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Risks to Water and Public Health from Unconventional Gas in B.C.

A review of new research on hydraulic fracturing impacts

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May 2018

photo: Province of British Columbia

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Executive summary

Due to the rapid proliferation of unconventional natural gas development (UNGD) across North America, scientific research investigating its potential impacts has lagged behind development, with British Columbia particularly lacking in relevant studies. However, a recent surge in literature, mostly focused on the United States, has demonstrated evidence of risks posed by hydraulic fracturing to water resources and public health.

This paper explores this literature and, given these recent findings, cautions against the assumption that the risks posed by UNGD to B.C.'s water resources and communities have been fully addressed. It highlights three key points:

- Evidence is inconclusive that the process of hydraulic fracturing itself risks water contamination and public health; rather, it is the management of unconventional natural gas activities and handling of wastewater that is the main concern. Proper management of wells and produced water is key to minimizing risk.
- Known contamination risks, therefore, depend mainly on management (not on geology of the target formation or hydrology of the region). Although regulation of these pathways does vary by jurisdiction, UNGD in B.C. exists in a comparable regulatory environment to other North American jurisdictions.
- Available studies conducted outside of B.C. can be used to inform UNGD in the province. The authors encourage B.C.'s Scientific Hydraulic Fracturing Review Panel to consider this broader literature and to pay specific attention to issues relating to management of wastewater and other operational practices. Furthermore, we encourage scientists, industry, and regulators to act quickly to fill data and knowledge gaps and to exercise prudence with regard to future development.

1. Introduction

In the 2013 provincial election, British Columbia's government campaigned on developing a liquefied natural gas (LNG) industry. Since then, LNG has been a controversial topic in B.C. with the debate largely focused on prospective economic benefits, government revenue, and job creation on one hand, and on the industry's potential to contribute to global climate change[1] and impact fisheries at the terminal site on the other. Important environmental and social issues have received less scrutiny, especially those associated with the upstream natural gas development needed to supply LNG projects — development that could grow dramatically should an LNG industry emerge.[2] In this paper, we undertake a comprehensive literature review — mostly focused on the United States — to explore the potential implications of unconventional natural gas development (UNGD)[3] on water quality in northeastern B.C., and the risks this could pose for public health.

Across North America, new production technologies, including horizontal drilling and hydraulic fracturing (commonly referred to as "fracking"), have made vast and previously inaccessible deposits of natural gas technically and economically viable to produce. In B.C., hydraulic fracturing has made it possible to develop the prolific unconventional natural gas resources found in the province's northeast, including the Montney Formation and the Horn River Basin. Proponents of the industry argue that, in order to develop these resources to their potential, an LNG export industry is needed to create access to energy-hungry Asian markets. Large-scale LNG development would increase demand for B.C. gas and, therefore, increase upstream development.[4]

[1] Dylan Heerema and Maximilian Kniewasser, *Liquefied Natural Gas, Carbon Pollution, and British Columbia in 2017* (Pembina Institute, 2017). http://www.pembina.org/pub/lng-carbon-pollution-bc

[2] Maximilian Kniewasser, *Limiting Methane Pollution from B.C.'s Gas Sector* (Pembina Institute, 2018). http://www.pembina.org/pub/methane-emissions-bc

[3] Unconventional natural gas development is commonly referred to as hydraulic fracturing for natural gas, shale gas (when accessing shale rock formations), or tight gas (when accessing low or impermeable sandstone formations). These terms can be used interchangeably since hydraulic fracturing is the unconventional portion of the UNGD supply chain. The production of coal-bed methane is excluded from the scope of this study.

[4] Maximilian Kniewasser and Matt Horne, *B.C. Shale Scenario Tool* (Pembina Institute, 2015). http://www.pembina.org/pub/BCShaleTool

Hydraulic fracturing involves large amounts of water, together with proppant (commonly sand) and fracturing fluids (chemicals that aid in the fracturing process, making up 0.5–2.0% of the total fluid volume[5]), being pumped underground under high pressure to create fissures in impermeable or low-permeable geological layers to allow natural gas to be extracted. The chemicals used in fracturing fluids have stirred intense debate. It's estimated up to 750 chemicals are routinely used for hydraulic fracturing in the U.S., with about 50 used in an average well.[6] Of commonly used chemicals, 29 are known carcinogens and over 100 are known endocrine disrupting chemicals (EDCs) — chemicals that interfere with human hormones and can impact reproduction and development.[7] After the initial fracturing process, a significant percentage of contaminated water returns to the surface and must be managed.[8]

Due to the rapid proliferation of hydraulic fracturing across North America, scientific research investigating its potential impacts has lagged behind development. There has been a recent surge, however, in peer-reviewed scientific studies on UNGD and, while no scientific consensus has been established, evidence is accumulating to suggest that hydraulic fracturing can pose risks to water quality and public health, among others. This paper assesses this recent literature in order to inform the public discussion surrounding LNG and natural gas development in B.C.

[5] Ernst & Young, *Review of British Columbia's Hydraulic Fracturing Regulatory Framework* (B.C. Oil and Gas Commission, 2015). https://www.bcogc.ca/node/12471/download

[6] Henry Waxman et al., *Chemicals Used in Hydraulic Fracturing* (U.S. House of Representatives Committee on Energy and Commerce Minority Staff, 2011). http://www.conservation.ca.gov/dog/general_information/Documents/Hydraulic Fracturing Report 4 18 11.pdf

[7] Christopher Kassotis et al., "Endocrine disrupting activities of surface water associated with a West Virginia oil and gas industry wastewater disposal site," *Science of the Total Environment* 557–558 (2016). doi:10.1016/j.scitotenv.2016.03.113

[8] John Deutch et al., *Ninety-Day Report* (Secretary of Energy Advisory Board Shale Gas Subcommittee, 2011). http://thehill.com/images/stories/blogs/energy/subcommrpt.pdf

2. Overview of hydraulic fracturing's implications for water resources

2.1 Water use

Horizontal drilling and hydraulic fracturing for unconventional natural gas is a water-intensive process. The amount of water required varies by geological formation, well depth and length, and the formulation of fracturing fluids. In B.C., the total amount of water per well ranges from 10,000–13,000 m^3 in the Montney tight gas formation, to 80,000 m^3 in the Horn River shale gas formation.[9] In 2015, 531 wells were drilled in B.C.,[10] requiring a total of 7.7 million m^3 of water to be injected for hydraulic fracturing (an average water intensity of 14,500 m^3 per well); 6.4 million m^3 of this water was sourced from surface water and freshwater aquifers (82.7%), 1.2 million m^3 was recycled from previous natural gas activity (15%), 131,000 m^3 came from deep saline aquifers (1.7%), and 46,000 m^3 (0.6%) came from municipal wastewater.[11] Most drilling occurs in the Montney Formation (94% of wells drilled in 2014 were in this formation), which uses around one-eighth as much water as developments in the Horn River Formation.[12]

After fracturing, a considerable amount of fluids return to the surface in the form of flowback or produced water.[13] These fluids are a mixture of injected hydraulic fracturing fluids and fluids from natural formations (e.g. brine layers and saline aquifers).

[9] B.C. Oil and Gas Commission, *Hydrocarbon and By-Product Reserves in British Columbia* (2014). https://www.bcogc.ca/node/12952/download

[10] B.C. Oil and Gas Commission, *British Columbia's Oil and Gas Reserves and Production Report* (2015). https://www.bcogc.ca/node/13607/download

[11] B.C. Oil and Gas Commission, *2015 Annual Report on Water Management for Oil and Gas Activity* (2015). https://www.bcogc.ca/node/13261/download

[12] Ibid.

[13] Fluids that return to the surface immediately after injection are referred to as "flowback"; fluids that return to the surface after a longer period of time (during oil and gas production) are referred to as "produced water." "Produced water" is used in this paper to refer to any water, including flowback, that returns to the surface.

Flowback rates can reach 1,000 m^3/day in the early stages,[14] while the rate of produced water slows to 2–8 m^3/day later in well life.[15] The amount of fluids that return to the surface commonly ranges from 10–40% of the initial water injected.[16] In B.C., about 2.9 million m^3 of fluids returned to the surface as produced water in 2015, giving a return volume of 38%.[17] This represents more water use but less produced water returns than the Barnett Shale in Texas and comparable water use and produced water to the Marcellus Shale in and around Pennsylvania.[18]

In B.C., produced water is either recycled or reused for further hydraulic fracturing, or disposed via deep underground injection wells. Surface discharge of produced water and disposal near surface aquifers that are used for potable water is not allowed. About 40% of produced water (approximately 1.2 million m^3 in 2015) is reused in further hydraulic fracturing operations (this accounts for approximately 15% of total water used for hydraulic fracturing), while all produced water that is not recycled (60% of total, or approximately 1.7 million m^3 in 2015) is disposed via deep injection wells.[19] This water is usually stored in temporary tailings ponds and then trucked from the well site to the injection wells.[20]

[14] Kelvin Gregory et al., "Water Management Challenges Associated with the Production of Shale Gas by Hydraulic Fracturing," *Elements* 7 (2011), no. 3. doi:10.2113/gselements.7.3.181

[15] A. Vengosh et al., "A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States," *Environmental Science and Technology* 48 (2014), no. 5. doi:10.1021/es405118y

[16] Deutch et al., *Ninety-Day Report*.

[17] Based on B.C. Oil and Gas Commission (BCOGC) information that 15% of the 7.7 million m^3 used for hydraulic fracturing came from reused and recycled sources, and that this accounts for 40% of the total volume of produced water. As well, the 38% of water returned does not necessarily indicate that 38% of the initial fluid that is injected returns to the surface, as the produced water includes brine from the formation.

[18] To draw relative comparisons across North America: The median volume of water injected per well in Texas from 2011 to 2013 was 5,378 m^3. Specifically, the Barnett Shale Formation in Texas utilized 48% groundwater, 48% surface water, and 4% reused hydraulic fracturing wastewater. Flowback from this formation produces an equivalent volume to that of the injected fluid volume. In Pennsylvania, a median of 15,842 m^3 of water is injected per well. The Marcellus Shale Formation utilizes 7% groundwater, 79% surface water, and 14% reused hydraulic fracturing wastewater. Flowback from this formation produces only 10–30% of the injected fluid volume. U.S. Environmental Protection Agency, *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States* (2016). https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990

[19] Based on BCOGC information that 15% of the 7.7 million m^3 used for hydraulic fracturing came from reused and recycled sources, and that this accounts for 40% of the total volume of produced water. The rest was disposed of almost entirely via underground deep well injection.

[20] B.C. Oil and Gas Commission, *Oil and Gas Water Use in British Columbia* (2010). https://www.bcogc.ca/node/5837/download

2.2 Water risks

Evidence of direct contamination of shallow groundwater by hydraulic fracturing fluids from deep formation fracturing is inconclusive, but this remains a controversial issue, even in shallower drilling areas. Direct contamination pathways depend on the geology of the target formation and hydrology of the region, making some formations more prone to contamination than others. However, even in shallower formations such as the Marcellus, which has a depth of around 900–1,800 m, contamination via these pathways has not been observed conclusively. B.C.'s shale and tight gas resources are at greater depth, between 1,400–3,200 m in the Montney, and 1,900–3,100 m in the Horn River, and therefore should be further protected from this risk.[21]

Aside from direct contamination, there are four distinct risk pathways, dependent on management and not inherent in the fracturing process, through which UNGD could impact water resources:

- Contamination of shallow aquifers with fugitive hydrocarbon gases due to inadequately sealed or abandoned wells
- Contamination of surface water and shallow aquifers from spills, leaks, and inappropriate discharge of produced water
- Accumulation of toxic and radioactive elements in soil and stream sediments near disposal sites
- Over-extraction of water resources in water-scarce regions

These four pathways highlight management of well integrity and wastewater as the primary risk factor. Given that direct contamination is not proven in the literature, we caution against the assumption that more favourable geology, such as increased depth between target formation and aquifer, reduces water contamination risks. Instead, we focus in this paper on the risks related to well and wastewater management that exist regardless of geology and hydrology.

There is evidence that UNGD throughout North America has led to contamination of groundwater and surface water — including stray gas contamination of shallow aquifers, contamination of surface water and shallow aquifers from leaks and spills of wastewater, and accumulation of toxic and radioactive materials at disposal and spill

[21] Stephen Osborne et al., "Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing," *Proceedings of the National Academy of Sciences of the United States of America* 108 (2011), no. 20. doi:10.1073/pnas.1100682108

sites.[22] Stray gas contamination has occurred in both the Montney and Horn River basins in B.C. due to leaks from poorly constructed wells,[23] and leaks and spills of wastewater have been documented in Alberta.[24, 25] Management of well integrity after production has ceased[26] is also a contamination concern, as wells left inactive for many years pose a risk of contamination if integrity is compromised.[27, 28] Water scarcity concerns are dependent on water availability within the region of development. This is of somewhat lesser concern (although certainly not of no concern[29]) in northeastern B.C., where water use represents a small proportion of total water available, compared to other regions that see more intense drilling activities with smaller water resources to draw from (i.e. arid regions in the U.S. with intense drilling, such as Texas).

People rely on clean and plentiful water resources to meet their basic needs. The chemicals, processes, and systems used in unconventional natural gas processes pose risks to these resources. As mentioned above, this includes contamination with chemicals harmful to human health, including known carcinogens and EDCs. Impacts

[22] A. Vengosh et al., "A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States."

[23] Ibid.

[24] Christine Rivard et al., "An overview of Canadian shale gas production and environmental concerns," *International Journal of Coal Geology* 126 (2014). doi:10.1016/j.coal.2013.12.004

[25] Energy Resources Conservation Board, *Field Surveillance and Operations Branch Provincial Summary 2009*, ST57-2010 (2010), 21. http://www.ercb.ca/docs/products/STs/ST57-2010.pdf

[26] The process for shutting down dry wells and wells no longer in use is referred to as "well abandonment," which includes down-hole abandonment, remedial cementing, and surface abandonment. In B.C., operators are required to return the land as close as possible to its original state. Sometimes the producer may become insolvent and thus fail to fully abandon and remediate the well site (i.e. so-called orphan wells). In these cases, for many jurisdictions (e.g. B.C. and Alberta) the proper abandonment and reclamation of orphan wells (and pipelines) is paid for through an orphan well fund, which is financed by public funds and a levy on existing operations.

[27] Maurice Dusseault and Richard Jackson, "Seepage pathway assessment for natural gas to shallow groundwater during well stimulation, in production, and after abandonment," *Environmental Geosciences* 21 (2014), no. 3. doi:10.1306/eg.04231414004

[28] Another concern related to well integrity is induced seismicity from the fracturing and deep disposal processes; however, the authors found no evidence of seismic activity having negatively impacted well integrity or created contamination pathways in B.C. A. Vengosh et al., "The effects of shale gas exploration and hydraulic fracturing on the quality of water resources in the United States," *Procedia Earth and Planetary Science* 7 (2013), 863–866. doi:10.1016/j.proeps.2013.03.213

[29] Scarcity concerns are still relevant in B.C. in densely drilled regions and during low flow periods. For example, much of the drilling activity in B.C. happens in the winter when stream flow is generally at its lowest. B.C has regulations in place to limit drilling activity during low flow periods, which have suspended drilling activity in the past.

may vary in frequency and severity, depending on the combination of hydraulic fracturing water cycle activities and regional scale factors (such as proximity to populations), but there are valid concerns that water contamination from UNGD could negatively impact human health (see below). For this reason, risks associated with water contamination need to be assessed carefully. Scientific literature surrounding this topic is rapidly increasing along with the industrial capacity to obtain shale gas.

2.3 Water use, wastewater, and proposed LNG development in B.C.

Proposed LNG development will require significant associated upstream development to supply the terminals with gas. This will further increase water pressures in northeastern B.C., where all of B.C.'s gas is produced. To assess the water use and wastewater production associated with LNG development, we used the Pembina Institute's B.C. Shale Scenario Tool.[30] While the future extent of LNG development is uncertain, we assessed a scenario that includes proceeding with the two LNG terminals that have received environmental certificates: LNG Canada (capacity: 24 million tonnes of LNG per year [MTPA]) and Woodfibre LNG (2.1 MTPA), with a total capacity of 26.1 MTPA. This is a little more than half the amount included in modelling used for B.C.'s 2016 Climate Leadership Plan.[31]

The model output shows that meeting the natural gas demand of these two LNG terminals (excluding any non-LNG demand) could require 343 wells to be drilled (see Table 1).[32] These could use 5.7 million m^3 of fresh water and produce 2.0 million m^3 of wastewater (all values for the year 2030), though it should be noted that ongoing industry efforts in water recycling and use of deep saline water could reduce the amount

[30] The model run includes the two currently approved LNG projects (LNG Canada and Woodfibre LNG) and all current policies implemented to increase efficiency of upstream operations, including commitments to increase electrification of power processes and reduce methane leaks by 45%, as well as continued efforts for water recycling (15%). See: *B.C. Shale Scenario Tool*. http://www.pembina.org/pub/BCShaleTool

[31] Government of British Columbia, *Climate Leadership Plan* (2016). https://climate.gov.bc.ca/app/uploads/sites/13/2016/10/4030_CLP_Booklet_web.pdf

[32] The scenario assumes an average weighted GHG intensity of the three projects. It also includes policies announced in B.C.'s climate plan, including measures to reduce upstream combustion through electrification, and to reduce methane emissions. Both decrease the gas required in producing gas for export, and therefore lower upstream development and water use. The model has a setting for 15% water recycling, which is the current rate in B.C. The model is run using the base assumptions for gas supply mix, which sees production in the Horn River Formation increase from current levels.

of fresh water required for and wastewater produced from hydraulic fracture stimulation.[33] Furthermore, significantly better management of water resources is possible and is already being implemented by a leading producer.[34] However, this is not yet common practice. In 2015, 531 wells were drilled, and natural gas operations used 6.6 million m^3 of fresh water and produced 2.9 million m^3 of wastewater.

Table 1. Environmental attributes of two approved LNG projects

	2030	2050
Wells drilled	343	316
Fresh water used (million m^3)	5.7	4.9
Wastewater produced (million m^3)	2.0	1.7
GHG emissions (Mt CO_2e)	9.1	10.2

Note: This table describes environmental attributes associated with two LNG projects that are currently approved (LNG Canada and Woodfibre LNG) and associated upstream development. It does not make assumptions about the extent to which this development is incremental to current production.

We do not make assumptions to what extent the gas demand from LNG development (and thus water consumption and wastewater production) will be incremental to existing production, as this depends on market developments in North America and abroad. However, given that these two projects will require gas volumes equivalent to 87% of B.C.'s 2017 production, even scenarios with significant redirection of current gas production towards LNG will still require material upstream development and, therefore, increase fresh water use and wastewater production in northeastern B.C.[35]

[33] An increase in water intensity per well is predicted due to model assumptions that see more future development occurring in the water-intensive Horn River Formation than is currently the case. The future contribution of the Horn River is impossible to predict and depends to a large degree on market development.

[34] For example, Shell Canada has developed an extensive water recycling facility and a pipeline network connecting well pads to the facility at its Groundbirch asset. Most to all of the water from fracturing is stored at the facility and can be reused for future fracturing stimulations. This achieves an essentially closed-loop water system. Maximilian Kniewasser, Pembina Institute, facility tour, May 2018. More information available at: www.shell.ca/groundbirch

[35] B.C.'s total sales gas production in 2017 was 46.8 billion cubic metres. Total sales gas needed for two approved LNG projects, including gas for export and gas for powering the terminal, is 40.5 billion cubic metres. Government of British Columbia, *Natural Gas and Oil Statistics*. https://www2.gov.bc.ca/gov/content/industry/natural-gas-oil/statistics (accessed 2017)

Lastly, not all of the gas needed to supply LNG terminals would necessarily come from B.C., which would decrease water consumption and wastewater production in B.C.[36]

[36] For example, the B.C. government assumes 75% of the gas needed to supply LNG will come from within B.C., while Pacific NorthWest LNG stated that almost all of its gas would come from its partner's assets in the Montney Formation in northeastern B.C. The model used here assumes that 100% of the gas to supply LNG terminals comes from B.C.

3. Scientific literature on water and health impacts of unconventional natural gas development

The rapidly evolving science surrounding UNGD in recent years is evidenced by a large increase in peer-reviewed literature on this issue, 80% of which has been published since 2013.[37] Although the majority of these recent studies have been conducted in the U.S., with a lack of relevant research currently available in B.C.,[38] this paper suggests that reports done outside of B.C. should be used to provide a broad and comprehensive view of the issues associated with UNGD. UNGD is primarily a North American phenomenon. Although there are differences in regulation between U.S. states and Canadian provinces, the regulatory framework of other North American jurisdictions is broadly comparable to that in B.C.,[39, 40, 41] especially given that the top five natural-gas-producing jurisdictions in the U.S. are well regulated.[42] It's also worth noting, as described above, that the risks associated with water contamination from UNGD are mainly due to well management and handling and management of wastewater (which is

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[37] Jake Hays and Seth Shonkoff, "Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development: A Categorical Assessment of the Peer-Reviewed Scientific Literature, 2009–2015," *PLOS One* 11 (2016), no. 4. doi:10.1371/journal.pone.0154164

[38] For relevant studies conducted in B.C., see: GW Solutions, *Peace River Regional District Water Quality Database and Analysis* (Peace River Regional District and Treaty 8 Tribal Association, 2016); and Judi Krzyzanowski, "Environmental pathways of potential impacts to human health from oil and gas development in northeast British Columbia, Canada," *Environmental Reviews* 20 (2012), no. 2.

[39] Ernst & Young, *Review of British Columbia's Hydraulic Fracturing Regulatory Framework*.

[40] Intrinsik Environmental Sciences, *Review of Regulatory Framework: Phase 2 Human Health Risk Assessment of Oil and Gas Activity in Northeastern British Columbia* (B.C. Ministry of Health, 2014). http://www.health.gov.bc.ca/library/publications/year/2014/health-risk-assessment-regulatory-framework-review.pdf

[41] James Daniel Arthur et al., "Summary of environmental issues, mitigation strategies, and regulatory challenges associated with shale gas development in the United States and applicability to development and operations in Canada," presented at the Canadian Unconventional Resources and International Petroleum Conference, Calgary, October 19–21, 2010. doi:10.2118/138977-MS

[42] Nathan Richardson et al., *The State of State Shale Gas Regulation* (Resources for the Future, 2013). http://www.rff.org/files/sharepoint/WorkImages/Download/RFF-Rpt-StateofStateRegs_Report.pdf

comparable across North America), not with the intrinsic geology of the target formation and hydrology of the region (for which there may be important regional differences). For these reasons, it is important to make use of the available reports and studies conducted outside of B.C. to help inform UNGD within the province.

3.1 Implications for water

The U.S. Environmental Protection Agency (EPA) conducted an independent research review of approximately 1,200 cited sources of data and information over a five-year period to better understand the implications of the hydraulic fracturing water cycle on drinking water resources in the U.S.[43] This is the most comprehensive analysis done to date on this issue. The review identified a number of activities that are likely to result in more frequent or severe water impacts, including:

1. Water withdrawals in times or areas of low water availability
2. Spills during the management of hydraulic fracturing fluids, chemicals, or produced water that can reach surface or groundwater resources
3. Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to reach groundwater resources
4. Injection of hydraulic fracturing fluids directly into groundwater resources
5. Discharge of inadequately treated hydraulic fracturing wastewater into surface water resources
6. Disposal or storage of hydraulic fracturing wastewater in unlined pits[44]

This list demonstrates the vulnerability of water resources to UNGD, and highlights that proper management of wells and produced water is key to avoiding contamination. While not in the list of primary risk factors above, water contamination from injection has occurred in some instances in the U.S., the EPA also notes, and both the mechanical integrity of the well (or other nearby wells) and the vertical distance between the target formation and the shallow aquifer are important factors in determining the frequency and severity of contamination (though there is little evidence, aside from model predictions, to support this latter factor to date).

This research indicates clear impacts of hydraulic fracturing on drinking water resources, but also identifies significant gaps in data and analysis preventing the EPA

[43] EPA, *Hydraulic Fracturing for Oil and Gas*.

[44] Ibid.

from estimating the full scale and severity of these impacts. This emphasizes the ongoing uncertainty in the frequency and severity of the risks to drinking water posed by UNGD.

Vengosh et al. undertook a comprehensive and critical review of the risks of UNGD on water resources all across North America, including B.C., and found evidence of water contamination from the activities highlighted by the EPA through the four risk pathways described in Section 2.2.[45]

Water was also one of three issue areas explored in the Hays and Shonkoff literature review, which analyzed 58 original research studies addressing UNGD and its impact on water quality in the U.S. This review found that 69% of studies identified potential, positive association, or actual incidence of water contamination associated with UNGD.[46] While these findings do not establish a broad consensus on water quality risks from UNGD, the increasing number of studies citing adverse risks or impacts of UNGD, when paired with the report released by the EPA, should motivate scientists, industry, and regulators to continue to take this issue seriously, to act quickly to fill data and knowledge gaps, and to pursue development prudently.

3.2 Implications for public health

Hays and Shonkoff also assessed the current literature investigating impacts of UNGD on public health in the U.S. Similar to their methodology on water impacts described above, the authors grouped peer-reviewed studies based on findings of adverse public health risks or outcomes due to unconventional natural gas activity. The authors identified 31 original and relevant studies, with 84% indicating public health hazards, elevated risks, or adverse public health outcomes associated with UNGD.[47] While these findings highlight a growing scientific consensus surrounding the public health risks associated with UNGD, the authors note that the majority of papers have not established a clear cause leading to these public health outcomes, as results may be due to deterioration of drinking water quality, local air pollution, or social and economic pressures often associated with resource development. As such, most papers express the

[45] A. Vengosh et al., "A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States."

[46] Hays and Shonkoff, "Toward an Understanding of the Environmental and Public Health Impacts of Unconventional Natural Gas Development."

[47] Ibid.

need for additional studies and epidemiological research to better understand the pathways by which public health is impacted by UNGD.

To obtain a better understanding of the health implications of oil and gas development in northeastern B.C., the B.C. Ministry of Health (in partnership with the Ministry of Natural Gas Development, the B.C. Oil and Gas Commission, and others) undertook a three-year human health risk assessment in the region starting in 2012.[48] The risk assessment focused on the potential impacts of oil and gas activity on air, water, land, and food quality, and how these impacts may relate to public health, with respiratory disease and cancer identified as the two primary health concerns. It found risks of elevated air contamination in some locations, though this is rare and/or occurs only in remote areas. Overall, this assessment suggests possibly elevated concentrations of potentially concerning chemicals in the air, water, and food in some locations, but finds the probability of adverse health impacts due to this exposure to be low. The literature review associated with the risk assessment, however, occurred before the recent surge in relevant scientific studies on this topic, and as a result, includes minimal recent research on the public health impacts of UNGD in North America.

One issue area in which evidence is accumulating to suggest adverse impacts of unconventional natural gas activity on public health is the contamination of water resources by endocrine disrupting chemicals. EDCs interfere with human hormone action and, even in low concentrations, are potentially harmful to human health, particularly developmental and reproductive health.[49] Over 100 known or suspected EDCs are commonly used in hydraulic fracturing.[50] Using water samples from densely drilled and control areas in Colorado, Kassotis et al. demonstrated that unconventional oil and natural gas activity is potentially associated with the presence of EDCs in surface and groundwater.[51]

Kassotis et al. then assessed the presence and concentration of EDCs in a West Virginia deep injection disposal well, where water and soil samples collected at and downstream of the injection well showed considerably higher concentrations of hormone

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[48] More information: Government of British Columbia, "Oil and Gas Activities in Northeastern B.C." http://www2.gov.bc.ca/gov/content/health/keeping-bc-healthy-safe/oil-and-gas-activities

[49] Christopher Kassotis et al., "Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region," *Endocrinology* 155 (2014), no. 3. doi:10.1210/en.2013-1697

[50] Ibid.

[51] Ibid.

suppressing chemicals (including chemicals known to suppress estrogen, androgen, progesterone, and thyroid hormone activity) than upstream and control site samples.[52] Downstream samples contained concentrations of hormone suppressing chemicals that are known to disrupt reproduction and/or development in aquatic animals, and may also indicate toxicity to mammalian cells, though these findings were less conclusive. These chemical concentrations indicate spills and leaks of unconventional natural gas wastewater during disposal, including all processes associated with disposal such as handling and storage of wastewater. Given the prevalence of deep disposal wells in B.C., these findings should raise concerns regarding the environmental and public health impacts of EDCs related to unconventional natural gas activity in the province.

There are few studies we are aware of that assess this risk in B.C., but a recent pilot study done in northeastern B.C., including regions of intense oil and gas drilling, found concentrations of a benzene biomarker (a known EDC) in the urine of pregnant women to be over three times higher than other Canadians. Effects of these compounds on human health, including development, have been widely studied, and high exposure to benzene during pregnancy is associated with low birth weight, increased risk of childhood leukemia, and greater incidence of birth defects.[53]

Another major public health concern is the contribution of the natural gas industry to climate change. The Canadian Medical Association points out that climate change is one of the greatest threats to human health in the 21st century,[54] and growth in B.C.'s fossil fuel industry will increase emissions and exacerbate this issue. However, a full analysis of the climate change contributions of B.C.'s natural gas industry falls outside the scope of this paper.

3.3 Regulation in B.C. and North America

UNGD is largely a North American phenomenon and is already happening at a significant scale in northeastern B.C. Regulatory frameworks are in place to help mitigate the risks of this development to water resources and human health and, in

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[52] Christopher Kassotis et al., "Endocrine disrupting activities of surface water associated with a West Virginia oil and gas industry wastewater disposal site."

[53] Élyse Caron-Beaudoin et al., "Gestational exposure to volatile organic compounds (VOCs) in Northeastern British Columbia, Canada: A pilot study," *Environment International* 110 (2018). doi:10.1016/j.envint.2017.10.022

[54] Canadian Medical Association, Climate Change and Human Health (2010). https://www.cma.ca/Assets/assets-library/document/en/advocacy/PD10-07-e.pdf

general, these regulations are comparable across major North American oil and gas producing jurisdictions.[55] The B.C. government and the B.C. Oil and Gas Commission (BCOGC) have implemented an extensive regulatory system to protect water, land, air, and human health. Regulations in place in B.C. to protect water resources include setbacks, well construction and drilling practices, wastewater storage and disposal, spill response, underground injection procedures, surface water withdrawal limits during low flow periods, disclosure of fracturing fluid chemicals,[56] abandonment of inactive wells, and a regional water strategy, among others. While an exhaustive review of the regulatory practices in place in B.C. is outside the scope of this paper, it is important to acknowledge these regulations are in place.

In 2015, BCOGC contracted Ernst and Young to review the existing regulatory framework governing hydraulic fracturing in the province. Overall, the review found that hydraulic fracturing was well governed in B.C., and that B.C. is considered a leading jurisdiction in the management of surface water for oil and gas activities. While the review highlighted many opportunities to improve the regulatory system, none of these opportunities were identified as a major failing of the regulatory framework.[57]

Similarly, Intrinsik Environmental Sciences, as part of a human health assessment for northeastern B.C. ordered by the B.C. Ministry of Health, reviewed B.C.'s regulatory system. The review found the system to be broadly protective of human health. In discussing water resources, the review did note some shortcomings, including insufficient pre-drilling water testing and the lack of a requirement for surface casing to be cemented underneath the deepest underground source of drinking water.[58] In general, the study found that B.C.'s regulatory system is comparable to other major oil and gas producing jurisdictions in North America, including Alberta and the U.S.[59]

Although B.C. has a comprehensive regulatory framework in place, there is also a lack of peer-reviewed studies analyzing the risks of UNGD that these regulations aim to minimize. Improvement of this framework, therefore, requires consideration of findings

[55] Based on the jurisdictional review of North America in: Intrinsik Environmental Sciences, *Review of Regulatory Framework*.

[56] B.C. regulations require disclosure of fracturing fluids within 30 days of completing a well. This information must be provided to the BCOGC and to the public via the FracFocus website. http://fracfocus.ca/

[57] Ernst & Young, *Review of British Columbia's Hydraulic Fracturing Regulatory Framework*.

[58] Intrinsik Environmental Sciences, *Review of Regulatory Framework*.

[59] Ibid.

from all other available regions with comparable practices and regulatory regimes. So far, most research exploring UNGD is focused on the U.S., and while there are important differences in resource characteristics (such as the depth of the target formations) and operational practices (such as the B.C. ban on releasing treated or untreated wastewater into freshwater or drinking water aquifers), overall this research is occurring in a comparable regulatory context. As such, even though B.C. has a comprehensive regulatory regime in place, the province is likely not immune to many of the concerns this research identifies. Considering this, industry, regulators, and the public should continue to be concerned with findings of significant health and environmental impacts from processes that are common in B.C.

4. Conclusion

Research on the risks associated with unconventional natural gas has typically lagged behind development. However, a recent influx of literature, mostly focused on the U.S., has demonstrated evidence of risks that UNGD poses to water resources and public health. The U.S. EPA's recent study indicates that risk pathways do exist between UNGD and drinking water, and highlights considerable data gaps preventing characterization of the severity of these risks. Hays and Shonkoff identify a significant number of recent studies that find these risks to be real, with adverse impacts of UNGD on water (69% of studies) and health (84%).

Although these studies are focused on the U.S., these jurisdictions have comparable regulatory frameworks to those in place in B.C., suggesting that B.C.'s regulations may be working to mitigate risk but not fully eliminate it. In addition, this research indicates that risks to water resources from UNGD are primarily related to management of produced water and well construction practices (which are comparable across North America), and not on the intrinsic geology of the target formation and hydrology of the region. As such, these studies and findings should be considered relevant to B.C.'s context, particularly considering the scarcity of similar studies done within the province.

Given these recent findings, we caution against the assumption that the risks posed by UNGD to B.C.'s water resources and communities have been fully addressed. Hydraulic fracturing for oil and gas is a practice that continues to evolve, and it's important that the evaluation of the potential for activities associated with UNGD to impact water resources and public health keeps pace with emerging technologies and scientific findings. These risks could increase if proposed LNG development proceeds in B.C., due to an associated increase in upstream development.

The Scientific Hydraulic Fracturing Review Panel is a positive step towards increasing British Columbians' understanding of the risks that UNGD potentially poses to our province's water resources and environment. We encourage the panel to consider the broader literature and research on UNGD throughout North America and to pay specific attention to the list of management-related activities — specifically wastewater management and well construction practices — identified by the EPA and others as most likely to impact water quality.

In addition to this panel, we encourage the B.C. government to support further study of the water and health impacts of UNGD to address the data gaps and uncertainties identified by the majority of papers represented in this report, as well as to provide the review panel with adequate resources to complete a thorough assessment of the environmental risks associated with UNGD.

Lastly, we encourage the B.C. government to support industry in adopting best practices for management, while ensuring transparency in monitoring and enforcement. With LNG investment decisions once again on the horizon, it is a crucial time to gain a better understanding of the risks associated with UNGD, to assess the implications for regulatory processes, and to adjust them accordingly to minimize risks to B.C.'s citizens and environment.