and reporting. Wellbore operations must also be suspended at 4.0M or greater, pending mitigation measures. In Alberta, the Fox Creek area of the Duvernay Zone (location of the pilot PBR) has been subject to a subsurface order using a 'traffic light' strategy to manage potential seismicity. Seismic monitoring must detect 2.0M or greater event within 5 km of an affected well, with the licensee implementing its induced seismicity plan should such an event occur. HF operations must cease at 4.0M or greater recorded event, then being subject to an AER permit to resume operations (Alberta Energy Regulator, 2015). Expansion and improvements to the Canadian National Seismograph Network (Table 3) are also underway in both provinces.

5. Summary

This article provides a synthesis of the policy and regulatory context for addressing the main risks of unconventional gas reservoir development using hydraulic fracturing in BC and Alberta, Canada, along with an analysis of these contexts in relation to commonly suggested human health and environmental risk management options for HF presented in the REACT integrated framework for risk management and population health (Krewski et al., 2007, Krewski et al., 2014).

Risk management for HF is positioned within a multi-dimensional spatial framework where governance (both the substance of the laws and the activities of entities that implement and

influence these) is challenged by perceived regional or even global benefits of the technological process, compared with local adverse impacts that can be the purview of several layers of government (Council of Canadian Academies, 2014, p. xix, Webler et al., 2015). The overarching policy drivers for UGD using hydraulic fracturing include domestic energy self-sufficiency, and the use of natural gas as a transitional fossil fuel to mitigate global climate change while societies move to a lower carbon economy. For example, BC sees itself contributing to global CO_2 reduction targets when gas exports replace higher emission coal and/or diesel in Asia. The Canadian policy context also requires final investment decisions for pipelines and liquefied natural gas (LNG) processing projects in order to advance shale gas exports. Pipelines to transport gas from BC's Liard and Horn River Basins to the west coast have been proposed, including the Pacific Trail Pipeline and the Pacific Northwest Liquefied Natural Gas project that include terminal development. The latter was approved with conditions by the federal government in 2016 (although the proponent since cancelled development because of the low world price for liquid natural gas).

Given Canada's distribution of powers, the federal government has a narrowly defined role in HF at the present time, being limited to a regulatory framework for methane emission reductions to be implemented through 2024 in partial response to our nationally determined contribution to the Paris Agreement. Canada, BC and Alberta have approved climate policies and targets, and the provinces have energy policies that promote these sources of natural gas as integral to future prosperity. In other provinces, however, UGD using HF is restricted such as in New Brunswick, Nova Scotia. Quebec only recently permitted HF activities to (potentially) resume.

Analysis of similarities and differences in the HF policy and regulatory contexts in BC and Alberta finds combined regulatory, advisory, community-based, and technological risk management approaches, where attempts are being made to integrate enhanced broad provincial policy with emerging UGD region-based regulatory frameworks. Broad environmental plans and value assessments are partially completed (BC) or not yet begun (Alberta) in the principle HF study regions. For the latter, AEMERA's initial focus on the oil sands region may be extended to HF regions, requiring collection and reporting for air, land, water, and biodiversity, including information to assist in understanding cumulative effects (Alberta Environmental Monitoring Evaluation and Reporting Agency, 2014). In both provinces, integrated decision making in all HF regions will remain challenging because this is limited to the speed with which environmental asset assessments in UGD zones are completed.

The present analysis finds less policy and regulatory emphasis for public, occupational, and socio-economic determinant of health issues than for environmental issues. However, while formal health impact assessments are not completed within project approval processes, a play-based regulatory goal in Alberta was to ensure that activities do not compromise public safety. It is also understood that maintaining environmental health and wellbeing is a critical determinant of human health and so measures to protect the environment should have positive human health effects. Health risk management options focus on protecting groundwater and surface water quantity and quality, wildlife, and habitat; reducing criteria air pollutants and GHG emissions; limiting induced seismicity; addressing transportation issues; and promoting sustainability in community social and economic development. Furthermore, local HF impacts may or may not be immediately known and could be of an intergenerational nature, in that geological and land-

based activities include direct and indirect pathways for potential hazards to reach the sub-surface, near surface, and surface environments.

The present analysis therefore also provides support for the development of a policy agenda with respect to broad and persistent HF risk management issues. Risk management options need to be implemented at multi-levels and multi-scales within regulatory, economic, advisory, community-based, and technological domains. Canadian and international investigations identified recommendations across this spectrum, which we categorized within the REACT framework. While not all risk management approaches apply to all HF issue areas, many recommendations recur, including: the need for a strong regulatory framework that works in concert with enhanced technological requirements, with adequate resourcing; evidence-based emissions standards; regulated and/or community-based setbacks and buffer zones; operational surveillance, reporting, and disclosure for all value-chain activities, including fracture fluid composition, in an accessible and transparent way; community participation in the development of these mechanisms; and provision for legacy sites. British Columbia and Alberta appear to be implementing these options variably. The role of economic options, such as performance-based taxes and fees, industry-funded studies, the role of carbon taxes, or cost allocations to protect or improve determinants of health is the least developed option.

Further implementation of these options should advance human health and environmental protection during UGD and further research could identify additional room for improvement. For instance, this could include progress with respect to a review or revision of air emission standards in light of key HF concerns such as flaring, venting, and fugitive emissions management. Another research area is the extent to which community participation is included in the development of risk management options and more specifically, whether regulated and/or community-based operational setbacks and buffer zones are working to protect human health. With respect to provisions for legacy sites, a provincial review of the tenure fee structure is underway in our study provinces. Further research could evaluate economic or other options to manage both short and longer term risk issues, including the potential effects of the federal carbon tax on HF GHG emissions.

Finally, perhaps most importantly, information disclosure and operational transparency regarding HF activities has been emphasized repeatedly, including in provincial policy statements. Proactive public disclosure of wide ranging information could help mitigate potential human health and environmental impacts of UGD using HF and ultimately support the knowledge base regarding the benefits of the industry as a whole.

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