Opinion: Potential Impact of Shale Gas Exploitation on Water Resources

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1. Introduction

The debate surrounding potential development of shale gas in New Brunswick has become polarized. Understandably, people are wary of this industry, particularly when it has been the subject of bad publicity. Perhaps it is important to emphasize that production of gas from shale is a new industry; not just new to our province, but to the world. In all cases when people are confronted with new circumstances, knowledge and information are required to develop an appropriate response. We are making an attempt through this article to provide objective and unbiased information that informs the debate. We are doing this because we believe it fits with the principal role of a public university – to generate and distribute knowledge for the benefit of society.

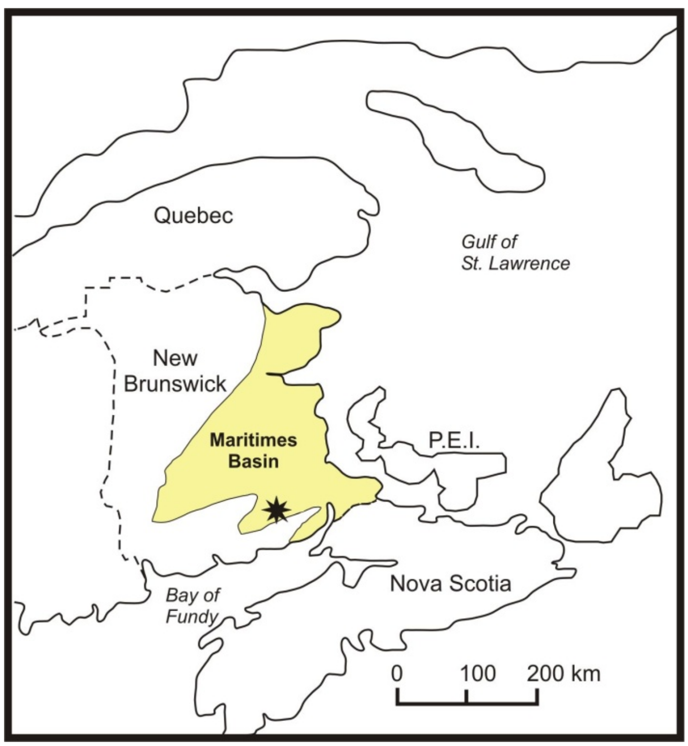
Much of the opposition to shale gas exploration and development is centered on issues of water – both quantity and quality. This article will focus on these important issues. As researchers from UNB who have significant experience and knowledge in the areas of geochemistry, hydrogeology, geophysics, and aquatic ecology, we hope that the following information is received as intended – an independent contribution to informed public debate. The authors have no connection to shale gas development.

If there are questions or comments, please send them to the authors in care of Mr. Gregoire Carriere (Gregoire.Carriere@unb.ca).

2. Life Cycle of Resource Exploitation

The life cycle of an industry built around a non-renewable resource follows a typical pattern of stages from exploration → development → production → abandonment. In the case of a resource that occurs over a large geographic area, as is potentially the case for shale gas, there will be overlap of these stages. For example, exploration could be underway in certain regions of the province while production is already occurring in other regions. This is presently the case in New Brunswick where a number of companies are exploring, while Corridor Resources is already producing gas from the McCully Field near Sussex (see Figure 1).

Figure 1. Distribution of the Maritimes Basin sedimentary rocks in New Brunswick (yellow). Gas-bearing shale units may be found at depth in these rocks. The McCully gas field is indicated by a star.



The exploration stage involves acquisition of land licenses over large areas where surface activities such as seismic surveys are conducted to identify prospective target areas. The area of land held in license usually decreases over time as exploration targets are defined and less interesting properties are released.

The development stage begins when an economic resource has been identified by exploration activities. Well pads are constructed to provide the space and stable ground surface from which the hydraulic fracturing and gas-production activities are conducted (see images of well pads at http://www.cbc.ca/nb/features/fracturedfuture/annotated_site.html). The production stage follows development when hydraulic fracturing has successfully stimulated release of gas to the well. If water has been used for stimulation then some portion of the hydraulic fracturing fluid will return to the surface (flow-back water) and must be collected for treatment, disposal or reuse. With the flow-back water recovered, the well produces gas, rapidly at the outset, but with a declining rate over time it may become necessary to re-stimulate the formation by another phase of hydraulic fracturing. When the gas is exhausted, the well would be abandoned. The wells must then be sealed and capped to prevent short circuiting between shallow freshwater resources and deep saline water. Sealing and capping wells will also prevent the escape of residual gas. The time period of production prior to re-stimulation or abandonment is dependent on the formation conditions, so for New Brunswick it is too early to say, but experience elsewhere suggests a lifespan of perhaps 10 to 20 years.

3. Groundwater in Sedimentary Basins

In New Brunswick there is potential for shale gas in sedimentary rocks that form part of what is called the Maritimes Basin (see Figure 1). This is a stratified or layered sequence of rocks that is approximately 300 to 350 million years old. The sediments that filled this basin to form these rocks were deposited in rivers, lakes and saline marine depositional environments.

Groundwater occurs below the ground surface everywhere, and the shallow rocks of the Maritimes Basin are used for groundwater supply. Wells that extract groundwater from these shallow rocks typically are drilled into the most porous and permeable formations (aquifers). Water also occurs in low-permeability formations (aquitards), however, the water in such rocks moves very slowly, or not at all, and these rocks are therefore not suitable for water supply. Even in aquifers, groundwater flows very slowly compared to streams and rivers. For example, a velocity of 100 m per year would be considered very fast moving groundwater. By contrast, stream velocities are close to 100 m per minute. The slow rate of groundwater movement is one of the reasons why we need to protect our groundwater resources because if aquifers become contaminated they cannot be “flushed” clean in a reasonable time.

Although groundwater is below the surface everywhere, it is not always suitable for consumption. By most estimates greater than 90% of groundwater is saline and therefore not potable. The salinity of groundwater generally increases with depth, and in sedimentary rocks the salinity may be traced back to sea water remaining from marine depositional environments. That means that the saline groundwater deep in these basins can be as old as the rocks themselves. Saline water has a higher density than fresh water, so like oil floating on water, the freshwater flowing in aquifers near the surface is essentially floating on the deeper, unmoving saline water. The fresh groundwater near the surface actively participates in the hydrologic cycle, and in doing so it provides vital freshwater input to ecosystems. In contrast, the high density of the deep saline water normally prevents it from moving up to discharge at the surface and joining the hydrologic cycle. In this way ecosystems are naturally protected from damaging effects of the saline water.

The depth at which groundwater changes from fresh to saline is variable from place to place because of changes in topography, climate and rock permeability. In a 2008 report on groundwater in the Maritimes Basin by the Geological Survey of Canada, the typical depth of this freshwater to saltwater transition is reported to be approximately 100 m, ranging to 300 m. Local knowledge of this transition depth is important because it defines the thickness of the fresh groundwater system that must be protected.

4. Water Supply Issues

The drilling and hydraulic fracturing of shale gas wells generally requires water which is mixed with sand and other additives and injected into the well at pressures high enough to “crack” the shale and increase the rate at which gas will flow toward the well. The quantities of water required are reported to vary depending on the depth of the well, the horizontal length of the well within the shale formation, and the permeability of the shale. Previous studies, however, suggest that quantities of between 20,000 and 60,000 cubic metres (m^3) may be required per well (20,000 m^3 is about equivalent to 8 Olympic swimming pools).

When assessing the potential impact of the water requirements for shale gas development, the cumulative aspects must be considered. For example, to increase operation efficiencies and reduce the impacted land area, a well site could have 12 to 16 horizontal wells. For 16 wells per site the water requirements could be in the range of 320,000 to 960,000 m^3, which would be required over a time period of perhaps several months during drilling and hydraulic fracturing. Water could be pumped directly from local aquifers, streams or lakes at the time of use, or collected and stored in constructed ponds for later use. The source of water and timing of extraction will be important, for example, during seasonal low flows or dry conditions, it may not be environmentally acceptable to allow additional depletion of stream flows.

If shale gas development proceeds as in other areas, the water demands will increase with time. For example in Pennsylvania shale gas drilling in the Marcellus Shale increased from 60 wells in 2007, to 1920 wells in 2011 (http://marcellus.psu.edu/resources/maps.php). If we make an assumption that at some point in the future 1000 wells would be drilled in New Brunswick in a given year, then the total amount of water required that year could be in the range of 20 million m^3 to 60 million m^3. This water demand would be about equivalent to the annual water use for two to six cities the size of Fredericton.

To supply water on a year-round basis for the drilling and hydraulic fracturing of 1000 wells would require a water supply capable of providing a continuous flow of about 0.6 to 2 m^3 per second, which is small compared to the average summer low flow in a large river like the Saint John River at Fredericton (about 400 m^3 per second). However, the future locations of gas well sites are currently unknown, and past practice suggests that water sources will be sought as close to the well sites as possible. The extraction of water from smaller local sources will require careful consideration of possible effects on existing water wells, stream flow, lakes and wetlands. These assessments and the associated monitoring of water withdrawals or diversion will require careful regulation.

Alternatives to the use of freshwater: To our knowledge, there are three principal ways to stimulate gas release from shale by fracturing. The most common method uses freshwater. In some areas, waste waters from different sources and/or recycled flow-back water are used to reduce freshwater consumption. The other two relatively new methods use either liquefied carbon dioxide (CO_2) or liquefied petroleum gas (LPG) which is greater than 90% propane but contains other hydrocarbons (for information on CO_2 fracturing see http://www.mde.state.md.us/programs/Land/mining/marcellus/Documents/Liquid_free_stimilations.pdf and for information on LPG fracturing see http://www.gasfrac.com/fracturing_process.aspx). The obvious benefits for the use of LPG and CO_2 are that there would be a decrease in water consumption and a corresponding decrease in the need for treatment and disposal of contaminated water. The LPG fracturing method has already been employed in New Brunswick by Corridor Resources.

5. Disturbance of Groundwater and Surface Water Quality

Disturbance and contamination of freshwater resources is another principal concern regarding potential impacts of shale gas development. We will discuss four possible causes: i) seismic exploration activities, ii) upward migration of hydraulic fracturing solutions through the overlying rocks, iii) upward leakage along the well casing, and iv) handling, treatment and disposal of waste water.

Seismic testing: Exploration for oil and gas involves the use of an energy source to send vibrations, known as seismic waves, into the earth. The waves are reflected back by rock layers and they are measured on surface using sensitive receivers. The two most common types of seismic sources used on land are explosive charges detonated in shot holes, and 'vibroseis' trucks that vibrate the ground surface. The risks to water resources are low, although there are three possible causes of groundwater disturbance: (i) seismic vibrations, (ii) movement of groundwater in fractures, and (iii) cross connections created by seismic shot holes.

Blasting handbooks indicate that the maximum distance for rock breakage around an explosive charge is 25 - 30 times the diameter of the shot hole. As a result, rock located more than 3 m away from a seismic shot hole is unlikely to be damaged. Vibroseis trucks, which emit weaker vibrations for a longer time period, are unlikely to induce rock fracturing. It is conceivable that water in existing fractures that intersect a shot hole may be accelerated to greater distances. Such 'squirting' of water, or vibration of a well, could disturb fine sediment and cause the water to become temporarily cloudy or turbid.

The potential for shot holes to introduce contamination to an aquifer must also be considered. While such holes are typically much shallower (typically 5 – 20 m deep) than water wells, if they are not sealed they can provide a path for surface water to infiltrate shallow aquifers. This can be a problem in areas where surface water is contaminated by agricultural or other activities.

In practice, the impacts of seismic surveys are minimized by the enforcement of regulations. Regulations require the plugging of shot holes, and prohibit the use of seismic sources within specified distances of water-supply wells. We understand that the province is currently specifying setback distances that are consistent with those used in Alberta and British Columbia – 100 m for vibroseis sources and 180 m (almost the length of two football fields) for explosive charges. It is good that the province is requiring that well water quality tests be done (with home owner consent) before and after seismic surveys for wells located within 200 m of seismic operations. These water tests should be completed within a few weeks of each other in order to minimize any differences associated with seasonal or weather-related effects.

Upward migration of fluids: There are several reasons why we would not expect hydraulic fracturing fluids to migrate upward to the surface through the overlying rocks. The principal reason relates to knowledge of the movement of high pressure fluids in horizontally layered rock formations. The permeability properties of the rock would cause pressurized fluids to spread out horizontally rather than vertically. The risk should be negligible even in the case where near-vertical fractures are present because, in the relatively soft clay-rich rocks of the Maritimes Basin, fractures are generally self sealing under the high loading pressure of the overlying rocks. A second reason relates to fluid densities. Water-based hydraulic fracturing fluids are saline and therefore have high density and do not easily move upwards into more buoyant fresh groundwater near the surface.

There are circumstances where the target shale layer may occur at shallow depths in which case we believe the risk of hydraulic fracturing fluids reaching the surface may become significant. Figure 2 presents a cross section of the sedimentary rocks in the Moncton area. The Frederick Brook member of the Albert Formation would be the principal target for shale gas exploration and the cross section demonstrates that in the centre of the basin this target occurs at depths in excess of 2000 m. However, there are locations in the southeast near Albert Mines where the Frederick Brook member reaches the surface. It seems reasonable that regulators in the province would account for increased risk at shallow depths by establishing some minimum depth for shale gas development. The occurrence of old, improperly abandoned oil and gas wells, which may be as deep as shale gas wells, presents another circumstance where hydraulic fracturing fluids could short-circuit to the surface. Here again, the regulatory system should deal with this by using the locations of old wells to define exclusion zones where gas production is not permitted.

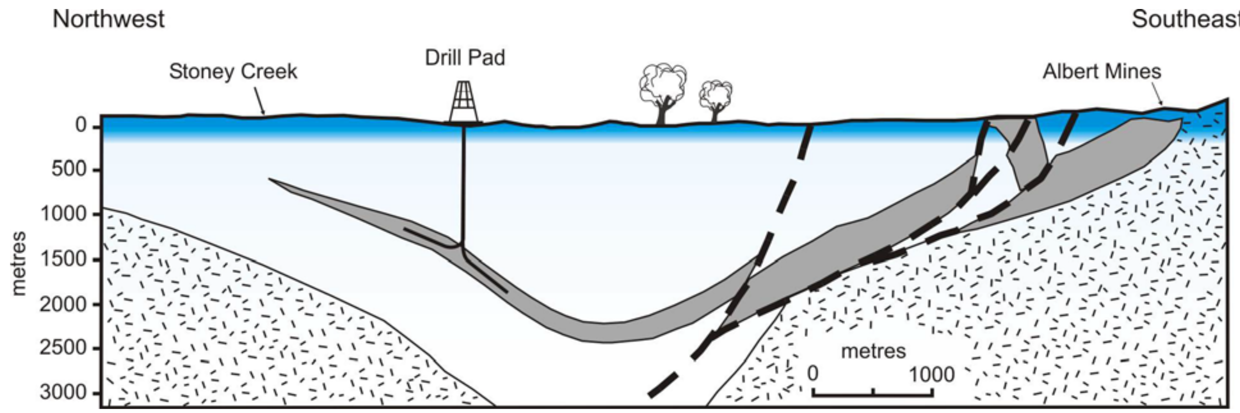


Figure 2. Simplified geologic cross section of the Moncton sub-basin in southeast New Brunswick. Sedimentary rocks of the Maritimes Basin are shown in white except for the Frederick Brook shale unit (grey) which is the principal target for shale gas exploration. The blue region near the surface represents the typical zone of fresh groundwater. The cross section is based on Figure 14 from a New Brunswick government report - St. Peter. C.J, and Johnston, S.C., 2009. Stratigraphy and structural history of the late Paleozoic Maritimes Basin in southeastern New Brunswick, Canada. New Brunswick Department of Natural Resources, Memoir 3, 348 p.

Upward leakage along the well casing: In our view, improperly constructed gas wells represent one of the principal potential pathways for contaminants from hydraulic fracturing fluids to impact fresh groundwater resources. There are many sources of information that describe the details of well construction with multiple nested strings of steel casing and cement seals between the casings and the surrounding rock, and we will not review these here. It appears that the best available practices in well construction are effective in preventing groundwater contamination when they are properly implemented. However, it is not inconceivable that a drilling contractor could cut corners in the interest of saving time (and money), or that inadvertent mistakes could be made during well construction. Recognizing this, some jurisdictions require that down-hole geophysical measurements be conducted to test the integrity of the completed well. The quality of well construction is critical for preventing shallow groundwater contamination, and we believe continuous oversight by technically-trained well-site inspectors is required. These inspectors must be independent from the industry.

Waste water: The use of large volumes of water for hydraulic fracturing leads to the unavoidable generation of large volumes of waste water and potential for ground and surface water contamination via leakage from storage lagoons and spills during transportation and water-treatment or disposal. It might be argued that the risk of leakage and spills in the shale-gas industry is no greater than from waste handling in more familiar activities such as food processing or municipal waste-water treatment. The difference is that flow-back water from hydraulic fracturing has some characteristics that limit the options for treatment or disposal. It contains high concentrations of salts, along with other toxic and biologically disruptive compounds (e.g., estrogen-mimicking chemicals). Some of these cannot be removed by conventional water treatment. The question of what to do with this waste water requires an answer. What are the options?

- The flow-back water from wells has been disposed of at publicly owned water treatment plants in some states but these plants are not designed to treat saline water and they do not remove the salinity, they only dilute it. This, in our opinion, is not an appropriate option.
- The flow-back water could be diluted and released to the environment. For example, landfilling of municipal waste leads to the generation of leachate as precipitation water infiltrates through the pile and becomes contaminated by the decomposing waste. The leachate must be collected, and in New Brunswick the site selection guidelines for sanitary landfills allow for leachate addition to streams and rivers provided a minimum dilution factor of 100 (1 part leachate to 100 parts stream water) is

maintained or exceeded. If this dilution approach was to be considered for waste water from the shale gas industry it may not be sufficient to protect aquatic organisms from chemicals that cause adverse impacts at very low concentrations. Again, we do not consider this as a suitable option for waste water disposal.

- It is our understanding that the gas industry is conducting research into the possibility of recycling flow-back water for use in subsequent operations. However, at the present time we are not aware that recycling can eliminate the need for disposal of saline flow-back water.
- Waste water brine from the potash mine in Sussex is currently piped to the Bay of Fundy for disposal. We are not aware of research that has investigated the ecological impacts of this practice, and we do not believe that it would be prudent to increase the loading of waste water to the Bay of Fundy without a comprehensive science-based assessment of the ecological risks.
- There are technologies such as reverse osmosis that can be used to desalinate brines. Desalination produces freshwater and a concentrated residual brine. The brine contains the original amount of salts and other chemicals in a smaller volume, so the problem of disposal of the waste remains.
- For decades the petroleum industry has been producing saline brines from conventional petroleum wells. Those brines are similar to the flow back water from hydraulic fracturing operations and the industry has used deep injection wells for disposal with good results (see the United States Environmental Protection Agency, US EPA, video on deep injection wells at http://water.epa.gov/type/groundwater/uic/wells_class1.cfm). In general, deep waste injection wells are a good option for disposing of saline waste water because the groundwater at depth is equally saline, and as mentioned previously, the deep groundwater systems generally do not mix with the shallow freshwater systems. In 2001 the US EPA studied the risks associated with deep waste injection wells. Their report is available at http://www.epa.gov/ogwdw/uic/pdfs/study_uic-class1_study_risks_class1.pdf. We are not aware of any deep waste injection wells in operation in New Brunswick. This may be a viable option for disposal of waste water from hydraulic fracturing but it would require a significant investment of time and resources to explore for deep saline aquifers that would have the capacity to store very large volumes of waste water. However, it is uncertain that suitable aquifers could be found because the Maritimes Basin is mostly comprised of low permeability rocks.

6. Summary: Opinions Regarding Realistic Risk to Ground and Surface Freshwater Resources

The motivation for writing this article was to offer science-based opinions on the water-related concerns that have been prominent in the New Brunswick shale-gas debate. It should be clear from the previous discussion that, if the choice of technology is hydraulic fracturing with water, then we share some of the concerns regarding water consumption and waste water treatment and disposal. With the goal of providing a positive contribution, if a shale gas industry is to develop in New Brunswick then we offer the following suggestions.

- Decisions regarding the allocation of water resources should be based on an assessment of sustainable yield that considers hydrologic water balance and ecosystem requirements.
- Alternative water sources should be considered (e.g. waste brines from potash mining).
- The impact of seismic testing on groundwater supplies is expected to be minimal provided there is conformance with relevant regulations.
- The risk of groundwater contamination due to leakage upward along gas well casings should be very low if best practices for well construction are followed. We recommend that independent technically-trained well-site inspectors provide continuous oversight at the well head during the critical stages of well construction.
- Hydraulic fracturing should not proceed unless there is an environmentally responsible option for disposal of waste water.
- In order to optimize water use, and limit uncontrolled releases of contaminated flow-back water, we recommend the implementation of a strict system of accounting. The volume and composition

of water moving through the cycle from initial purchase, through to disposal, should be tracked, recorded and reported.

- Saline wastewater should not be sent to public water treatment plants or diluted into surface water courses.
- Recycling of flow-back water should be encouraged.
- The use of deep waste-water injection wells should be considered.
- In developing new regulations for this industry, consideration should be given to establishing exclusion zones. One way to define exclusion zones would be on the basis of depth to the resource. A minimum depth would be established, above which hydraulic fracturing operations would not be permissible. Establishment of a minimum depth should be based on scientific principles. There may be other worthwhile criteria for defining exclusion zones such as proximity to property boundaries, water wells and abandoned petroleum wells.

One thing that is surprising is the lack of debate on hydraulic fracturing with water versus CO_2 or LPG. Our focus in this article is on water so we do not address the pros and cons of CO_2 and LPG fracturing. However, the one very obvious benefit of CO_2 or LPG fracturing is that it does not require water. Most of the concerns about water consumption and contamination are consequently diminished. In the interest of getting it right, we believe the CO_2 and LPG fracturing technologies deserve serious consideration.

7. Contributor's Background and Expertise

Dr. Tom Al is a professor in the Department of Earth Sciences at the University of New Brunswick in Fredericton. His expertise is in the areas of hydrogeology, water geochemistry and groundwater contamination. For 20 years his research has focused on environmental geoscience related to waste management in the mining and nuclear-energy industries, water supplies, and industrial contaminants in groundwater.

Dr. Karl Butler is a professor in the Department of Earth Sciences and Director of the Program in Geological Engineering at the University of New Brunswick in Fredericton. He has over 20 years research experience concerning applications of geophysics to resource exploration, engineering, and the environment with an emphasis on aquifers, groundwater, and geotechnical issues.

Dr. Rick Cunjak is a professor and Canada Research Chair in River Ecosystem Science at the University of New Brunswick (Fredericton). He holds a joint appointment in the Department of Biology and the Faculty of Forestry & Environmental Management. He was the founding director of the Canadian Rivers Institute. He has more than 30 years experience studying freshwater ecology and fish biology, including human impacts from hydroelectric operations, forestry and agriculture.

Dr. Kerry MacQuarrie is a professor in the Department of Civil Engineering, a member of the Canadian Rivers Institute, and a Canada Research Chair in groundwater–surface water interaction. He has over 20 years of research experience in the areas of hydrology, contaminant hydrogeology, municipal drinking water supply, and agricultural impacts on groundwater quality.