Évaluation du chapitre V du RPEP

Compilation ciblée de la littérature scientifique pertinente

Risques environnementaux pour la sous-surface

Références générales faisant la définition des risques environnementaux des puits de pétrole et gaz et de leurs encadrements réglementaires

Références	Constats spécifiques et citations
	Références générales
Lefebvre, R., 2017. Mechanisms leading to potential impacts of shale gas development on groundwater quality. *WIREs Water*, 4(1), Jan./Feb. 2017, 15 pp., doi: 10.1002/wat2.1188.	**Résumé :** Development of shale gas resources was made possible by the combination of horizontal drilling and high-volume hydraulic fracturing (fracking). Environmental concerns have been raised relative to shale gas production, especially potential impacts on groundwater. Fluids related to unconventional O&G operations contain chemical compounds that can impact groundwater quality. Such impacts can occur due to 1) the infiltration of surface contaminant releases, 2) failures of the integrity of oil and gas (O&G) wells and 3) upward fluid migration from a shale/tight reservoir along preferential paths that can be natural (faults or fracture zone) or man-made (O&G wells). Surface releases represent the most probable mechanism leading to groundwater contamination. Improvements in O&G drilling operations under stringent regulations can minimize this risk. Experts identify O&G well integrity as the most challenging issue that may lead to groundwater contamination. Failure of casing and cement can lead to upward fluid flow within or outside O&G wells, especially of methane. Integrity failures leading to fluid migration to shallow fresh water aquifers or to the surface are well-understood and can be detected and repaired, but this can be complex and costly. A few regulators now impose groundwater monitoring to detect impacts from integrity failures. Occurrences of communication with existing O&G wells from fracking operations have also led some regulators to impose rules aiming to avoid such potential fluid migration paths. There is an on-going scientific debate regarding the potential for fluids to migrate upward from exploited shale gas units to aquifers through natural preferential paths.
Centre Hydrocarbures Non Conventionnels (CHNC), 2017. Pétrole et gaz de schiste : Développements internationaux. France, Mars 2017, 82 p.	**Extrait de l'avant-propos :** Depuis quelques années, la production de pétrole et gaz de schiste bouleverse profondément la donne énergétique mondiale en modifiant les relations entre pays producteurs et consommateurs. C'est aux États-Unis, pays pionnier dans l'exploration et l'exploitation de pétrole et de gaz de schiste, que la production est la plus avancée. En quelques années, ce pays, qui était il y a dix ans le premier pays importateur, est devenu autonome pour sa consommation de gaz et a réduit très fortement ses importations de pétrole. En ce début d'année 2017, après plusieurs mois d'adaptation de cette industrie a la baisse du prix du baril, les activités d'exploration sont en forte reprise et les exportations de gaz sous forme de GNL et de pétrole prennent de l'ampleur. Le pétrole et gaz de schiste font aujourd'hui partie du paysage énergétique, non seulement en Amérique du Nord, mais également dans d'autres régions du monde. C'est le cas en particulier pour l'Argentine et la Chine, qui connaissent leurs premières productions commerciales et affichent des ambitions fortes de développement. D'autres pays s'intéressent à ces nouvelles ressources et les intègrent dans leurs politiques énergétiques. Comment les producteurs de pétrole et gaz de schiste ont-ils mené ces développements et quelles sont les tendances actuelles. Quels sont les pays qui cherchent à développer leurs réserves. Quels sont les enjeux qui se présentent à eux, tant sur les plans techniques, économiques et sociétaux. Comment inscrivent-ils ces projets en cohérence avec leurs objectifs environnementaux. Ce sont ces questions que le présent ouvrage aborde sous un angle synthétique, à partir d'exemples sélectionnés sur l'ensemble des continents, avec des stades de développement très différents et des expériences contrastées propres à chaque pays.
U.S. Environmental Protection Agency (U.S. EPA), 2016. Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States	**Extrait du rapport sommaire (*Executive Summary*) :** The goals of the study were to assess the potential for activities in the hydraulic fracturing water cycle to impact the quality or quantity of drinking water resources and to identify factors that affect the frequency or severity of those impacts.

(Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/236F, 2016.	The hydraulic fracturing water cycle describes the use of water in hydraulic fracturing, from water withdrawals to make hydraulic fracturing fluids, through the mixing and injection of hydraulic fracturing fluids in oil and gas production wells, to the collection and disposal or reuse of produced water. These activities can impact drinking water resources under some circumstances. The following combinations of activities and factors are more likely than others to result in more frequent or more severe impacts: • Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources; • Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources; • Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources; • Injection of hydraulic fracturing fluids directly into groundwater resources; • Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources; and • Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources.
Acatech (Ed.), 2016. Hydraulic Fracturing - A technology under debate (Acatech POSITION PAPER). Acatech – National Academy of Science and Engineering, Munich, Germany, 59 pp. www.acatech.de/publications	**Extraits du sommaire (*Executive Summary*) :** (…) Addressing the various facets of fracking, the paper wishes to contribute to objectifying the debate. It aims at broadening the available information base by a comprehensive scientific and technical overview of the method and its risks and benefits. This will allow decision-makers from politics as well as interested members of the public to draw their own conclusions about hydraulic fracturing and to decide on the further use of the technology. (…) There are several major environmental risks that are commonly attributed to fracking – particularly since reports on shale gas production in the United States fuelled the public debate. These risks include: contaminants infiltrating from the surface into drinking water horizons as a result of accidents or technical failures, toxic or environmentally hazardous substances and methane being released and ascending to the surface out of and along leaking boreholes as well as contaminants escaping from the fracked rock and rising up to the surface and emissions of methane into the atmosphere. Other concerns include the large land areas required for fracking, the significant amount of water used in the process, and, in particular, the phenomenon known as induced seismicity. (…) Best Practice: Options and recommendations for hydraulic fracturing acatech has drawn up a comprehensive list of best practice measures aimed at minimising any environmental risks that might arise in the context of hydraulic fracturing operations. These include: • Preparatory geological and geophysical studies and 3D-modelling of the subsurface: (…) • Site-specific risk assessment of the well site and drilling strategy: (…) • Baseline measurements and long-term monitoring: (…) • Frac-fluids: (…) • Flowback: (…) • Cluster drilling: (…) • Induced seismicity/seismic monitoring: (…) • Well Integrity Management System: (…) • Well integrity monitoring: (…) • Communication with the media and public: (…) Conclusion Scientific or technical facts do not justify a general ban on hydraulic fracturing. Its use should, however, be subject to strict safety standards and requires clear regulations and comprehensive monitoring. In Germany, high technical standards are already in place for the various different process steps involved in drilling, reservoir engineering and fracking. These standards would also have to be observed for potential shale gas production or the recovery of deep geothermal energy.

CNBFH (Commission du Nouveau-Brunswick sur la Fracturation Hydraulique), 2016. Éventuelles retombées de l'exploitation du gaz de schiste sur l'économie, l'environnement et la santé – Volume II. Février 2016.	Le rapport contient plusieurs recommandations pour la réduction de divers types de risques liés à la fracturation hydraulique. **Conclusion du rapport :** Nous concluons notre travail sur la Commission en nous tournant vers l'avenir. Bien que nous soyons encore préoccupés par les graves défis que doit relever la province, nous pensons qu'un nombre important de Néo-Brunswickois éprouve un désir commun, soit de commencer la transition vers une nouvelle réalité économique et environnementale. Tel qu'il a été mentionné précédemment, toute activité d'exploitation comporte un certain niveau de risque. Notre objectif doit être de gérer et d'atténuer les risques les plus susceptibles de perturber la vie dans les collectivités. L'industrie du gaz de schiste pourrait générer environ 200 millions de dollars en redevances pour la population du Nouveau- Brunswick, mais cela comporte des risques qui ne peuvent pas tous être atténués. Le présent rapport, qui comporte un examen détaillé des risques et avantages potentiels de l'exploitation du gaz de schiste, se veut un guide à l'intention des décideurs pendant qu'ils déterminent s'il faut poursuivre l'exploitation du gaz de schiste. Il est important de comprendre le tableau complet de l'impact que les activités d'exploitation du gaz de schiste et plus particulièrement la fracturation hydraulique peuvent avoir sur la vie des Néo-Brunswickois pour choisir la direction que nous devons tous emprunter pour rétablir la confiance mutuelle et dans nos institutions.
Gallegos, T.J., and Varela, B.A., 2015. Trends in hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010—Data analysis and comparison to the literature: U.S. Geological Survey Scientific Investigations Report 2014–5131, 15 p., *http://dx.doi.org/10.3133/sir20145131*.	**Sommaire du rapport (*Abstract*) :** Hydraulic fracturing is presently the primary stimulation technique for oil and gas production in low-permeability, unconventional reservoirs. Comprehensive, published, and publicly available information regarding the extent, location, and character of hydraulic fracturing in the United States is scarce. This national spatial and temporal analysis of data on nearly 1 million hydraulically fractured wells and 1.8 million fracturing treatment records from 1947 through 2010 (aggregated in Data Series 868) is used to identify hydraulic fracturing trends in drilling methods and use of proppants, treatment fluids, additives, and water in the United States. These trends are compared to the literature in an effort to establish a common understanding of the differences in drilling methods, treatment fluids, and chemical additives and of how the newer technology has affected the water use volumes and areal distribution of hydraulic fracturing. Historically, Texas has had the highest number of records of hydraulic fracturing treatments and associated wells in the United States documented in the datasets described herein. Water-intensive horizontal/directional drilling has also increased from 6 percent of new hydraulically fractured wells drilled in the United States in 2000 to 42 percent of new wells drilled in 2010. Increases in horizontal drilling also coincided with the emergence of water-based "slick water" fracturing fluids. As such, the most current hydraulic fracturing materials and methods are notably different from those used in previous decades and have contributed to the development of previously inaccessible unconventional oil and gas production target areas, namely in shale and tight-sand reservoirs. Publicly available derivative datasets and locations developed from these analyses are described.
U.S. Department of Energy (U.S. DOE), 2015. Report on the Multiagency Collaboration on Unconventional Oil and Gas Research. Report to Congress, December 2015, United States Department of Energy, Washington, DC 20585, 21 pp.	**Sommaire du rapport (*Executive Summary*) :** America's abundant unconventional oil and gas (UOG) resources are vital components of our Nation's energy portfolio. UOG development can enhance America's energy, economic, and environmental security; however, these resources must be extracted in a prudent manner. The Department of Energy (DOE)—on behalf of the Multiagency Collaboration (MAC)—submits this Report to Congress detailing the accomplishments and next steps for each of seven research topics that DOE, the Department of Interior, and the Environmental Protection Agency (Agencies) identified in the multiagency UOG Research Strategy.[1] The goal of research conducted under this Strategy is to provide information to stakeholders in support of safely and responsibly developing domestic UOG resources. The overview section of this Report highlights the major accomplishments from the three agencies. Subsequent sections provide more detail on examples of key activities, research accomplishments, examples of remaining knowledge gaps, and examples of possible next steps. The Agencies have collaborated on some of their research activities, coordinated with others**,** and shared the results of their work. In addition to interagency communication, the Agencies also communicate the results of their work with stakeholders, including Congress, the Executive Office of the President, States, tribes, other federal agencies, industry, academia, non-governmental organizations, local officials, and the public. Throughout our outreach efforts at various venues, the MAC, has presented its research activities, results, and remaining knowledge gaps for each of the research topics identified in the Strategy. Each research topic has been divided into three subsections: research activities overview; research results, including key accomplishments, and remaining knowledge gaps and possible next steps. Progress has been made on some of the research topics, but more research and development is needed to continue advancing the information available to decision-makers.

	The following includes important research needs: • Understanding potential impacts on water quality and availability over the entire cycle of UOG operations, • Developing best practices and mitigation technologies for UOG development, • Understanding the relationship between induced seismicity and UOG operations, • Evaluating UOG-related air emissions and possible impacts on human health and the environment, • Understanding the composition of UOG hydraulic fracturing fluids and/or wastewaters and potential risk, • And understanding the environmental pathways that could lead to exposures to toxic chemicals during extraction and waste management activities. Given congressionally appropriated resources consistent with the President's Budget requests, the Agencies look forward to working together and with others in the future.
Ryan, M. C., D. Alessi, A. B. Mahani, A. Cahill, J. Cherry, D. Eaton, R. Evans, N. Farah, A. Fernandes, O. Forde, P. Humez, S. Kletke, B. Ladd, J. M. Lemieux, B. Mayer, K. U. Mayer, J. Molson, J. Muehlenbachs, A. Nowamooz, and B. Parker. 2015. Subsurface Impacts of Hydraulic Fracturing: Contamination, Seismic Sensitivity, and Groundwater Use and Demand Management. 138 pp. http://www.cwn-rce.ca/assets/resources/pdf/Hydraulic-Fracturing-Research-Reports/Ryan-et-al-2015-CWN-Report-Subsurface-Impacts-of-Hydraulic-Fracturing.pdf	**Sommaire (*Executive Summary*) :** A major concern with unconventional gas development relates to hydraulic fracturing and the associated risk of adverse subsurface impacts, including groundwater contamination, induced seismicity, and unsustainable groundwater use. As extraction of tightly-bound natural gas becomes more economically feasible due to improved technologies, unconventional gas development is likely to expand. However, many knowledge gaps exist regarding environmental impacts from hydraulic fracturing, and it is vital to groundwater resources and environmental protection that these are addressed and filled. This report reviews ten of the most important knowledge gaps around subsurface impacts from hydraulic fracturing, each in their own section of the report, in which the authors assess the current state of knowledge, identify the knowledge gaps themselves, and provide general research approaches to address these gaps. Sections 1-3 pertain to stray gas and water quality issues. Section 1 focuses on baseline water quality and the natural methane system in the absence of hydraulic fracturing activities, which first must be understood in order to identify impacts from hydraulic fracturing. While many aspects of the methane system are well constrained, our understanding is not complete, especially regarding the intermediate zone and on time scales relevant to shale gas development. Furthermore, current monitoring strategies largely rely on domestic water wells, which are useful to understand *well water quality*, but offer insufficient information about *groundwater quality* and subsurface hydrogeochemical processes. Section 2 identifies challenges in understanding stray gas migration from production and intermediate zones. Leaking wells have been established to be an important source of stray gas, but there is little research on the role of natural fractures and faults in creating pathways for methane to reach shallow aquifers. Additionally, it is difficult to track and predict methane migration due to ebullition, degassing, and oxidation. In Section 3, several knowledge gaps are identified relating to water quality impacts from stray gas in shallow aquifers. Accumulation of free methane can result in an explosion hazard, while biogeochemical reactions that remove methane such as bacterial sulfate reduction can form H2S and increase solubility of metals, affecting water quality from health-based and aesthetic concerns. However, there is a lack of high-quality scientific data in the peer-reviewed literature to understand the real risk to drinking water. Section 4 examines mathematical models as a tool to understand water quality impacts from hydraulic fracturing. Advanced new models that include coupled geo-mechanical and multi-phase flow and reactive processes are needed together with reliable field data for model calibration and testing. Importantly, test sites need to be established where deep and shallow groundwater can be monitored to improve process understanding and to help detect the impacts of shale-gas extraction activities. Section 5 addresses the risk of induced seismicity from hydraulic fracturing. Although there have been few occurrences of felt seismicity from hydraulic fracturing compared to other activities (e.g. waste water disposal), seismic events have been associated with shale gas activity in Canada and the U.S. The serious nature of potential consequences requires consideration of inherent hazards of fault-slip triggering during fracturing operations. Major challenges exist in understanding the relationship between various factors of hydraulic fracturing (e.g. injection volume, rate, reservoir pressure, etc.) and induced seismicity, as well as how to identify critically stressed faults. Sections 6-8 consider groundwater quantity issues in relation to hydraulic fracturing. Findings within these sections reveal a lack of accessible and easily interpretable data regarding groundwater use for shale gas extraction activities. Section 6 examines how much groundwater is used in hydraulic fracturing, a question that is difficult to answer in part due to different permitting, regulating, and reporting standards in each province. In many cases, regulations were establishes several decades ago, before the rapid development of shale gas extraction. Gaps in information about groundwater use lead to incomplete understanding of the impact on the overall water budget, the subject of Section 7. Canada is a water-rich country, and thus effects are likely to be local. This section highlights the goal to avoid incidence, as Canada is in a position to prevent water scarcity issues. Section 8 investigates impacts of groundwater use for hydraulic fracture on other users in the water market. A lack of accessible data constitutes the largest

	challenge in addressing this knowledge gap. Section 9 explores the challenges in understanding externalities related to subsurface impacts from hydraulic fracturing. For instance, perceptions of groundwater contamination can have significant economic impacts, such as changes in the housing market, even if those risks are not real. This section shows that to fully understand all external impacts of hydraulic fracturing, a full cost-benefit analysis is needed. Section 10 reviews the knowledge gaps around the chemicals injected into the subsurface in the hydraulic fracturing process and deep well injection. The former subject is currently not considered to be a high priority, but was the topic that garnered significant public attention early in the hydraulic fracturing process. The principal knowledge gap around deep well injection are related to Section 5 (induced seismicity) insofar as induced fractures may provide pathways by which frack chemicals might migrate out of the target zone.
Council of Canadian Academies (CCA), 2014. Environmental impacts of Shale Gas Extraction in Canada. The expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction, Council of Canadian Academies, Ottawa, ON, Canada, 262 pp.	**Extraits du sommaire (*Executive Summary*) :** The assessment of environmental impacts is hampered by a lack of information about many key issues, particularly the problem of fluids escaping from incompletely sealed wells. If wells can be sealed, the risk to groundwater is expected to be minimal, although little is known about the mobility and fate of hydraulic fracturing chemicals and wastewater in the subsurface. The pertinent questions are difficult to answer objectively and scientifically, either because the relevant data have not been obtained; because some relevant data are not publicly available; or because existing data are of variable quality, allow for divergent interpretations, or span a wide range of values with different implications. Two issues of particular concern to panel members are water resources, especially groundwater, and GHG emissions. Both relate to well integrity. Many of the operational procedures used in shale gas extraction are similar to those used in conventional oil and gas extraction. Thus industry experience is relevant to understanding these issues. Environmental impacts to water Accidental surface releases of fracturing chemicals and wastewater, and changes in hydrology and water infiltration caused by new infrastructure, may affect shallow groundwater and surface water resources. A risk to potable groundwater exists from the upward migration of natural gas and saline waters from leaky well casings, and possibly also natural fractures in the rock, old abandoned wells, and permeable faults. These pathways may allow for migration of gases and possibly saline fluids over long time scales, with potentially substantial cumulative impact on aquifer water quality. The risks due to surface activities will likely be minimal if proper precautionary management practices are followed. However, not enough is known about the fate of the chemicals in the flowback water to understand potential impacts to human health, the environment, or to develop appropriate remediation. Monitoring, assessment, and mitigation of impacts from upward migration are more difficult than for surface activities. The greatest threat to groundwater is gas leakage from wells for which even existing best practices cannot assure long-term prevention. The degree to which natural assimilation capacity can limit the impacts of well leakage is site specific due to variability in the magnitude of natural gas fluxes (or loadings) and aquifer hydro-geochemical compositions. These potential impacts are not being systematically monitored, predications remain unreliable, and approaches for effective and consistent monitoring need to be developed. On average, about one-quarter to half of the water used in a single hydraulic fracturing treatment returns up the well to the surface after stimulation. This return flow, or flowback, is a potentially hazardous waste because it typically contains hydrocarbons including variable amounts of benzene and other aromatics, fracturing chemicals, and potentially hazardous constituents leached from the shale (e.g., salts, metals, metalloids, and natural radioactive constituents). Although flowback water is now commonly re-used in later fracturing treatments, a fraction eventually remains that poses technical challenges for treatment where deep wastewater injection for disposal may not be feasible (e.g., eastern Canada).
Vengosh, A., R. B. Jackson, N. Warner, T. H. Darrah, and A. Kondash, 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environ Sci Technol*, 48: 8334-48.	**Résumé (*Abstract*) :** The rapid rise of shale gas development through horizontal drilling and high volume hydraulic fracturing has expanded the extraction of hydrocarbon resources in the U.S. The rise of shale gas development has triggered an intense public debate regarding the potential environmental and human health effects from hydraulic fracturing. This paper provides a critical review of the potential risks that shale gas operations pose to water resources, with an emphasis on case studies mostly from the U.S. Four potential risks for water resources are identified: (1) the contamination of shallow aquifers with fugitive hydrocarbon gases (i.e., stray gas contamination), which can also potentially lead to the salinization of shallow groundwater through leaking natural gas wells and subsurface flow; (2) the contamination of surface water and shallow groundwater from spills, leaks, and/or the disposal of inadequately treated shale gas wastewater; (3) the accumulation of toxic and radioactive elements in soil or stream sediments near disposal or spill sites; and (4) the overextraction of water resources for high-volume hydraulic fracturing that could induce water shortages or conflicts with other water users, particularly in water-scarce areas. Analysis of published data (through January 2014) reveals evidence for stray gas contamination, surface water impacts in areas of intensive shale gas development, and the accumulation of radium isotopes in some disposal and spill sites. The direct

	contamination of shallow groundwater from hydraulic fracturing fluids and deep formation waters by hydraulic fracturing itself, however, remains controversial.
Rivard, C., D. Lavoie, R. Lefebvre, S. Séjourné, C. Lamontagne, E. G. Johnson, and M. J. Duchesne, 2014. An overview of Canadian shale gas production and environmental concerns. *International Journal of Coal Geology (IJCG)*, 126: 64-76.	**Résumé (*Abstract*) :** Production of hydrocarbons from Canadian shales started slowly in 2005 and has significantly increased since. Natural gas is mainly being produced from Devonian shales in the Horn River Basin and from the Triassic Montney shales and siltstones, both located in northeastern British Columbia and, to a lesser extent, in the Devonian Duvernay Formation in Alberta (western Canada). Other shales with natural gas potential are currently being evaluated, including the Upper Ordovician Utica Shale in southern Quebec and the Mississippian Frederick Brook Shale in New Brunswick (eastern Canada). This paper describes the status of shale gas exploration and production in Canada, including discussions on geological contexts of the main shale formations containing natural gas, water use for hydraulic fracturing, the types of hydraulic fracturing, public concerns and on-going research efforts. As the environmental debate concerning the shale gas industry is rather intense in Quebec, the Utica Shale context is presented in more detail.
The Royal Society and Royal Academy of Engineering (RS & RAE), 2012. Shale Gas Extraction in the U.K.: A Review of Hydraulic Fracturing. The Royal Society and The Royal Academy of Engineering, London, United Kingdom, 75 pp.	**Extraits du résumé (*Summary*) :** The health, safety and environmental risks associated with hydraulic fracturing (often termed 'fracking') as a means to extract shale gas can be managed effectively in the UK as long as operational best practices are implemented and enforced through regulation. Hydraulic fracturing is an established technology that has been used in the oil and gas industries for many decades. The UK has 60 years' experience of regulating onshore and offshore oil and gas industries. (…) Concerns have been raised about the risk of fractures propagating from shale formations to reach overlying aquifers. The available evidence indicates that this risk is very low provided that shale gas extraction takes place at depths of many hundreds of metres or several kilometres. Geological mechanisms constrain the distances that fractures may propagate vertically. Even if communication with overlying aquifers were possible, suitable pressure conditions would still be necessary for contamination to flow through fractures. More likely causes of possible environmental contamination include faulty wells, and leaks and spills associated with surface operations. Neither cause is unique to shale gas. Both are common to all oil and gas wells and extractive activities. Ensuring well integrity must remain the highest priority to prevent contamination. (…) Monitoring should be carried out before, during and after shale gas operations to inform risk assessments. Methane and other contaminants in groundwater should be monitored, as well as potential leakages of methane and other gases into the atmosphere. (…) An Environmental Risk Assessment (ERA) should be mandatory for all shale gas operations. Risks should be assessed across the entire lifecycle of shale gas extraction, including risks associated with the disposal of wastes and abandonment of wells. Seismic risks should also feature as part of the ERA.
	Références sur le Québec
Évaluation environnementale stratégique (ÉES), 2016a. Évaluation environnementale stratégique sur les hydrocarbures - Rapport sur l'ensemble de la filière des hydrocarbures. Gouvernement du Québec, Mai 2016, Bibliothèque et Archives nationales du Québec, ISBN : 978-2-550-75723-8 (PDF), 198 pp.	**Sommaire :** L'évaluation environnementale stratégique (EES) est un processus analytique et participatif en amont de la prise de décision stratégique visant à intégrer les considérations environnementales dans les politiques, les plans et les programmes et à évaluer leurs interactions avec les considérations économiques et sociales, et ce, afin d'éclairer la prise de décision.1 L'EES sur l'ensemble de la filière des hydrocarbures (EES globale) et celle propre à l'île d'Anticosti ont permis : de dresser le bilan des connaissances actuelles et des connaissances acquises dans le cadre du Plan d'acquisition de connaissances additionnelles (PACA); de circonscrire les impacts environnementaux, sociaux et économiques potentiels; déterminer les mesures d'atténuation pour mettre en valeur de façon responsable les ressources en assurant la protection des personnes et des biens et en respectant l'environnement; d'établir les bonnes pratiques légales et réglementaires qui devraient s'appliquer à cette industrie; de définir les besoins en matière de connaissances additionnelles qui devraient être acquises par le gouvernement ou par l'industrie.

	Au terme des présentes EES, les besoins en matière de connaissances additionnelles ont été définis et sont résumés dans la section 4 pour l'EES globale et dans la section 5 pour l'EES propre à l'île d'Anticosti. Plusieurs de ces connaissances pourraient être acquises pendant les travaux d'exploration ou même d'exploitation des hydrocarbures, selon des conditions et des obligations que le gouvernement pourrait inclure dans le nouveau cadre législatif et réglementaire. Il convient de mentionner que les travaux réalisés et les connaissances additionnelles acquises dans le cadre de l'EES globale et de l'EES propre à l'île d'Anticosti ont contribué à combler, en grande partie, les lacunes qui avaient été relevées dans l'EES sur le gaz de schiste et dans les précédentes EES. Le sommaire présente les principales considérations dont le gouvernement devrait tenir compte dans sa réflexion sur l'industrie des hydrocarbures et dans la décision qui en résultera.
Évaluation environnementale stratégique (ÉES), 2016b. Évaluation environnementale stratégique sur les hydrocarbures - Rapport propre à l'île d'Anticosti. Gouvernement du Québec, Mai 2016, Bibliothèque et Archives nationales du Québec, ISBN : 978-2-550-75724-5 (PDF), 108 pp.	**Recommandations en relation avec la contamination des nappes :** La contamination des nappes phréatiques découlant de la fracturation hydraulique peut être occasionnée par une défaillance de l'équipement, des réservoirs ou des puits, par une erreur humaine ou par d'autres causes telles que les conditions climatiques et le vandalisme. À ce sujet, il y aurait lieu : de caractériser l'état initial des nappes phréatiques; de déterminer le risque de migration des fluides vers les aquifères par des fissures naturelles ou induites; d'utiliser une membrane imperméable sur le site pour réduire l'impact des fuites et la contamination des sols; de stocker les eaux usées dans des réservoirs fermés et de les manipuler avec précaution, en particulier lorsqu'elles sont transportées, en s'assurant de ne pas contaminer le milieu naturel par ruissellement ou par infiltration; d'installer des bermes en bordure des sites de forage pour diminuer les impacts des fuites et la contamination des sols; d'implanter une usine de traitement des eaux centralisée avec rejet en mer (phase exploitation); d'élaborer un plan de gestion des matières résiduelles; d'instaurer un suivi de la qualité des eaux souterraines, conformément au RPEP.
Malo, M., Lefebvre, R., Comeau, F.-A. et S. Séjourné, 2015. Synthèse des connaissances portant sur les pratiques actuelles et en développement dans l'industrie pétrolière et gazière – Chantier technique, R-1553. Institut national de la recherche scientifique – Centre Eau Terre Environnement, Janvier 2015, 142 p.	**Extraits du sommaire :** Le présent rapport propose une synthèse des connaissances portant sur les pratiques actuelles et en développement dans l'industrie pétrolière et gazière. Les techniques d'exploration suivantes sont décrites : levés géochimiques, levés géophysiques, sondages stratigraphiques, forage pétrolier, fracturation hydraulique, techniques de fermeture des puits et de restauration des sites. Pour chacune des techniques, le rapport discute des risques d'impact et des mesures de mitigation appropriées. Les techniques spécifiques au milieu marin sont brièvement abordées, soit la sismique marine, les forages pétroliers en milieu marin, et les techniques impliquées pour le démantèlement des infrastructures. L'évolution des techniques qui ont permis l'exploitation des ressources non conventionnelles est présentée par la suite. Selon notre mandat, nous avons analysé plus particulièrement les risques potentiels de migration des hydrocarbures dans les puits et les risques de sismicité suite à la fracturation hydraulique à haut volume, technique la plus souvent utilisée pour exploiter les ressources non conventionnelles. Les principales avancées technologiques déjà mises en pratique ou en devenir, en ce qui a trait aux opérations sur le terrain pour le gaz et le pétrole de shale, sont également décrites. En guise de conclusion, nous établissons l'état des connaissances pour les techniques d'exploration en milieu terrestre et marin, et pour les risques de migration et de sismicité. Pour chacun de ces thèmes, nous établissons les lacunes générales de connaissances, les lacunes de connaissances spécifiques au Québec, et enfin nous dressons une liste de recommandations d'acquisition de connaissances pour alimenter les évaluations environnementales stratégiques en cours, soit celle pour la filière du gaz et du pétrole au Québec et celle spécifique à l'île d'Anticosti. Pour les techniques en développement, nous dressons plutôt des constats sur les avantages et inconvénients d'utilisation de ces techniques dans le contexte de l'exploration et de l'exploitation des hydrocarbures au Québec. (…) Le bilan des risques de migration Le transfert et le stockage des liquides aux sites de forage des puits pétroliers et gaziers représentent le principal risque de contamination de l'eau souterraine. L'intégrité des puits est toutefois le mécanisme jugé le plus important à considérer par rapport à la contamination de l'eau souterraine par des experts de différents milieux. L'intégrité des puits pétroliers et gaziers implique l'établissement et le maintien du scellement établi par une séries de coffrages cimentés qui isolent les zones interceptées par le puits et préviennent la circulation de fluides entre les zones en confinant l'écoulement à l'intérieur du puits. La mise en place d'un ciment assurant un scellement adéquat des coffrages des puits pétroliers et gaziers demeure toutefois un

	défi technologique. Dans les cas de perte d'intégrité des puits, c'est le méthane qui est le plus susceptible de migrer autour ou dans les puits à cause de sa faible densité qui fait en sorte qu'il a tendance à remonter vers la surface par effet de flottaison. Il y a un potentiel de contamination de l'eau souterraine par la migration de fluides par des voies de migration préférentielle de la profondeur jusqu'aux aquifères superficiels. Ces voies préférentielles pourraient être naturelles (zones de fractures ou failles) ou constituées par des puits en opération ou hors service. La propagation des fractures induites par la fracturation hydraulique jusqu'aux aquifères superficiels est très peu probable. Cependant, il y a un consensus à l'effet qu'une profondeur minimale doit être respectée pour la fracturation afin d'assurer la protection des aquifères. La profondeur minimale à laquelle la fracturation hydraulique peut être réalisée sans risque significatif pour l'environnement superficiel doit être définie en fonction des conditions géologiques locales et des approches et résultats de la fracturation hydraulique dans une région donnée. Plusieurs experts ont fait la recommandation de faire le monitoring de l'eau souterraine aux sites de forages pétroliers et gaziers. Pour être en mesure de reconnaître un effet potentiel, il est nécessaire d'établir les conditions préalables de la qualité de l'eau souterraine avant la réalisation de travaux d'exploration ou d'exploitation des hydrocarbures. Le monitoring des puits pétroliers et gaziers doit couvrir la qualité de l'eau souterraine (puits d'observation), la quantité et la qualité de l'eau de surface (stations de jaugeage), la sismicité et les effets de la fracturation hydraulique (microsismique), l'émission de gaz à effet de serre et les impacts sociaux et sur la santé. La présence de méthane dans l'eau souterraine change significativement sa composition chimique. Cependant, la présence naturelle de méthane dans l'eau souterraine est très commune et elle ne reflète pas nécessairement l'effet d'une contamination par des activités pétrolières. Le bilan des risques de sismicité Les mouvements de l'écorce terrestre induisent des ondes dans la terre qui sont ressenties comme des tremblements de terre lorsque leur magnitude est assez importante. Le Québec est situé dans une région continentale stable avec une activité sismique relativement faible, et plutôt sporadique dans les Basses-Terres du Saint-Laurent. La fracturation hydraulique n'induit que de très faibles effets, nommé microsismicité. Ces microséismes sont de trop faible magnitude pour être détectés par le réseau national de Ressources naturelles Canada. Des systèmes d'acquisition de signaux microsismiques pendant la fracturation hydraulique donnent des indications sur la propagation des fractures induites par la fracturation. Le processus de la fracturation hydraulique des puits pétroliers et gaziers tel qu'appliqué pour exploiter le gaz de shale ne représente pas un risque élevé d'induire des événements sismiques ressentis par la population. Aux États-Unis, l'augmentation des débits et des volumes d'injection d'eaux de reflux de la fracturation hydraulique a été associée à un certain nombre de tremblements de terre de magnitude faible à modérée.
Lavoie, D., C. Rivard, R. Lefebvre, S. Séjourné, R. Thériault, M. J. Duchesne, J. Ahad, B. Wang, N. Benoit, and C. Lamontagne. 2014. The Utica Shale and gas play in southern Quebec: Geological and hydrogeological synthesis and methodological approaches to groundwater risk evaluation. *International Journal of Coal Geology (IJCG),* 126: 77-91.	**Résumé (*Abstract*) :** The risk of groundwater contamination from shale gas exploration and development is a major societal concern, especially in populated areas where groundwater is an essential source of drinking water and for agricultural or industrial use. Since groundwater decontamination is difficult, or nearly impossible, it is essential to evaluate exploration and production conditions that would prevent or at least minimize risks of groundwater contamination. The current consensus in recent literature is that these risks are primarily related to engineering issues, including casing integrity and surface activities, such as truck traffic (equipment and fluid haulage), waste management (mainly drill cuttings), and water storage and treatment when hydraulic fracturing is utilized. Concerns have also been raised with respect to groundwater contamination that could result from potential fracture or fault interconnections between the shale unit and surficial aquifers, which would allow fracturing fluids and methane to reach the surface away from the wellbore. Despite the fact that groundwater resources are relatively well characterized in some regions, there is currently no recognized method to evaluate the vulnerability or risks to aquifers resulting from hydrocarbon industry operations carried out at great depths. This paper focuses on the Utica Shale of the St. Lawrence Platform (Quebec), where an environmental study aiming to evaluate potential risks for aquifers related to shale gas development has been initiated. To provide the context of these research efforts, this paper describes the regional tectono-stratigraphic evolution and current stress regime of the Cambrian–Ordovician St. Lawrence Platform, as well as the Utica Shale internal stratigraphy, mineralogy and thermal maturation. Then, the hydrogeological context of the St. Lawrence Platform is discussed. Finally, the methodology for this environmental study, based on geological, geophysical, geomechanical, hydrogeological and geochemical data, is presented.
Séjourné, S., Lefebvre, R., Malet, X., et Lavoie, D., 2013. Synthèse géologique et hydrogéologique du Shale d'Utica et des unités sus-jacentes (Lorraine, Queenston et dépôts meubles), Basses-Terres du Saint-Laurent, Québec; Commission géologique du	**Extrait du résumé :** Le présent travail a été initié dans le cadre d'un mandat donné à l'INRS-ETE par la Commission géologique du Canada (CGC) et le Ministère du Développement durable, de l'Environnement, de la Faune et des Parcs du Québec (MDDEFP). Ce rapport constitue le produit initial d'un projet de recherche de quatre ans du secteur des Sciences de la Terre de Ressources Naturelles du Canada portant sur l'évaluation de l'intégrité géologique des roches en couverture au-dessus des unités de shales à potentiel gazier de l'est canadien (Québec, Nouveau-Brunswick et Nouvelle-Écosse). Le mandat initial au Québec impliquait la production d'une synthèse des connaissances et des données publiques disponibles sur le Shale d'Utica et les

Canada, Dossier Public 7338, 165 p. doi:10.4095/292430.	unités sus-jacentes, sédiments quaternaires inclus, dans les Basses-Terres du Saint-Laurent. L'objectif de cette synthèse est de supporter et orienter des travaux futurs destinés à évaluer le degré d'imperméabilité géologique des successions rocheuses entre les shales cibles pour l'exploitation du gaz de shale et les aquifères peu profonds, dans les dépôts meubles ou le roc fracturé. Cette synthèse doit notamment permettre de faire ressortir des régions ou des types de données pour lesquelles il y a peu d'information, guidant ainsi le choix de travaux futurs de recherche scientifique sur la problématique des gaz de shale au Québec.
Comité de l'Évaluation Environnementale Stratégique sur le gaz de schiste (CÉES), 2014. Rapport synthèse – Évaluation environnementale stratégique sur le gaz de schiste. Bibliothèque et Archives nationales du Québec, ISBN 978-2-550-69741-1 (PDF), 279 p.	**Extrait des constats sur les enjeux touchant l'eau :** • La quantité d'eau de surface disponible est suffisante pour répondre aux besoins de l'industrie du gaz de schiste sans que les prélèvements aient des impacts négatifs sur les écosystèmes ou les autres utilisateurs, même dans le cas d'un développement à grande échelle. • Le faible débit des aquifères proches de la surface rend ceux-ci inutilisables pour l'industrie. • Trois additifs chimiques [dans les fluides de fracturation hydraulique à grand volume] présentent un potentiel à la fois de persistance, de bioaccumulation et de toxicité. Une attention particulière devrait être portée à la gestion de ces produits et il serait pertinent d'amorcer une recherche de produits de substitution. • De façon générale, les composés les plus fréquemment utilisés dans la fracturation hydraulique se sont révélés pour la plupart relativement peu toxiques. • Les eaux de reflux contiennent des composantes qui pourraient être nuisibles à la vie aquatique à court ou à moyen terme. Advenant le développement de cette industrie, un suivi particulier de certains paramètres permettrait de déterminer l'efficacité du traitement. Il est question notamment de la demande biologique en oxygène, du baryum, du fer, du plomb, du zinc, des chlorures, des solides dissous totaux, des nitrites et des hydrocarbures pétroliers (C10-C50), du pH, de la conductivité, de la demande chimique en oxygène et des matières en suspension. De plus, même s'il est attendu que les eaux de reflux de l'Utica au Québec présentent une radioactivité largement inférieure à celle du shale de Marcellus, il apparaît prudent de procéder à la caractérisation des différents radionucléides. • Un suivi exploratoire pour certaines composantes non détectées par les études de caractérisation en laboratoire est désirable. C'est le cas des composés organiques volatils et semi-volatils, des substances phénoliques, des bromures, du lithium, du strontium et des glycols. • Plus globalement, puisque les données disponibles sur la caractérisation des résidus générés par l'industrie sont d'usage limité et que l'expérience en laboratoire ne reproduit pas nécessairement fidèlement la fracturation hydraulique *in situ* de l'Utica, un suivi des eaux de reflux est souhaitable pour valider les résultats obtenus. En outre, les essais de toxicité globale des eaux usées avant et après traitement, pourraient également faire partie des suivis, par mesure de précaution. • La caractérisation de la vulnérabilité des aquifères et des puits d'alimentation en eau potable joue un rôle • important pour la protection des ressources en eaux souterraines. • Dans les zones cibles du gaz de schiste, les systèmes hydrogéologiques peu profonds (c.-à-d. les aquifères d'eau douce) sont assez bien connus à l'échelle régionale. La plupart de cette connaissance provient des projets PACES récemment coordonnés par le MDDEFP (MDDEFP, 2013a). • La vulnérabilité des aquifères aux sources de contamination profondes est plus difficile à déterminer par rapport aux sources situées en surface et des données suffisantes n'existent pas encore pour caractériser cette vulnérabilité. • Une revue de la littérature suggère que les risques les plus importants de contamination des eaux souterraines peuvent être attribués à la conception des puits (gaziers ou pétroliers). Les fuites à l'évent du tubage de surface ou la migration de gaz lié à une mauvaise cimentation des coffrages constituent un problème reconnu par l'industrie. • Les risques de contamination via des cheminements naturels (failles ou fractures) ou des cheminements induits, loin du puits, sont relativement plus faibles, mais leur importance est difficile à déterminer à cause du manque de données et du faible nombre de puits de suivi. • Des risques non négligeables existent aussi à la surface d'un site, par exemple des bassins de rétention, des fuites de fluides et des fuites de carburants (diesel, gazoline). • Le comportement de nouveaux contaminants associés au développement du gaz de schiste (fluides ou gaz) dans les aquifères d'eau douce peu profonds n'est pas bien connu. Les essais requis afin de prédire ce comportement n'ont pas encore été effectués. • Les données existantes sur les teneurs en méthane naturel dans les basses-terres du Saint-Laurent suggèrent que la majorité du méthane naturel présent dans l'eau souterraine échantillonnée dans des puits d'alimentation en eau potable (95 % des échantillons) est d'origine biogénique, c'est-à-dire qu'il provient de sources moins profondes que celles dans l'Utica. Cette observation suggère que les unités intermédiaires entre le shale

	d'Utica et les ressources en eau douce peu profondes (c.-à-d. le groupe de Lorraine) sont relativement imperméables à l'échelle régionale et sur une échelle de temps géologique. • Les simulations multiphasiques du scénario 1 de l'étude, dans le cadre d'une analyse de sensibilité, suggèrent que les fuites le long du coffrage ou à l'intérieur du puits à travers le ciment après fermeture seraient négligeables si un ciment de bonne qualité était utilisé et si le ciment était bien installé autour du puits ou à l'intérieur du puits après sa fermeture. • Les simulations du scénario 2 (migration le long d'une faille) suggèrent que la fracturation hydraulique du shale d'Utica ne pourrait pas causer une migration importante des fluides de formation et du méthane vers la surface. • La modélisation numérique multiphasique des scénarios de fuites, avec une analyse de sensibilité, démontre que les fuites de saumure et de gaz le long des failles ou des fractures naturelles devraient être faibles, même après la fracturation.
Bureau d'audiences publiques sur l'environnement (BAPE), 2011. Développement durable de l'industrie des gaz de schiste au Québec, Rapport 273. Février 2011, 1–323.	**Extrait de la conclusion :** La commission d'enquête a examiné les avenues et a analysé les enjeux liés au développement durable de l'industrie du gaz de shale à partir des faits recueillis et des témoignages de citoyens, de groupes, de municipalités et de l'industrie. (…) Pour certaines questions fondamentales, les réponses sont toutefois partielles ou inexistantes. Pour répondre à ce besoin d'acquisition de connaissances scientifiques et en l'absence de faits probants permettant de déterminer les risques que pourraient comporter l'exploration et l'exploitation du gaz de shale, il est proposé de procéder à une évaluation environnementale stratégique. Tant que l'évaluation serait en cours, la fracturation hydraulique ne serait autorisée que pour les travaux requis par l'évaluation. Les travaux d'exploration pourraient continuer, mais sans l'utilisation de la fracturation hydraulique. Une telle évaluation constitue un passage obligé, tant pour un processus de prise de décision éclairée que pour la recherche d'une meilleure acceptabilité sociale. En vue de favoriser une cohabitation harmonieuse de l'industrie du gaz de shale avec le milieu, un comité de concertation sur les activités de l'industrie devrait être formé. Le ministre des Ressources naturelles et de la Faune et le ministre du Développement durable, de l'Environnement et des Parcs devraient évaluer la possibilité de confier à la commission régionale des ressources naturelles et du territoire, instituée au sein de la conférence régionale des élus de chaque région concernée, le mandat de réaliser cette concertation. Après l'analyse, la commission régionale devrait donner son avis sur l'acceptabilité du projet au ministre du Développement durable, de l'Environnement et des Parcs. Dans le respect des responsabilités de l'État, fiduciaire de la ressource naturelle, les autorités municipales devraient être impliquées pour une gestion intégrée des activités de l'industrie du gaz de shale sur leur territoire. Des orientations gouvernementales devraient être établies afin de permettre aux municipalités d'encadrer le développement de l'industrie du gaz de shale, comme elles le font pour tout autre type d'industrie, dont les activités agricoles. L'encadrement actuel de l'industrie du gaz de shale se fait de façon cloisonnée, principalement entre deux ministères en fonction des lois dont chacun est responsable. Cette situation ne favorise pas la surveillance et le contrôle intégrés des activités. En conséquence, il est proposé que les activités d'exploration et d'exploitation soient autorisées par le ministère du Développement durable, de l'Environnement et des Parcs de manière à considérer l'ensemble des enjeux environnementaux à l'intérieur d'un même certificat d'autorisation. Les avis et les orientations formulés dans le rapport visent à améliorer les façons de faire pour assurer notamment un encadrement légal et réglementaire concernant le développement sécuritaire de l'industrie du gaz de shale. Certaines mesures avancées peuvent requérir un certain temps pour être effectives. D'autres propositions ne requièrent pas de modifications législatives ou réglementaires et peuvent être réalisées à court terme, par exemple l'adoption de mesures pour assurer de façon diligente la surveillance des sites de forage relativement aux émissions fugitives de méthane, à la qualité des eaux de surface et souterraines et aux nuisances.

Références sur la réglementation des puits pétroliers et gaziers et de la fracturation hydraulique

Références	Constats spécifiques et citations
Notte, C., Allen, D.M., Gehman, J., Alessi, D.S., Goss, G.G., 2017. Comparative analysis of hydraulic fracturing wastewater practices in unconventional shale developments: Regulatory regimes. Canadian Water Resources Journal, 42(2), 122-137.	**Résumé (*Abstract*) :** This paper is the second of a two-part series that assesses and summarizes extant knowledge regarding hydraulic fracturing wastewater management using a comparative, multidisciplinary approach. This study compares the regulatory regimes related to wastewater handling (storage and transport), treatment, and disposal practices as they apply to the hydraulic fracturing industry in four unconventional shale plays in North America: the Montney in British Columbia (BC), the Duvernay in Alberta (AB), the Marcellus in the northeastern United States (U.S.), and the Barnett in Texas. In North America, handling, treatment, and disposal practices in the regulation of oil and gas wastewater is complex and multifaceted due to shared jurisdiction over many aspects across provincial or state lines, and/or across provincial/state and federal levels. All jurisdictions considered in this assessment have highly specific regulations for many elements of wastewater handling, treatment, and disposal. However, much of the guidance for these practices comes from other legislation that makes provisions for environmental or safety performance, or prohibitions against pollution. The research suggests that knowledge gaps exist in the areas of regulatory outcomes, and compliance and best management practices, particularly in how those factors enable and constrain environmentally sustainable practices. BC's area-based management model and AB's play-based-regulation pilot project are examples of attempted cumulative effects assessment and management noticeably absent from the Marcellus or Barnett plays.
Centner, T.J., 2016. Reducing pollution at five critical points of shale gas production: Strategies and institutional responses. Energy Policy 94, 40–46.	**Résumé (*Abstract*) :** While the public and governments debate the advisability of engaging in shale gas production, the United States has proceeded to develop its resources with an accompanying remarkable increase in natural gas production. The development of shale gas has not been without problems, and some countries have decided that shale gas production should not proceed until more is known about the accompanying health issues and environmental damages. From experiences in the United States, careful consideration of five critical points relating to shale gas production can form the basis for developing strategies for reducing discharges of pollutants: (1) casing and cementing, (2) handling wastewater, (3) venting and flaring, (4) equipment with air emissions, and (5) seismic events. For each strategy, institutional responses to markedly reduce the risks of harm to people and the environment are identified. These responses offer state and local governments ideas for enabling shale gas resources to be developed without sacrificing public health and environmental quality.
Campin, D., 2016. Is there scientific evidence to support the selection of hydraulic fracturing rules? SPE-179353-MS, Society of Petroleum Engineers (SPE), SPE International Conference and Exhibition on Health, Safety, Security, Environment and Social Responsibility, Stavanger, Norway, 11-13 April 2016, 34 pp.	**Contenu général de l'article :** Article faisant une revue très détaillée des orientations des réglementations de la fracturation hydraulique dans différentes juridictions et des évidences scientifiques soutenant les règles établies. Représente une source importante de références d'intérêt sur les enjeux environnementaux de la fracturation hydraulique.
Rezazadeh, M., van Hattum, J., Marozzi, D., 2016. Unconventional resources exploration and development in the Northern Territory – Challenges from a regulator's perspective. SPE-182404-MS, Society of Petroleum Engineers (SPE), SPE Asia Pacific Oil & Gas Conference and Exhibition, Perth, Australia, 25-27 October 2016, 17 pp.	**Contenu général de l'article :** Décrit les orientations envisagées pour une nouvelle réglementation encadrant le début prévu de l'exploitation du gaz de shale dans l'état des Territoires du Nord de l'Australie.
Fleming, R., 2015. Towards Reasonable European Shale Gas Regulation – the European Commission's 2014 Recommendation and Communication on Shale Gas Extraction. SPE-175503-MS, Society of Petroleum Engineers (SPE), SPE Offshore Europe Conference and	**Contenu général de l'article :** Décrit la recommandation de l'Union Européenne relative à l'exploitation du gaz de shale.

Exhibition, Aberdeen, Scotland, UK, 8-11 september 2015, 11 pp.	
Becklumb, P., Chong, J., Williams, T., 2015. Le gaz de schiste au Canada – Risques environnementaux et réglementation. Bibliothèque du Parlement, Étude générale, Publication 2015-18-F, 26 février 2015, Ottawa, Canada, 24 pp.	**Contenu générale du rapport :** Revue générale sur les risques environnementaux et la réglementation environnementale de l'exploitation du gaz de shale au Canada.

Risques pour la quantité d'eau souterraine

Références	Constats spécifiques et citations
Notte, C., Allen, D.M., Gehman, J., Alessi, D.S., Goss, G.G., 2017. Comparative analysis of hydraulic fracturing wastewater practices in unconventional shale developments: Regulatory regimes. Canadian Water Resources Journal, 42(2), 122-137.	Voir références sur la réglementation pour le résumé.
Gallegos, T.J., and Varela, B.A., 2015. Trends in hydraulic fracturing distributions and treatment fluids, additives, proppants, and water volumes applied to wells drilled in the United States from 1947 through 2010—Data analysis and comparison to the literature. U.S. Geological Survey Scientific Investigations Report 2014–5131, 15 p., *http://dx.doi.org/10.3133/sir20145131*.	Voir références générales pour le résumé.
U.S. Department of Energy (U.S. DOE), 2015. Report on the Multiagency Collaboration on Unconventional Oil and Gas Research. Report to Congress, December 2015, United States Department of Energy, Washington, DC 20585, 21 pp.	Voir références générales pour le résumé.
Scanlon, B.R., Reedy, R.C., Nicot, J.P., 2014. Will water scarcity in semiarid regions limit hydraulic fracturing of shale plays? Environmental Research Letters 9(2014), 14 pp. doi: 10.1088/1748-9326/9/12/124011.	**Résumé (*Abstract*) :** There is increasing concern about water constraints limiting oil and gas production using hydraulic fracturing (HF) in shale plays, particularly in semiarid regions and during droughts. Here we evaluate HF vulnerability by comparing HF water demand with supply in the semiarid Texas Eagle Ford play, the largest shale oil producer globally. Current HF water demand (18 billion gallons, bgal; 68 billion liters, bL in 2013) equates to ~16% of total water consumption in the play area. Projected HF water demand of ~330 bgal with ~62 000 additional wells over the next 20 years equates to ~10% of historic groundwater depletion from regional irrigation. Estimated potential freshwater supplies include ~1000 bgal over 20 yr from recharge and ~10 000 bgal from aquifer storage, with land-owner lease agreements often stipulating purchase of freshwater. However, pumpage has resulted in excessive drawdown locally with estimated declines of ~100–200 ft in ~6% of the western play area since HF began in 2009–2013. Nonfreshwater sources include initial flowback water, which is ⩽5% of HF water demand, limiting reuse/recycling. Operators report shifting to brackish groundwater with estimated groundwater storage of 80 000 bgal. Comparison with other semiarid plays indicates increasing brackish groundwater and produced water use in the Permian Basin and large surface water inputs from the Missouri River in the Bakken play. The variety of water sources in semiarid

	regions, with projected HF water demand representing ~3% of fresh and ~1% of brackish water storage in the Eagle Ford footprint indicates that, with appropriate management, water availability should not physically limit future shale energy production.
Nicot, J.-P., and Scanlon, B. R., 2012. Water use for shale-gas production in Texas, U.S. Environmental Science and Technology, 46, p. 3580–3586. doi**:** 10.1021/es204602t.	**Résumé (*Abstract*) :** Shale-gas production using hydraulic fracturing of mostly horizontal wells has led to considerable controversy over water-resource and environmental impacts. The study objective was to quantify net water use for shale-gas production using data from Texas, which is the dominant producer of shale gas in the U.S. with a focus on three major plays: the Barnett Shale (~15000 wells, mid-2011), Texas-Haynesville Shale (390 wells), and Eagle Ford Shale (1040 wells). Past water use was estimated from well-completion data, and future water use was extrapolated from past water use constrained by shale-gas resources. Cumulative water use in the Barnett totaled 145 Mm3 (2000−mid-2011). Annual water use represents ~9% of water use in Dallas (population 1.3 million). Water use in younger (2008−mid-2011) plays, although less (6.5 Mm3 TexasHaynesville, 18 Mm3 Eagle Ford), is increasing rapidly. Water use for shale gas is <1% of statewide water withdrawals; however, local impacts vary with water availability and competing demands. Projections of cumulative net water use during the next 50 years in all shale plays total ~4350 Mm3, peaking at 145 Mm3 in the mid-2020s and decreasing to 23 Mm3 in 2060. Current freshwater use may shift to brackish water to reduce competition with other users.

Risques pour la qualité de l'eau souterraine

Références	Constats spécifiques et citations
	Références générales
McMahon, P.B., Barlow, J.R.B., Engle, M.A., Belitz, K., Ging, P.B., Hunt, A.G., Jurgens, B.C., Kharaka, Y.K., Tollett, R.W., Kresse, T.M., 2017. Methane and benzene in drinking-water wells overlying the Eagle Ford, Fayetteville, and Haynesville shale hydrocarbon production areas. *Environ. Sci. Technol.*, *51* (12), 6727–6734, doi**:** 10.1021/acs.est.7b00746.	**Contenu général de l'article :** Étude qui n'a pas trouvé d'impact de l'exploitation des gaz de shale sur la qualité de l'eau souterraine dans des régions intensément exploitées aux USA. L'étude souligne toutefois qu'à cause du long temps de résidence (âge important) de l'eau souterraine, il faudra au moins des décennies pour déceler un impact potentiel de l'exploitation des gaz de shale sur l'eau souterraine. Cette conclusion peut être mise en relation avec le monitoring à très long terme entrepris au Royaume Uni par le BGS dans les bassins où la fracturation hydraulique pourrait s'amorcer. Voir le résumé et des extraits de l'introduction dans la section sur la caractérisation, le monitoring et l'évaluation du risque.
Harkness, J.S., Darrah, T.H., Warner, N.R., Whyte, C.J., Moore, M.T., Millot, R., Kloppman, W., Jackson, R.B., Vengosh, A., 2017. The geochemistry of naturally occurring methane and saline groundwater in an area of unconventional shale gas development. Geochimica et Cosmochimica Acta, July, 2017, doi: http://dx.doi.org/10.1016/j.gca.2017.03.039.	**Contenu général de l'article :** Cet important article scientifique fait l'inventaire des études précédentes et de la controverse scientifique entourant l'impact potentiel de l'exploitation des gaz de shale sur la qualité de l'eau souterraine. L'article fait une contribution scientifique majeure en utilisant des méthodes géochimiques uniques pour trancher ce débat. L'article tire la conclusion que la qualité de l'eau souterraine (notamment la présence de méthane et d'eaux salines) résulte de processus naturels et n'est pas affectée par une contamination. Par contre les eaux de surface montrent une dégradation de qualité qui peut être reliées aux eaux de reflux (*flowback fluids*) de la fracturation hydraulique du Shale de Marcellus. Voir le résumé et des extraits de l'introduction dans la section sur la caractérisation, le monitoring et l'évaluation du risque.
Birdsell, D. T., H. Rajaram, D. Dempsey, and H. S. Viswanathan. 2015. Hydraulic fracturing fluid migration in the subsurface: A review and expanded modeling results. *Water Resources Research*, 51: 7159–88, doi:10.1002/2015WR017810.	**Résumé (*Abstract*) :** Understanding the transport of hydraulic fracturing (HF) fluid that is injected into the deep subsurface for shale gas extraction is important to ensure that shallow drinking water aquifers are not contaminated. Topographically driven flow, overpressured shale reservoirs, permeable pathways such as faults or leaky wellbores, the increased formation pressure due to HF fluid injection, and the density contrast of the HF fluid to the surrounding brine can encourage upward HF fluid migration. In contrast, the very low shale permeability and capillary imbibition of water into partially saturated shale may sequester much of the HF fluid, and well production will remove HF fluid from the subsurface. We review the literature on important aspects of HF fluid migration. Single-phase flow and transport simulations are performed to quantify how much HF fluid is removed via the wellbore with flowback and

	produced water, how much reaches overlying aquifers, and how much is permanently sequestered by capillary imbibition, which is treated as a sink term based on a semianalytical, one-dimensional solution for two-phase flow. These simulations include all of the important aspects of HF fluid migration identified in the literature review and are performed in five stages to faithfully represent the typical operation of a hydraulically fractured well. No fracturing fluid reaches the aquifer without a permeable pathway. In the presence of a permeable pathway, 10 times more fracturing fluid reaches the aquifer if well production and capillary imbibition are not included in the model.
	Références sur le Québec
	Voir aussi les références générales, notamment Lavoie et al. (2014), Séjourné et al. (2013) et les rapports du BAPE et des ÉES.
Séjourné, S., 2017. Étude géomécanique du Shale d'Utica et de sa couverture sédimentaire d'après les puits pétroliers et gaziers de la région de Saint-Édouard-de-Lotbinière, Québec; Commission géologique du Canada, Dossier public 8196, 54 p. doi: 10.4095/299662.	**Résumé :** L'objectif principal de l'étude visait à estimer les propriétés géomécaniques du Shale d'Utica et de sa couverture sédimentaire pour trois puits forés pour le gaz de shale dans ou à proximité de la région de Saint-Édouard-de-Lotbinière. Pour chacun de ces puits le module de Young, le coefficient de Poisson ainsi que deux indices de fragilité ont été calculés puis évalués. La portée de l'étude a ensuite été étendue à quatre puits pétroliers et gaziers plus anciens ne ciblant pas les gaz de shale mais des réservoirs pétroliers conventionnels. Les propriétés géomécaniques ainsi estimées pour le Groupe de Lorraine soulignent un fort contraste mécanique avec le Shale d'Utica sous-jacent, le premier étant plus ductile (moins fragile) que le second. Les propriétés géomécaniques définies pour le Shale d'Utica soulignent que celui-ci est aussi plus ductile que le Groupe de Trenton sous-jacent, avec un contact et un contraste géomécanique plus ou moins bien marqués de part et d'autre de la base du Shale d'Utica. Dans la plupart des puits il a également été possible de différencier deux membres au sein du Shale d'Utica, avec un membre supérieur plus fragile et un membre inférieur plus ductile. Les résultats indiquent que, dans un contexte de fracturation hydraulique pour le gaz de shale, les propriétés géomécaniques de la couverture sédimentaire du Shale d'Utica ne sont pas propices à la propagation des fractures hydrauliques en direction de la surface. Cette étude a également permis d'identifier un certain nombre de travaux additionnels qui permettraient de confirmer ou raffiner les résultats obtenus ici. Les principales recommandations en ce sens sont regroupés sous trois thèmes principaux, soit 1) la caractérisation des réseaux de fractures naturelles, 2) l'étude des propriétés géomécaniques de la couverture à faible profondeur et 3) l'étude des propriétés géomécaniques de la couverture dans les zones faillées.
Raynauld, M., Peel, M., Lefebvre, R., Molson, J., Crow, H., Ahad, J., Ouellet, M., Aquilina, L., 2016. Understanding shallow and deep flow for assessing the risk of hydrocarbon development to groundwater quality. Online 25 September 2016, Special issue on '*Basin hydrodynamics & Resources*', *J. of Marine and Petroleum Geology*, 78C, 728-737, doi: 10.1016/j.marpetgeo.2016.09.026.	Note : Les lecteurs intéressés trouveront plus de détails dans le rapport de Raynauld et al. (2014) réalisé pour le MDDELCC ainsi que les mémoires de maîtrise de Raynauld (2014) et de Peel (2014) qui sont cités dans notre rapport. **Résumé (*Abstract*) :** In recent years, concerns have been raised about the potential environmental impacts of oil and gas (O&G) exploitation, especially regarding groundwater resources. However, there have been few studies carried out to assess the actual risk of O&G exploitation based on specific local conditions. This paper reports on a study aiming to assess the potential risk to groundwater quality related to the development of a tight sandstone petroleum reservoir underlying a shallow fractured rock aquifer system in the Haldimand sector of Gaspé, Québec, Canada. In this generally rural setting, the drilling of a provincially permitted horizontal O&G exploration well was halted by new municipal regulations. Draft provincial environmental regulations were subsequently issued to define environmental requirements for hydrocarbon exploration wells. Our study thus also aimed to provide an example of how to comply with the new hydrogeological characterization requirements. This paper reports on the process followed to qualitatively assess the risk of O&G operations and natural oil seeps to groundwater quality. The assessment focused on indicators of potential preferential fluid migration paths between the reservoir level and shallow aquifers. Field work and data analysis were used to define geological, hydrogeological and geochemical contexts on which a numerical model was developed to represent groundwater flow, mass transport and groundwater residence time. The risk for groundwater quality was qualitatively assessed from the implications of the study area context relative to 1) the new provincial regulatory requirements; 2) potential contaminant release mechanisms related to O&G exploration drilling operations; and 3) the expected effects that contaminant releases could have on groundwater.

Risques de sismicité (injection d'effluents et fracturation hydraulique)

Références	Constats spécifiques et citations
Davis, C., et J.M. Fisk, 2017. Mitigating Risks From Fracking-Related Earthquakes: Assessing State Regulatory Decisions. Society & Natural Resources, 18 pp., doi: 10.1080/08941920.2016.1273415.	**Résumé (*Abstract*) :** Public concern about earthquakes linked to wastewater injection from fracking operations is rising. However, few have examined how "induced seismicity" is acted upon by state officials. For some, an incremental response to smaller quakes can be viewed as an acceptable risk policy orientation because of the sizeable economic benefits that accompany drilling activities while others prefer risk mitigation policies (such as the use of "threshold policies") as a better way to address quake-related problems. To account for state response to induced seismicity impacts, we examine three factors: the emergence of quakes as focusing events, the economic importance of oil and gas to state jobs and revenue, and selected characteristics of earthquakes as a policy issue, i.e., complexity and categorical precedence. Using information drawn from documentary sources, we consider which factors are most helpful in accounting for agency decisions aimed at reducing seismic risks linked to nearby injection wells.

Caractérisation, monitoring et évaluation du risque pour la sous-surface

Présence de méthane dans l'eau souterraine (inventaire des principales études régionales et études au Québec)

Références	Constats spécifiques et citations
	Principales références sur les études régionales récentes
McMahon, P.B., Barlow, J.R.B., Engle, M.A., Belitz, K., Ging, P.B., Hunt, A.G., Jurgens, B.C., Kharaka, Y.K., Tollett, R.W., Kresse, T.M., 2017. Methane and benzene in drinking-water wells overlying the Eagle Ford, Fayetteville, and Haynesville shale hydrocarbon production areas. *Environ. Sci. Technol.*, *51* (12), 6727–6734, doi**:** 10.1021/acs.est.7b00746.	**Contenu général de l'article :** Étude qui n'a pas trouvé d'impact de l'exploitation des gaz de shale sur la qualité de l'eau souterraine dans des régions intensément exploitées aux USA. L'étude souligne toutefois qu'à cause du long temps de résidence (âge important) de l'eau souterraine, il faudra au moins des décennies pour déceler un impact potentiel de l'exploitation des gaz de shale sur l'eau souterraine. Cette conclusion peut être mise en relation avec le monitoring à très long terme entrepris au Royaume Uni par le BGS dans les bassins où la fracturation hydraulique pourrait s'amorcer. **Résumé (*Abstract*) :** Water wells (n = 116) overlying the Eagle Ford, Fayetteville, and Haynesville Shale hydrocarbon production areas were sampled for chemical, isotopic, and groundwater-age tracers to investigate the occurrence and sources of selected hydrocarbons in groundwater. Methane isotopes and hydrocarbon gas compositions indicate most of the methane in the wells was biogenic and produced by the CO2 reduction pathway, not from thermogenic shale gas. Two samples contained methane from the fermentation pathway that could be associated with hydrocarbon degradation based on their co-occurrence with hydrocarbons such as ethylbenzene and butane. Benzene was detected at low concentrations (<0.15 µg/L), but relatively high frequencies (2.4−13.3% of samples), in the study areas. Eight of nine samples containing benzene had groundwater ages >2500 years, indicating the benzene was from subsurface sources such as natural hydrocarbon migration or leaking hydrocarbon wells. One sample contained benzene that could be from a surface release associated with hydrocarbon production activities based on its age (10 ± 2.4 years) and proximity to hydrocarbon wells. Groundwater travel times inferred from the age-data indicate decades or longer may be needed to fully assess the effects of potential subsurface and surface releases of hydrocarbons on the wells.
Harkness, J.S., Darrah, T.H., Warner, N.R., Whyte, C.J., Moore, M.T., Millot, R., Kloppman, W., Jackson, R.B., Vengosh, A., 2017. The geochemistry of naturally occurring methane and saline groundwater in an area of unconventional	**Contenu général de l'article :** Cet important article scientifique fait l'inventaire des études précédentes et de la controverse scientifique entourant l'impact potentiel de l'exploitation des gaz de shale sur la qualité de l'eau souterraine. L'article fait une contribution scientifique majeure en utilisant des méthodes géochimiques uniques pour trancher ce débat. L'article tire la conclusion que la qualité de l'eau souterraine (notamment la présence de méthane et d'eaux salines) résulte de

shale gas development. Geochimica et Cosmochimica Acta, July, 2017, doi: http://dx.doi.org/10.1016/j.gca.2017.03.039.	processus naturels et n'est pas affectée par une contamination. Par contre les eaux de surface montrent une dégradation de qualité qui peut être reliées aux eaux de reflux (*flowback fluids*) de la fracturation hydraulique du Shale de Marcellus. **Résumé (*Abstract*) :** Since naturally occurring methane and saline groundwater are nearly ubiquitous in many sedimentary basins, delineating the effects of anthropogenic contamination sources is a major challenge for evaluating the impact of unconventional shale gas development on water quality. This study investigates the geochemical variations of groundwater and surface water before, during, and after hydraulic fracturing and in relation to various geospatial parameters in an area of shale gas development in northwestern West Virginia, United States. To our knowledge, we are the first to report a broadly integrated study of various geochemical techniques designed to distinguish natural from anthropogenic sources of natural gas and salt contaminants both before and after drilling. These measurements include inorganic geochemistry (major cations and anions), stable isotopes of select inorganic constituents including strontium (87Sr/86Sr), boron (d11B), lithium (d7Li), and carbon (d13C-DIC), select hydrocarbon molecular (methane, ethane, propane, butane, and pentane) and isotopic tracers (d13C-CH4, d13C-C2H6), tritium (3H), and noble gas elemental and isotopic composition (helium, neon, argon) in 105 drinking-water wells, with repeat testing in 33 of the wells (total samples = 145). In a subset of wells (n = 20), we investigated the variations in water quality before and after the installation of nearby (<1 km) shale-gas wells. Methane occurred above 1 ccSTP/L in 37% of the groundwater samples and in 79% of the samples with elevated salinity (chloride > 50 mg/L). The integrated geochemical data indicate that the saline groundwater originated via naturally occurring processes, presumably from the migration of deeper methane-rich brines that have interacted extensively with coal lithologies. **These observations were consistent with the lack of changes in water quality observed in drinking-water wells following the installation of nearby shale-gas wells. In contrast to groundwater samples that showed no evidence of anthropogenic contamination, the chemistry and isotope ratios of surface waters (n = 8) near known spills or leaks occurring at disposal sites mimicked the composition of Marcellus flowback fluids, and show direct evidence for impact on surface water** by fluids accidentally released from nearby shale-gas well pads and oil and gas wastewater disposal sites. Overall this study presents a comprehensive geochemical framework that can be used as a template for assessing the sources of elevated hydrocarbons and salts to water resources in areas potentially impacted by oil and gas development. **Extrait de l'introduction :** Development of unconventional hydrocarbon resources from previously uneconomical black shales and tight sands through the advent of horizontal drilling and hydraulic fracturing technologies has revitalized the domestic energy industry in the U.S. and reduced dependency on coal combustion for electricity generation (USEIA, 2014). However, numerous environmental concerns, including the potential for compromised drinking-water quality, have tempered public opinions about the economic benefits of unconventional energy development in the U.S. (Jackson et al., 2014; Vengosh et al., 2014). For example, evidence for stray gas contamination in shallow drinking-water wells was reported in a subset of wells located less than 1 km from shale gas sites in Pennsylvania (PA) and Texas (TX) using both geospatial statistics and hydrocarbon and noble gas geochemistry (Osborn et al., 2011; Jackson et al., 2013; Darrah et al., 2014; Heilweil et al., 2015). The debate around the potential for wide spread contamination from hydraulic fracturing stems from the lack of predrilling datasets that include a comprehensive suite of geochemical tracers. The nearly ubiquitous presence of naturally occurring inorganic and hydrocarbon contaminants in many areas of hydrocarbon extraction, and the potential for legacy contamination from conventional oil and gas development and other industries (e.g., coal), can also deteriorate water quality (Vengosh et al., 2014). Several studies have suggested that dissolved methane (CH4) and saline groundwater in shallow aquifers in the Appalachian Basin likely originated from natural processes (Schon, 2011; Warner et al., 2012; Molofsky et al., 2013; Baldassare et al., 2014; Siegel et al., 2015a, 2015b; Darrah et al., 2015b).
Humez, P., B. Mayer, J. Ing, M. Nightingale, V. Becker, A. Kingston, O. Akbilgic, et S. Taylor. 2016a. Occurrence and origin of methane in groundwater in Alberta (Canada): Gas geochemical and isotopic approaches. *Science of the Total Environment*, 541: 1253-68.	**Résumé (*Abstract*) :** To assess potential future impacts on shallow aquifers by leakage of natural gas from unconventional energy resource development it is essential to establish a reliable baseline. Occurrence of methane in shallow groundwater in Alberta between 2006 and 2014 was assessed and was ubiquitous in 186 sampled monitoring wells. Free and dissolved gas sampling and measurement approaches yielded comparable results with low methane concentrations in shallow groundwater, but in 28 samples from 21 wells methane exceeded 10 mg/L in dissolved gas and 300,000 ppmv in free gas. Methane concentrations in free and dissolved gas samples were found to increase with well depth and were especially elevated in groundwater obtained from aquifers containing coal seams and shale units. Carbon isotope ratios of methane averaged−69.7± 11.1‰(n=63) in free gas and−65.6 ±

	8.9‰(n=26) in dissolved gas. δ13C values were not found to vary with well depth or lithology indicating that methane in Alberta groundwater was derived from a similar source. The low δ13C values in concert with average δ2HCH4 values of −289 ± 44‰ (n = 45) suggest that most methane was of biogenic origin predominantly generated via CO2 reduction. This interpretation is confirmed by dryness parameters typically N500 due to only small amounts of ethane and a lack of propane in most samples. Comparison with mud gas profile carbon isotope data revealed that methane in the investigated shallow groundwater in Alberta is isotopically similar to hydrocarbon gases found in 100–250 meter depths in the WCSB and is currently not sourced from thermogenic hydrocarbon occurrences in deeper portions of the basin. The chemical and isotopic data for methane gas samples obtained from Alberta groundwater provide an excellent baseline against which potential future impact of deeper stray gases on shallow aquifers can be assessed.
Humez, P., B. Mayer, M. Nightingale, J. Ing, V. Becker, D. Jones, et V. Lam. 2016b. An 8-year record of gas geochemistry and isotopic composition of methane during baseline sampling at a groundwater observation well in Alberta, Canada. *Hydrogeology Journal*, 24: 109-22.	**Résumé (*Abstract*) :** Variability in baseline groundwater methane concentrations and isotopic compositions was assessed while comparing free and dissolved gas sampling approaches for a groundwater monitoring well in Alberta (Canada) over an 8-year period. Methane concentrations in dissolved gas samples (n=12) were on average 4,380±2,452 µg/L, yielding a coefficient of variation (CV) >50 %. Methane concentrations in free gas samples (n=12) were on average 228,756±62, 498 ppm by volume, yielding a CV of 27 %. Quantification of combined sampling, sample handling and analytical uncertainties was assessed via triplicate sampling (CV of 19 % and 12 % for free gas and dissolved gas methane concentrations, respectively). Free and dissolved gas samples yielded comparable methane concentration patterns and there was evidence that sampling operations and pumping rates had a marked influence on the obtained methane concentrations in free gas. δ13CCH4 and δ2HCH4 values of methane were essentially constant (−78.6±1.3 and −300±3‰, respectively) throughout the observation period, suggesting that methane was derived from the same biogenic source irrespective of methane concentration variations. The isotopic composition of methane constitutes a robust and highly valuable baseline parameter and increasing δ13CCH4 and δ2HCH4 values during repeat sampling may indicate influx of thermogenic methane. Careful sampling and analytical procedures with identical and repeatable approaches are required in baseline-monitoring programs to generate methane concentration and isotope data for groundwater that can be reliably compared to repeat measurements once potential impact from oil and gas development, for example, may occur.
Humez, P., B. Mayer, M. Nightingale, J. Ing, V. Becker, Becker, V., Kingston, A., Taylor, S., Bayegnak, G., Millot, R., et W. Kloppmann, 2016c. Redox controls on methane formation, migration and fate in shallow aquifers. Hydrol. Earth Syst. Sci., 20, 2759–2777, 2016, doi: 10.5194/hess-20-2759-2016.	**Contenu général de l'article :** Étude qui a analysé les données géochimiques du réseau de suivi de l'Alberta qui permet d'établir les conditions préalables de la qualité de l'eau souterraine, notamment la présence de méthane, dans une région productrice d'hydrocarbures. L'étude n'a pas trouvé d'évidence d'apports de méthane profond, via des voies naturelles ou anthropogéniques de migration des fluides. **Résumé (*Abstract*) :** Development of unconventional energy resources such as shale gas and coalbed methane has generated some public concern with regard to the protection of groundwater and surface water resources from leakage of stray gas from the deep subsurface. In terms of environmental impact to and risk assessment of shallow groundwater resources, the ultimate challenge is to distinguish (a) natural in situ production of biogenic methane, (b) biogenic or thermogenic methane migration into shallow aquifers due to natural causes, and (c) thermogenic methane migration from deep sources due to human activities associated with the exploitation of conventional or unconventional oil and gas resources. This study combines aqueous and gas (dissolved and free) geochemical and isotope data from 372 groundwater samples obtained from 186 monitoring wells of the provincial Groundwater Observation Well Network (GOWN) in Alberta (Canada), a province with a long record of conventional and unconventional hydrocarbon exploration. We investigated whether methane occurring in shallow groundwater formed in situ, or whether it migrated into the shallow aquifers from elsewhere in the stratigraphic column. It was found that methane is ubiquitous in groundwater in Alberta and is predominantly of biogenic origin. The highest concentrations of biogenic methane (>0.01mM or >0.2 mgL^{-1}), characterized by $\delta^{13}C_{CH4}$ values < -55 ‰, occurred in anoxic Na-Cl, Na-HCO3, and Na-HCO3-Cl type groundwaters with negligible concentrations of nitrate and sulfate suggesting that methane was formed in situ under methanogenic conditions for 39.1% of the samples. In only a few cases (3.7 %) was methane of biogenic origin found in more oxidizing shallow aquifer portions suggesting limited upward migration from deeper methanogenic aquifers. Of the samples, 14.1% contained methane with $\delta^{13}C_{CH4}$ values > -54 ‰, potentially suggesting a thermogenic origin, but aqueous and isotope geochemistry data revealed that the elevated $\delta^{13}C_{CH4}$ values were caused by microbial oxidation of biogenic methane or postsampling degradation of low CH4 content samples rather than migration of deep thermogenic gas. A significant number of samples (39.2 %) contained methane with predominantly biogenic C isotope ratios ($\delta^{13}C_{CH4}$ < -55 ‰) accompanied by elevated concentrations of ethane and sometimes trace concentrations of propane. These gases, observed in 28.1%of the samples, bearing both biogenic

	($\delta^{13}C$) and thermogenic (presence of C3) characteristics, are most likely derived from shallow coal seams that are prevalent in the Cretaceous Horseshoe Canyon and neighboring formations in which some of the groundwater wells are completed. The remaining 3.7% of samples were not assigned because of conflicting parameters in the data sets or between replicates samples. Hence, despite quite variable gas concentrations and a wide range of $\delta^{13}C_{CH4}$ values in baseline groundwater samples, **we found no conclusive evidence for deep thermogenic gas migration into shallow aquifers either naturally or via anthropogenically induced pathways in this baseline groundwater survey**. This study shows that the combined interpretation of aqueous geochemistry data in concert with chemical and isotopic compositions of dissolved and/or free gas can yield unprecedented insights into formation and potential migration of methane in shallow groundwater. This enables the assessment of cross-formational methane migration and provides an understanding of alkane gas sources and pathways necessary for a stringent baseline definition in the context of current and future unconventional hydrocarbon exploration and exploitation.
Sherwood, O.A., Rogers, J.D., Lackey, G., Burke, T.L., Osborn, S.G., Ryan, J.N., 2016. Groundwater methane in relation to oil and gas development and shallow coal seams in the Denver-Julesburg Basin of Colorado. PNAS, 113(30), 8391–8396, doi: 10.1073/pnas.1523267113.	**Contenu général de l'article :** Article montrant l'importance de l'intégrité des puits pétroliers et gaziers pour empêcher la migration de méthane, alors que la fracturation hydraulique à grand volume dans les puits horizontaux a été jugée comme n'ayant pas eu d'incidence sur la migration de méthane. **Résumé (*Abstract*) :** Unconventional oil and gas development has generated intense public concerns about potential impacts to groundwater quality. Specific pathways of contamination have been identified; however, overall rates of contamination remain ambiguous. We used an archive of geochemical data collected from 1988 to 2014 to determine the sources and occurrence of groundwater methane in the Denver-Julesburg Basin of northeastern Colorado. This 60,000-km2 region has a 60-y-long history of hydraulic fracturing, with horizontal drilling and high-volume hydraulic fracturing beginning in 2010. Of 924 sampled water wells in the basin, dissolved methane was detected in 593 wells at depths of 20–190 m. Based on carbon and hydrogen stable isotopes and gas molecular ratios, most of this methane was microbially generated, likely within shallow coal seams. A total of 42 water wells contained thermogenic stray gas originating from underlying oil and gas producing formations. Inadequate surface casing and leaks in production casing and wellhead seals in older, vertical oil and gas wells were identified as stray gas migration pathways. The rate of oil and gas wellbore failure was estimated as 0.06% of the 54,000 oil and gas wells in the basin (lower estimate) to 0.15% of the 20,700 wells in the area where stray gas contamination occurred (upper estimate) and has remained steady at about two cases per year since 2001. These results show that wellbore barrier failure, not high-volume hydraulic fracturing in horizontal wells, is the main cause of thermogenic stray gas migration in this oil- and gas-producing basin.
LeDoux, St.T.M., Szynkiewicz, A., Faiia, A.M., Mayes, M.A., McKinney, M.L., Dean, W.G., 2016. Chemical and isotope compositions of shallow groundwater in areas impacted by hydraulic fracturing and surface mining in the Central Appalachian Basin, Eastern United States. Applied Geochemistry 71 (2016), 13 pp., doi: 10.1016/j.apgeochem.2016.05.007.	**Contenu général de l'article :** Cet article donne un exemple des processus complexes qui peuvent influencer la concentration et la signature isotopique du méthane. Dans la région étudiée, la présence de méthane n'a pas été trouvée reliée aux puits d'exploitation du gaz de shale ayant été fracturés hydrauliquement. **Résumé (*Abstract*) :** Hydraulic fracturing of shale deposits has greatly increased the productivity of the natural gas industry by allowing it to exploit previously inaccessible reservoirs. Previous research has demonstrated that this practice has the potential to contaminate shallow aquifers with methane (CH_4) from deeper formations. This study compares concentrations and isotopic compositions of CH_4 sampled from domestic groundwater wells in Letcher County, Eastern Kentucky in order to characterize its occurrence and origins in relation to both neighboring hydraulically fractured natural as wells and surface coal mines. The studied groundwater showed concentrations of CH_4 ranging from 0.05 mg/L to 10 mg/L, thus, no immediate remediation is required. The $\delta^{13}C$ values of CH_4 ranged from -66‰to -16‰, and $\delta 2H$ values ranged from -286‰ to -86‰, suggesting an immature thermogenic and mixed biogenic/thermogenic origin. The occurrence of CH_4 was not correlated with proximity to hydraulically fractured natural gas wells. Generally, CH_4 occurrence corresponded with groundwater abundant in Na^+, Cl^-, and HCO_3^-, and with low concentrations of SO_4^{2-}. The CH_4 and SO_4^{2-} concentrations were best predicted by the oxidation/reduction potential of the studied groundwater. CH_4 was abundant in more reducing waters, and SO_4^{2-} was abundant in more oxidizing waters. Additionally, groundwater in greater proximity to surface mining was more likely to be oxidized. This, in turn, might have increased the likelihood of CH_4 oxidation in shallow groundwater.
Schloemer, S., Elbracht, J., Blumenberg, M., Illing, C.J., 2016. Distribution and origin of dissolved	**Résumé (*Abstract*) :**

methane, ethane and propane in shallow groundwater of Lower Saxony, Germany. Applied Geochemistry, 67 (2016), 118-132, doi: 10.1016/j.apgeochem.2016.02.005.	More than 90% of Germany's domestic natural gas production and reserves are located in Lower Saxony, North Germany. Recently, research has been intensified with respect to unconventional shale gas, revealing a large additional resource potential in northern Germany. However, many concerns arise within the general public and government/political institutions over potential groundwater contamination from additional gas wells through hydraulic fracturing operations. In order to determine the naturally occurring background methane concentrations, ~1000 groundwater wells, covering ~48 000 km2, have been sampled and subsequently analyzed for dissolved methane, ethane and propane and the isotopic composition of methane (δ13C). Dissolved methane concentrations cover a range of ~7 orders of magnitude between the limit of quantification at ~20 nl/l and 60 ml/l. The majority of groundwater wells exhibit low concentrations (<1 ml/l), a small number of samples (65) reveal concentration in the range >10 ml/l. In 27% of all samples ethane and in 8% ethane and propane was detected. The median concentration of both components is generally very low (ethane 50 nl/l, propane 23 nl/l). Concentrations reveal a bimodal distribution of the dissolved gas, which might mirror a regional trend due to different hydrogeological settings. The isotopic composition of methane is normally distributed (mean ~ -70‰ vs PDB), but shows a large variation between -110‰ and +20‰. Samples with δ13C values lower than -55‰ vs PDB (66%) are indicative for methanogenic biogenic processes. 5% of the samples are unusually enriched in 13C (>=25‰ vs PDB) and can best be explained by microbial methane oxidation. According to a standard diagnostic diagram based on methane δ13C values and the ratio of methane over the sum over ethane plus propane (“Bernard”-diagram) less than 4% of the samples plot into the diagnostic field of typical thermogenic natural gases. However, in most cases only ethane has been detected and the remaining less than 15 samples demonstrate an uncommon ratio of ethane to propane compared to typical thermogenic hydrocarbons. These data do not suggest a migration of deeper sourced gases, but a thermogenic source cannot be excluded entirely for some samples. However, ethane and propane can also be generated by microbial processes and might therefore represent ubiquitous background groundwater abundances of these gases. Nevertheless, our data suggest that due to the exceedingly low concentration of ethane and propane, respective concentration changes might prove to be a more sensitive parameter than methane to detect possible migration of deeper sourced (thermally generated) hydrocarbons into a groundwater aquifer.
Molofsky, L.J., Connor, J.A., McHugh, T.E., Richardson, S.D., Woroszylo, C., and Alvarez, P.J., 2016a. Environmental factors associated with natural methane occurrence in the Appalachian Basin. Groundwater 2016, 13 pp., doi: 10.1111/gwat.12401.	**Résumé (*Abstract*) :** The recent boom in shale gas development in the Marcellus Shale has increased interest in the methods to distinguish between naturally occurring methane in groundwater and stray methane associated with drilling and production operations. This study evaluates the relationship between natural methane occurrence and three principal environmental factors (groundwater redox state, water type, and topography) using two pre-drill datasets of 132 samples from western Pennsylvania, Ohio, and West Virginia and 1417 samples from northeastern Pennsylvania. Higher natural methane concentrations in residential wells are strongly associated with reducing conditions characterized by low nitrate and low sulfate ([NO3−]<0.5 mg/L; [$SO4^{2-}$]<2.5mg/L). However, no significant relationship exists between methane and iron [Fe(II)], which is traditionally considered an indicator of conditions that have progressed through iron reduction. As shown in previous studies, water type is significantly correlated with natural methane concentrations, where sodium (Na) -rich waters exhibit significantly higher ($p<0.001$) natural methane concentrations than calcium (Ca)-rich waters. For water wells exhibiting Na-rich waters and/or low nitrate and low sulfate conditions, valley locations are associated with higher methane concentrations than upland topography. Consequently, we identify three factors (‘‘Low NO3− & $SO4^{2-}$’’ redox condition, Na-rich water type, and valley location), which, in combination, offer strong predictive power regarding the natural occurrence of high methane concentrations. Samples exhibiting these three factors have a median methane concentration of 10,000 µg/L. These heuristic relationships may facilitate the design of pre-drill monitoring programs and the subsequent evaluation of post-drill monitoring results to help distinguish between naturally occurring methane and methane originating from anthropogenic sources or migration pathways.
Molofsky, L.J., Richardson, S.D., Gorody, A.W., Baldassare, F., Blacks, J.A., McHugh, T.E., and Connor, J.A., 2016b. Effect of different sampling methodologies on measured methane concentrations in groundwater samples. Groundwater, 12 pp., doi: 10.1111/gwat.12415.	**Résumé (*Abstract*) :** Analysis of dissolved light hydrocarbon gas concentrations (primarily methane and ethane) in water supply wells is commonly used to establish conditions before and after drilling in areas of shale gas and oil extraction. Several methods are currently used to collect samples for dissolved gas analysis from water supply wells; however, the reliability of results obtained from these methods has not been quantified. This study compares dissolved methane and ethane concentrations measured in groundwater samples collected using three sampling methods employed in pre- and post-drill sampling programs in the Appalachian Basin. These include an open-system collection method where 40 mL volatile organic analysis (VOA) vials are filled directly while in contact with the atmosphere (Direct-Fill VOA) and two alternative methods: (1) a semi-closed system method whereby 40mL VOA vials are filled while inverted under a head of water (Inverted VOA) and (2) a relatively new (2013) closed system method in which the sample is collected without direct contact with purge water or the atmosphere (IsoFlask®). This study reveals that, in the absence of effervescence, the

	difference in methane concentrations between the three sampling methods was relatively small. However, when methane concentrations equaled or exceeded 20 mg/L (the approximate concentration at which effervescence occurs in the study area), IsoFlask® (closed system) samples yielded significantly higher methane concentrations than Direct-Fill VOA (open system) samples, and Inverted VOA (semi-closed system) samples yielded lower concentrations. These results suggest that open and semi-closed system sample collection methods are adequate for non-effervescing samples. However, the use of a closed system collection method provides the most accurate means for the measurement of dissolved hydrocarbon gases under all conditions.
Christian, K. M., L. K. Lautz, G. D. Hoke, D. I. Siegel, Z. Lu, and J. Kessler, 2016. Methane occurrence is associated with sodium-rich valley waters in domestic wells overlying the Marcellus shale in New York State. Water Resour. Res., 52, 206–226, doi: 10.1002/2015WR017805.	**Résumé (*Abstract*) :** Prior work suggests spatial parameters (e.g., landscape position, distance to nearest gas well) can be used to estimate the amount of dissolved methane in domestic drinking water wells overlying the deep Marcellus Shale. New York (NY) provides an opportunity to investigate methane occurrence prior to expansion of high-volume hydraulic fracturing because unconventional gas production is currently banned in the state. We sampled domestic groundwater wells for methane in 2013 (n5137) across five counties of NY bordering Pennsylvania, and then resampled a subset of those wells in 2014 for methane concentrations and δ13C-CH4 and δD-CH4. The majority of waters from wells sampled (77%) had low concentrations of methane (<0.1 mg/L), and only 5% (n57) had actionable levels of methane (>10 mg/L). Dissolved methane concentrations did not change as a function of proximity to existing vertical gas wells, nor other parameters indicating subsurface planes of weakness (i.e., faults or lineaments). Methane levels were significantly higher in wells closer to hydrography flow lines, and most strongly correlated to Na-HCO3 water type. The distribution of methane between Ca-HCO3 (n576) and Na-HCO3 (n523) water types significantly differed (p<0.01), with median methane concentrations of 0.002 and 0.78 mg/L, respectively. Combined classification of sampled waters based on the dominant water cation, well topographic position, and geologic unit of well completion effectively identified wells with a greater than 50% probability of having methane concentrations exceeding 1 mg/L. Such classification schemes may be useful as a screening tool to assess natural versus gas production-related sources of methane in domestic wells.
Siegel, D.I., Azzolina, N.A., Smith, B.J., Perry, A.E., Bothun, R.L., 2015. Methane concentrations in water wells unrelated to proximity to existing oil and gas wells in Northeastern Pennsylvania. Environ. Sci. Technol. 2015, 49, 4106−4112, doi: 10.1021/es505775c.	**Résumé (*Abstract*) :** Recent studies in northeastern Pennsylvania report higher concentrations of dissolved methane in domestic water wells associated with proximity to nearby gas-producing wells [Osborn et al. Proc. Natl. Acad. Sci. U. S. A. 2011, 108, 8172] and [Jackson et al. Proc. Natl. Acad. Sci. U. S. A., 2013, 110, 11250]. We test this possible association by using Chesapeake Energy's baseline data set of over 11,300 dissolved methane analyses from domestic water wells, densely arrayed in Bradford and nearby counties (Pennsylvania), and near 661 pre-existing oil and gas wells. The majority of these, 92%, were unconventional wells, drilled with horizontal legs and hydraulically fractured. Our data set is hundreds of times larger than data sets used in prior studies. In contrast to prior findings, we found no statistically significant relationship between dissolved methane concentrations in groundwater from domestic water wells and proximity to pre-existing oil or gas wells. Previous analyses used small sample sets compared to the population of domestic wells available, which may explain the difference in prior findings compared to ours.
Hammond, P.A., 2016. The relationship between methane migration and shale-gas well operations near Dimock, Pennsylvania, USA. Hydrogeol J (2016) 24, 503–519, doi: 10.1007/s10040-015-1332-4.	**Contenu général de l'article :** Exemple de l'application des isotopes pour l'identification de la provenance du méthane, dans ce cas-ci relié à un problème d'intégrité de puits gaziers. **Résumé (*Abstract*) :** Migration of stray methane gas near the town of Dimock, Pennsylvania, has been at the center of the debate on the safety of shale gas drilling and hydraulic fracturing in the United States. The presented study relates temporal variations in molecular concentrations and stable isotope compositions of methane and ethane to shale-gas well activity (i.e., vertical/horizontal drilling, hydraulic fracturing and remedial actions). This was accomplished by analyzing data collected, between 2008 and 2012, by state and federal agencies and the gas well operator. In some cases, methane migration started prior to hydraulic fracturing. Methane levels of contaminated water wells sampled were one to several orders of magnitude greater than the concentrations due to natural variation in water wells of the local area. Isotope analyses indicate that all samples had a thermogenic origin at varying maturity levels, but from formations above the hydraulically fractured Marcellus Shale. The results from the initial water well samples were similar to annular gas values, but not those of production gases. **This indicates that leakage by casing cement seals most likely caused the impacts, not breaks in the production casing walls.** Remediation by squeeze cementing was partially effective in mitigating impacts of gas migration. In several cases where remediation caused a substantial reduction in methane levels, there were also substantial changes in the isotope values, providing evidence of two sources, one natural and the other man-induced. Sampling water wells while venting gas wells appears to be a cost-effective method for determining if methane migration has occurred.

Li, Z., You, C., Gonzales, M., Wendt, A.K., Wu, F., Brantley, S.L., 2016. Searching for anomalous methane in shallow groundwater near shale gas wells. Journal of Contaminant Hydrology 195 (2016), 23–30, doi: 10.1016/j.jconhyd.2016.10.005.	**Résumé (*Abstract*) :** Since the 1800s, natural gas has been extracted from wells drilled into conventional reservoirs. Today, gas is also extracted from shale using high-volume hydraulic fracturing (HVHF). These wells sometimes leak methane and must be re-sealed with cement. Some researchers argue that methane concentrations, C, increase in groundwater near shale-gas wells and that “fracked” wells leak more than conventional wells. We developed techniques to mine datasets of groundwater chemistry in Pennsylvania townships where contamination had been reported. Values of C measured in shallow private water wells were discovered to increase with proximity to faults and to conventional, but not shale-gas, wells in the entire area. However, in small subareas, C increased with proximity to some shale-gas wells. Data mining was used to map a few hotspots where C significantly correlates with distance to faults and gas wells. Near the hotspots, 3 out of 132 shale-gas wells (~2%) and 4 out of 15 conventional wells (27%) intersect faults at depths where they are reported to be uncased or uncemented. These results demonstrate that even though these data techniques do not establish causation, they can elucidate the controls on natural methane emission along faults and may have implications for gas well construction.
Down, A., Schreglmann, K., Plata, D.L., Elsner, M., Warner, N.R., Vengosh, A., Moore, K., Coleman, D., Jackson, R.B., 2015. Pre-drilling background groundwater quality in the Deep River Triassic Basin of central North Carolina, USA. Applied Geochemistry 60 (2015) 3–13, doi: 10.1016/j.apgeochem.2015.01.018.	**Résumé (*Abstract*) :** Unconventional natural gas development via horizontal drilling and hydraulic fracturing has greatly increased the supply of natural gas in the United States. However, the practice presents concerns about the possibility for impacts on shallow groundwater aquifers. The Deep River Triassic Basin in central North Carolina is likely to contain natural gas that could be extracted via hydraulic fracturing in the future. Unlike other states where hydraulic fracturing has been employed, North Carolina has no history of commercial oil and gas extraction. In this study, we measured water chemistry, dissolved gases, and volatile organic compounds in 51 private drinking water well samples over the Deep River Triassic Basin. Our data document the background water quality of shallow aquifers in the Deep River Basin, which could provide an important baseline dataset if hydraulic fracturing occurs here in the future. We found only two of the 51 water wells sampled had dissolved CH4 concentrations >0.1 mg/L, and no well had a methane concentration >0.5 mg/L. The δ13C–CH4 of the two highest CH4 concentration water wells (_69.5‰ and _61‰) suggest a biogenic CH4 source and are distinct from the d13C–CH4 of two test gas wells drilled in the area (-54.41‰ and -45.11‰). Unlike other basins overlying shale gas formations in the US, we find no evidence for CH4 migration into shallow groundwater in the Triassic basin. In addition, we found only seven VOCs in five water samples, with all levels below the US EPA’s maximum contaminant levels. Ion and trace metal concentrations in most samples were also below US EPA primary drinking water standards, with the exception of two samples that exceed the standards for As. We modeled the depth of the upper surface of the Cumnock Shale formation in the Deep River Basin using a kriging algorithm and found that its depth below the surface is shallow (0–≈1500 m) relative to other shale formations that have been drilled commercially in the US, including the Marcellus in Pennsylvania and the Fayetteville in Arkansas. The relatively shallow shale, combined with the presence of multiple faults and diabase intrusions that characterize the geology of the area, may make the Deep River Triassic Basin more vulnerable to deep fluid connectivity to shallow aquifers.
Boothroyd, I.M., Almond, S., S.M., Worrall, Q.F., Davies, R.J., 2016. Fugitive emissions of methane from abandoned, decommissioned oil and gas wells. Science of the Total Environment 547 (2016) 461–469, doi: 10.1016/j.scitotenv.2015.12.096.	**Contenu général de l’article :** Cette étude a identifié des problèmes potentiels d’intégrité de puits pétroliers et gaziers hors services depuis 8 à 79 ans en milieu terrestre au Royaume-Uni. Ces problèmes potentiels d’intégrité ont été identifiés à l’aide de l’échantillonnage de gaz de sol et de la mesure de la concentration en méthane près des puits pétroliers et gaziers comparé au gaz du sol dans un terrain analogue. L’étude a conclu que les puits ayant de plus fortes concentrations en méthane dans le gaz du sol pouvaient avoir des problèmes d’intégrité. Ces problèmes d’intégrité se révèlent généralement à l’intérieur de 10 ans suite à la mise hors service du puits pétrolier et gazier. **Résumé (*Abstract*) :** This study considered the fugitive emissions of methane (CH4) from former oil and gas exploration and production wells drilled to exploit conventional hydrocarbon reservoirs onshore in the UK. This study selected from the 66% of all onshore wells in the UK which appeared to be properly decommissioned (abandoned) that came from 4 different basins and were between 8 and 79 years old. The soil gas above each well was analysed and assessed relative to a nearby control site of similar land use and soil type. The results showed that of the 102 wells considered 30% had soil gas CH4 at the soil surface that was significantly greater than their respective control. Conversely, 39% of well sites had significant lower surface soil gas CH4 concentrations than their respective control. We interpret elevated soil gas CH4 concentrations to be the result of well integrity failure, but do not know the source of the gas nor the route to the surface. Where elevated CH4 was detected it appears to have occurred within a decade of it being drilled. The flux of CH4 from wells was 364±677 kg CO2eq/well/year with a 27% chance that the well would have a negative flux to the atmosphere

	independent of well age. This flux is low relative to the activity commonly used on decommissioned well sites (e.g. sheep grazing), however, fluxes from wells that have not been appropriately decommissioned would be expected to be higher.
Soeder, D.J., 2015. Adventures in groundwater monitoring: Why has it been so difficult to obtain groundwater data near shale gas wells? Environmental Geosciences, 22(4), 139–148, doi: 10.1306/eg.09221515011.	**Résumé (*Abstract*) :** Shale gas development in the United States has revolutionized energy production and supply, making the nation energy independent for the first time in decades. However, many people remain concerned that the large-scale hydraulic fracturing necessary to recover hydrocarbons from shale may degrade the environment, including groundwater. Improving the understanding of how groundwater may be impacted by shale gas development requires field monitoring at multiple sites on different shale plays under a variety of climates and hydrologic conditions. Such monitoring has been difficult to achieve because of a lack of access to commercial sites and an absence of funding to drill dedicated research wells.
	Principales références sur les études réalisées au Québec
Bordeleau, G., Rivard, C, Lavoie, D., Lefebvre, R., Ahad, J., Mort, A., Xu, X., en préparation. A multi-isotope approach to determine the origin of methane and higher alkanes in groundwater of the St. Lawrence Platform, Saint-Édouard area, eastern Canada. Manuscrit à soumettre en 2017.	**Résumé préliminaire (*Abstract*) :** A multidisciplinary project was carried out to evaluate shallow aquifer vulnerability to eventual shale gas exploration and exploitation in the Saint-Édouard area located in the St. Lawrence Lowlands near Quebec City, eastern Canada. This paper presents the multi-isotope approach that was used to identify the origin of dissolved methane and higher alkanes in shallow aquifers. Groundwater samples were collected from 30 residential wells and 14 dedicated observation wells drilled for the project. All wells are open boreholes in fractured sedimentary rock. Shallow bedrock gas samples at various depths were also obtained from rock cores from the drilling of observation wells. For groundwater samples, the suite of analyzed parameters includes concentrations of C_1-C_3 alkanes (methane, ethane, propane) and of dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC), stable isotopes of water ($\delta^{18}O$, $\delta^{2}H$), of C1-C3 alkanes ($\delta^{13}C$, $\delta^{2}H$), and of DIC and DOC ($\delta^{13}C$), as well as radiocarbon (^{14}C) in methane and DIC. Analyses for gas extracted from bedrock samples include concentrations and stable isotopes ($\delta^{13}C$, $\delta^{2}H$) of C1-C3 alkanes, as well as ^{14}C in methane. Results were compared with local and regional data available for gas in deep formations, from the Utica Shale and overlying Lorraine Group shales. The Utica Shale, which was the target of shale gas exploration between 2006 and 2010, is located in this region at a depth varying between ~500 m to the north and ~2 km to the south. The stratigraphically overlying Lorraine Group, which corresponds to the caprock, extends to the surficial sediment cover. Methane is ubiquitous in groundwater of this area, with concentrations ranging from the detection limit to above 80 mg/L. The use of multiple lines of evidence helped decipher the complex groundwater-methane system in the region, and supported the following conclusions: 1) most of the methane in shallow groundwater is of microbial origin; 2) this microbial methane was mainly produced in the distant geological past; 3) methane oxidation in shallow parts of the aquifer, and late-stage methanogenesis in deeper parts of the aquifer, are responsible for ambiguous methane isotopic signatures; 4) a contribution of thermogenic gas occurs in 15% of the wells; and 5) both microbial and thermogenic methane come from the local aquifer rather than through migration from greater depths, with the exception of one sample which had an isotopic ratio corresponding to somewhat greater depths. Based on the extensive combination of geochemical results, it appears that the thick sequence of shales constituting the caprock acts as an effective impermeable barrier between the Utica Shale and shallow groundwater resources. However, evidence of upward migration of very old, saline groundwater near a major fault indicates that these geological features or their vicinity may serve as preferential fluid migration pathways, at least over a certain distance (probably < 500 m deep). This finding, combined with results of the geomechanical and structural geology components that were also performed within the framework of this multidisciplinary project, certainly warrants caution, and these areas should be carefully investigated if shale gas exploitation, involving hydraulic fracturing, is to occur in the future.
Bordeleau, G., Rivard, C., Lavoie, D., Lefebvre, R., Malet, X., Ladevèze, P., soumis. Geochemistry of groundwater in the Saint-Édouard area, Quebec, Canada, and its influence on the distribution of methane in shallow aquifers. Manuscrit soumis le 16 février 2017 à *Applied Geochemistry*.	**Résumé préliminaire (*Abstract*) :** Shale gas and tight oil production has undergone a tremendous increase in the last decade in North America, which was accompanied by animated scientific debate and local public uproar concerning environmental issues, especially the risks of contamination for shallow groundwater resources. In Quebec (eastern Canada), public concerns led to a de facto fracking moratorium in 2010 for the St. Lawrence Lowlands, where the underlying Utica Shale is known to contain significant gas resources. As only a few exploration gas wells have been drilled, this area may still be considered “virgin” with respect to exploitation. In 2012, a 4-year project was initiated by the Geological Survey of Canada, which aimed at characterizing aquifer vulnerability to deep industrial activities in the St-Édouard region, located close to Quebec City in the St Lawrence Lowlands. As part of this project, a baseline study of hydrocarbons and other geochemical parameters was conducted in shallow aquifers. This paper presents groundwater geochemical characteristics in the region and assesses the geological, hydrogeological and geochemical controls on methane distribution.

	Results show that methane is present in 96% of the sampled wells and that concentrations are highly variable (from 0.006 mg/L to above 80 mg/L), sometimes over short distances and through time. Methane concentrations do not appear to be directly related to bedrock geology, but rather to specific hydrogeochemical conditions, such as those found below the active groundwater flow zone (0-30 m), where relatively old, chemically evolved water is found under semi-confined to confined conditions. Two main fault zones are well documented in the area, and there is clear evidence that some deep formation brines, in addition to marine water originating from the Champlain Sea, are migrating into shallow aquifers in the vicinity of the Jacques-Cartier River fault in the northern part of the study area. This salty groundwater contribution is attributed to the regional groundwater flow coming from the Appalachians and discharging along this normal fault zone close to the St. Lawrence River. The depth from which the brine originates is, however, unknown, There is no indication that deep thermogenic gas from the Utica Shale is currently reaching the surface, through this pathway or elsewhere in this region.
Rivard, C., Bordeleau, G., Lavoie, D., Lefebvre, R., Malet, X., en préparation. Can groundwater sampling techniques used in observation wells influence methane concentrations and isotopes? Manuscrit à soumettre en juillet 2017 à *Environmental Monitoring and Assessment.*	**Résumé préliminaire (*Abstract*) :** An investigation to assess the impact of different sampling techniques used in observation wells on methane concentrations and isotopes was carried out in the Saint-Édouard area (southern Québec, Canada). This study was part of a larger project for which one of the objectives was to identify the origin of methane in groundwater. Three common sampling devices were tested in 10 wells open in a fractured rock aquifer and exhibiting a wide range of concentrations and isotopic signatures: two submersible pumps (impeller and bladder) and disposable sampling bags (HydraSleeve) used before and after pumping. Samples were collected in vials filled and capped under water in a larger container. Although groundwater highly charged with dissolved gases will exsolve when pumped and brought to the surface at atmospheric pressure, underestimation of methane concentrations was not an issue here, as key information about methane sources comes from the isotopic signature. Results from three sampling campaigns showed that methane concentrations obtained with the selected sampling techniques are usually similar and that there are no systematic bias related to a specific technique, but they can nonetheless sometimes vary quite significantly (up to 3.5 times) for a given well and sampling event. Isotopic values obtained with all sampling techniques are very similar, except in the case where HydraSleeve bags were used before pumping (no-purge approach) in a well that had different initial (ambient) conditions, related to upward flow within the well.
Rivard, C., Bordeleau, G., Lavoie, D., Lefebvre, R., Malet, X., accepté. Temporal variations of methane concentration and isotopic composition in groundwater of the St. Lawrence Lowlands, eastern Canada. Manuscrit HJ-2017-4679 soumis le 2 mars 2017 et accepté avec révisions le 19 juin 2017 par *Hydrogeology Journal*.	**Résumé préliminaire (*Abstract*) :** Dissolved methane concentrations in shallow groundwater are known to vary both spatially and temporally. However, the extent of these variations is poorly documented and this knowledge is critical for distinguishing natural fluctuations from anthropogenic impacts stemming from deep oil and gas activities. This issue was addressed as part of a groundwater research program aiming to assess the risk of shale gas development for groundwater quality over a 500 km^2 area in the St-Édouard region, located in the St. Lawrence Lowlands, Quebec, Canada. The St. Lawrence Lowlands were the target of shale gas exploration between 2006 and 2010, before a fracking moratorium was imposed. Only 28 shale gas wells were drilled and 18 of those wells were hydraulically fractured over this 20 500 km^2 region. In the St-Édouard area, methane is naturally ubiquitous in groundwater, with concentrations ranging from the detection limit up to 80 mg/L. A specific study aimed to define the natural variability of methane concentrations and isotopic composition in groundwater prior to potential shale gas development in the study area. Monitoring was carried out in seven water wells over a period of up to 2.5 years, including five dedicated observation wells and two residential wells. Results showed that for a given well, using the same sampling depth and sampling technique, methane concentrations can vary over time from 2.5 to 6 times relative to the lowest recorded value. Methane isotopes, which are a useful tool to distinguish the gas origin, were found to be stable for most wells, but they varied significantly over time in the two wells where methane concentrations are the lowest. The use of gas dryness ratios (concentrations of methane over total ethane and propane), carbon and hydrogen isotopes of methane, and carbon isotopes of dissolved inorganic carbon (DIC) helped unravel the processes responsible for these variations. This study indicates that both methane concentrations and isotopes, as well as DIC isotopes, should be regularly monitored over at least one year to establish the potential natural variations of baseline values prior to hydrocarbon development.
Lavoie, D., Pinet, N., Bordeleau, G., Ardakani, O.H., Ladevèze, P., Duchesne, M.J., Rivard, C., Mort, A., Brake, V., Sanei, H., Malet, X., 2016. The Upper Ordovician black shales of southern Quebec (Canada) and their significance for naturally occurring hydrocarbons in shallow groundwater.	**Résumé (*Abstract*) :** Shale gas exploration in the St. Lawrence Platform of southern Quebec (eastern Canada) focussed on the Upper Ordovician Utica Shale from 2006 to 2010 during which 28 wells were drilled, 18 of which were fracked. The St. Lawrence Platform is thus considered as a pristine geological domain where potential environmental effects of fracking can be evaluated relative to the natural baseline conditions of the shallow aquifers. In the Saint-Édouard area southwest of Quebec City, it has been shown that groundwater carries variable and locally high levels of naturally occurring dissolved hydrocarbons in which thermogenic ethane and propane can be found. Fifteen shallow (30–147 m) wells were drilled into bedrock and sampled (cores and cuttings) with the purpose of characterizing the shallow bedrock in a shale gas pre-development context.

International Journal of Coal Geology 158 (2016), 44-64, doi: 10.1016/j.coal.2016.02.008.	The shallow bedrock geology is made of three Upper Ordovician clastic formations. The Lotbinière and Les Fonds formations are time- and facies-correlative with the Utica Shale present at a depth of 1.5 to 2 km in this area. They are dominated by calcareous black shales with minor siltstone and micrite beds. The Nicolet Formation is the youngest unit of the area and consists of gray to dark gray shales with locally abundant thick siltstone and fine-grained sandstone beds. The organic matter in the Lotbinière and Les Fonds formations is represented by solid bitumen with subordinate liptinite algae, graptolites and chitinozoans representing normal marine Type II kerogen. Both formations are at the post-peak hydrocarbon generation as indicated by the equivalent random vitrinite reflectance of 0.94 to 1.04%. Rock Eval data support the Type II nature of the kerogen and the late oil window maturation level. Hydrocarbon extracts from the three formations have yielded high to low concentrations of C1 to C6. For all units, an upward decrease in total volatiles (C1+C2+C3) together with an increase in the gas dryness ratio (C1/C2+C3) is recorded, the transitions occurring at depths shallower than 50mwhere the shales are more fractured. The upward increase in the gas dryness ratio results from the more significant reduction of ethane and propane concentrations compared to that of methane. Consistent with the dryness ratio trend, the δ13CVPDB values of methane change from thermogenic values (≈−50‰) for deeper samples, to more biogenic (negative) values (b−60‰) at shallow depths. A similar δ2HVSMOWtrend of more negative values at shallower depths is noted. The δ13CVPDB and δ2HVSMOWvalues of rock-hosted methane indicate that samples at shallow depth recorded a microbial influence. It is proposed that diffusion and some microbial degradation of hydrocarbons are responsible for the decrease of rock volatiles and the in situ generation of biogenic methane in the shales at shallow depths to mix with the in situ thermogenic methane. The Utica Shale is a very good source rock with high generation potential. However, thermogenic volatiles can also originate from shallower units with much shorter migration pathways. The mixed thermogenic and biogenic methane in the groundwater results from fracture-enhanced diffusion and biodegradation of volatiles at shallow depths.
Moritz, A., Hélie, J.F., Pinti, D.L., Larocque, M., Barnatche, D., Retailleau, S., Lefebvre, R., Gélinas, Y., 2015. Methane baseline concentrations and sources in shallow aquifers from the shale gas-prone region of the St. Lawrence Lowlands (Quebec, Canada). Online March 9, 2015, *Environmental Science & Technology*, 49(7), 4765-4771, doi: 10.1021/acs.est.5b00443.	**Résumé (*Abstract*) :** Hydraulic fracturing is becoming an important technique worldwide to recover hydrocarbons from unconventional sources such as shale gas. In Quebec (Canada), the Utica Shale has been identified as having unconventional gas production potential. However, there has been a moratorium on shale gas exploration since 2010. The work reported here was aimed at defining baseline concentrations of methane in shallow aquifers of the St. Lawrence Lowlands and its sources using δ13C methane signatures. Since this study was performed prior to large-scale fracturing activities, it provides background data prior to the eventual exploitation of shale gas through hydraulic fracturing. Groundwater was sampled from private (n = 81), municipal (n = 34), and observation (n = 15) wells between August 2012 and May 2013. Methane was detected in 80% of the wells with an average concentration of 3.8 ± 8.8 mg/L, and a range of <0.0006 to 45.9 mg/L. Methane concentrations were linked to groundwater chemistry and distance to the major faults in the studied area. The methane δ13C signature of 19 samples was > −50‰, indicating a potential thermogenic source. Localized areas of high methane concentrations from predominantly biogenic sources were found throughout the study area. In several samples, mixing, migration, and oxidation processes likely affected the chemical and isotopic composition of the gases, making it difficult to pinpoint their origin. Energy companies should respect a safe distance from major natural faults in the bedrock when planning the localization of hydraulic fracturation activities to minimize the risk of contaminating the surrounding groundwater since natural faults are likely to be a preferential migration pathway for methane.