NOFRAC
Nova Scotia Fracking Resource and Action Coalition

This is a response to the draft paper titled "What are the interactions between unconventional gas resources and water resources? Input quality and quantity requirements and water treatment needs and impacts" (referred to as the "draft paper"). The draft paper does not provide a reasoned scientific evaluation of the risks posed by hydraulic fracturing on water resources. Overall, the draft paper offers superficial consideration of the risks.

The draft paper gives relatively little consideration to the risks of water contamination posed by the hydraulic fracturing industry from cradle to grave and beyond. The analysis of risks to water needs to include the risks: (i) from trucking contaminants to and from the site; (ii) leaks from ponds, tanks, lines and other surface spills; (iii) of intermediate and long term migration of contaminants, long after active hydraulic fracturing on the site ends; (iv) posed by the extraordinary legal, technical and financial burden borne by the government and citizens to prove the source of contamination and the existence and extent of liability of the polluter; (v) of contamination that occurs, or is discovered, long after hydraulic fracturing on a site ends and the operator and owner have liquidated, gone bankrupt or are otherwise beyond the reach of the law; and (v) posed by contamination that cannot be remediated or cannot be remediated quickly enough or is beyond the financial means of government and citizens to remediate. To the extent risks are considered, there is a paucity of scientific authority cited. In some instances, sweeping conclusions are made with almost nothing offered to support them. For example, that existing regulations are sufficient in any respect.

The draft paper largely ignores and often takes positions contrary to the positions taken by the Council of Canadian Academies ("CCA") in the 292 page assessment the CCA prepared after a four year long study at the request of Environment Canada captioned "Environmental Impacts of Shale Gas Extraction in Canada" ("CCA Report"). The draft paper generally takes the tack that there is sufficient information to answer some very important questions that have been raised about the potential impact of the hydraulic fracturing life and death cycle. The CCA Report concludes that in many respects there is simply not enough scientific information and not enough time has elapsed to determine the risks and how those risks might be mitigated. The draft paper does not explain why the authors have taken such a different approach with such a different result. This is notable as both the pending panel review and the CCA Report aspire to be evidence based. The draft paper needs to explain where the scientific bases are found for taking such a different approach and reaching such a different result.

The draft paper fails to take into account the relative paucity of information available about the risks posed to our water by hydraulic fracturing and the risks of rushing to judgment. The CCA observes (CCA Report at Page 7):

> The strongly contrasting views of shale gas development point to the **need for much more extensive and comprehensive studies. They also point to the need to consider past experience when dealing with new forms of environmental risk. Retrospective analysis suggests that western societies — driven by technological optimism and a belief in the desirability, if not inevitability, of economic expansion — have often underestimated the risks posed by the introduction of new technologies.** The detailed study by the European Environment Agency, *Late Lessons from Early Warnings*, documents numerous examples in which evidence of adverse environmental impacts from economic activity was discounted based on justifications that seemed logical at the time but turned out to be incomplete at best (EEA 2001, 2013). These examples include factors that are relevant

> here, such as the demand for employment and economic development, and the tendency of advocates for new technologies and economic activity to assert that a lack of proof of harm is equivalent to a proof of safety. **At this stage in shale gas development, there are many unanswered questions. This should be taken as an indication of the need for more and better information…** [emphasis supplied]

The draft paper fails to recognize the significance of the risks and the cumulative effects of hydraulic fracturing. The CCA observes (CCA Report at Page 13):

> Some risks, such as cumulative impacts on the land and contamination of groundwater, are more problematic: either we do not know enough about the probability of the risks or, where we do, they may force difficult trade-offs.

The draft paper suggests that there is scant reason to be concerned about the potential risks to groundwater, based on the premise that the fracturing occurs at an impermeable level of the earth. Paper fails to acknowledge there is no such thing as impermeable layers of rock. The CCA (CCA Report at Page 12) states:

> A major environmental concern regarding shale gas development — regional groundwater contamination — hinges on the flow of fluids in low permeability but commonly fractured geological strata. However, **because past scientific interest has largely focused on high permeability rocks (aquifers and petroleum reservoirs), fluid flow in low permeability rocks is poorly understood. Thus, the basic scientific knowledge needed to evaluate potential risks to groundwater on the regional scale is largely lacking.**
> •
> In areas where peer-reviewed studies are available, they do not necessarily agree. For example, there is a substantial range of expert opinion on the extent of fugitive methane emissions from shale gas development.
> •
> **Some of the possible environmental effects of shale gas development, such as the creation of sub-surface pathways between the shale horizons being fractured and fresh groundwater, gas seepage from abandoned wells, and cumulative effects on the land and communities, may take decades to become apparent**. [emphasis supplied]
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> [at Page 79:]
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> …**verifying the stability of the hydraulic conductivity properties of the overburden during and after hydraulic fracturing requires sophisticated *in situ* strain measurements and long-term monitoring, <u>neither of which has been done.</u>** Wang (2013a, 2013b) conducted geomechanical modelling to assess changes in stress conditions in response to gas extraction from the Utica shale region in Quebec that suggest that the caprock may experience an increase in bulk hydraulic conductivity. [emphasis supplied]
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> [at Page 72:]

> **A common misconception** in some of the literature **is that the Intermediate Zone typically has strata that are impermeable,** such that they completely protect or isolate the FGWZ from the deep strata containing gas and saline waters. [emphasis supplied]

At Page 11, the draft paper states "The Council of Canadian Academies, 2014 noted:" and then includes this statement from the AWWA "At this time, AWWA is aware of no proven cases of groundwater contamination directly attributable to hydraulic fracturing." The paper implies that the CCA cited this quote as an important point of evidence or otherwise adopted the AWWA position. The authors of the paper have either misread or misinterpreted the CCA. The quotation of the AWWA position is included by the CCA, to illustrate the multitude of weaknesses in the AWWA position.. The CCA paper describes this position as "common in non-peer reviewed literature." The CCA then goes on to delineate the problems with the AWWA statement, based on peer reviewed articles. Among the points the CCA makes (CCA Report at Page 67) are:

> a) [Tilley and Muehlenbachs (2011)] …"clearly point out the limitation of relying on absence of evidence to support the more general statements of no proven effect that are reflected in the AWWA statement."
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> b) "Note also the distinction between contamination "directly attributable to hydraulic fracturing," as the AWWA stated, and the larger array of processes associated with shale gas extraction, which may also include wastewater reinjection and cross-contamination between Intermediate Zone layers and shallow groundwater due to poor or absent cement seals surrounding oil and gas industry wells."
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> c) "… confidentiality requirements dictated by legal investigations, combined with the expedited rate of development and the limited funding for research, are substantial impediments to peer-reviewed research into environmental impacts." Vidic et al. (2013)

The CCA Report sums up by stating:

> It is important to recognize three issues here:
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> > (i) **sufficient** data to evaluate the claims (for and against) of contamination related to hydraulic fracturing **have not been collected;**
> > (ii) **sufficient data to understand the various possible pathways of contamination** that may occur in the future have **not been collected;** and
> > (iii) **the time frame to judge potential long-term, cumulative impacts has been inadequate**.
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> A claim that shale gas developments have no impacts on groundwater needs to be based on generally accepted science including appropriate data obtained from the groundwater system using modern investigative methods. T**o the Panel's knowledge, such data have not been collected.** Moreover, because intense development in most shale gas plays has been taking place for less than 20 years, questions about the longer-term cumulative effects cannot yet be answered. Experience from other types of contamination shows that impacts on groundwater typically take decades to develop and become increasingly difficult to remediate." [emphasis supplied, at CCA Pages 67-8 Section 4.1]

The CCA also had the following points to make about the unverified claim that there has never been a documented instance of groundwater contamination from hydraulic fracturing:

> [CCA Report at Page 7] **…claims, particularly those related to the migration of hydraulic fracturing fluids from deep underground into regional groundwater resources, are difficult to evaluate because of a lack of baseline data and scientific monitoring, and because the time-frame in which adverse effects may manifest is long. Claims there are *no proven adverse effects* on groundwater from shale gas development lack credibility for the obvious reason that absence of evidence is not evidence** of absence. Further, groundwater has been affected due to incidents such as loss of containment due to faulty well casings or leakage from holding ponds.
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> [at Page 96] Although there are published claims that no proven or verified impacts of shale gas development on groundwater exist, more recent publications and reports dispute these. **The burden of proof should not be on the public to show impacts, but on industry to verify that their claims of performance are accurate and reliable over the relevant scales in space and time. There is reason to believe that shale gas development poses a risk to water resources, but the extent of that risk, and whether substantial damage has already occurred, cannot be assessed because of a lack of scientific data and understanding.** [emphasis supplied]

Also germane on this point but ignored by the draft paper, is the analysis by the CCA at Page 72 of the CCA Report:

> Even when the depth of the source gas is clear, the pathway from the source to shallow groundwater is difficult if not impossible to discern because of the complexity of natural fracture systems and a lack of system characterization and monitoring to assess these systems. Furthermore, contamination may go undetected because of an absence of ongoing monitoring and sampling of domestic wells, dedicated monitoring wells, or other borehole sampling devices.

The attitude expressed in the draft paper is inconsistent with the position taken by the CCA above. The paper turns the burden of proof upside down: "Insufficient evidence exists that links hydraulic fracturing at depths greater than 300 m to aquifer contamination." The burden is not on the public to demonstrate beyond a reasonable doubt that contamination occurs as a result of hydraulic fracturing. The burden is upon the panel to find incontrovertible evidence that negates all reasonable possibility of contamination. The paper should read "insufficient evidence exists that hydraulic fracturing is not linked to aquifer contamination."

The draft paper does not consider cumulative effects that are an express concern of the CCA (Report at Page 5): "...risks do not exist in isolation and can give rise to cumulative effects.

The draft Paper does not consider the existing pathways for migration of toxins, that are reflected these findings by the CCA nor the dearth of hard information on the underlying rock structure (CCA Report at Page 29):

> The sedimentary basins in Nova Scotia are part of the broader Maritimes Sedimentary Basin and underlie the northern and eastern parts of the province.

> Geologically complex, **with numerous faults and fractures**, they are nevertheless seismically stable. Nova Scotia is very much a frontier in terms of onshore petroleum exploration; because few wells have been drilled, **information about** shale gas (e.g.**,** the possible extent of deposits, **rock mechanics) is sparse. [**emphasis supplied)

The draft paper does not address Environment Act precautionary principal.

The draft paper does not address First Nations' water rights.

The draft paper does not address impacts on aquatic life needs (not farm fish). Impacts on aquatic life vary by species, location (freshwater bodies, wetlands, rivers, streams, mud flats, estuaries, the Bay of Fundy, the Minas Basin, Cobequid Bay, the Northumberland Strait etc), and in particular those species that are threatened or endangered.

The draft papers gives virtually no consideration of surface water contamination risks. For example, the paper does not consider risks posed by storage of hydraulic fracturing wastewater. The CCA Report states (at Page 93):

> Flowback water is usually stored in lined surface ponds or tanks before being either treated on-site or off-site in a specialized treatment plant, reused to fracture another well, or reinjected into a deep saline formation. **Lined ponds, even when built with double liners, are rarely free from flaws and can be expected to leak over time. Similarly, the permeability of clay-lined ponds can be increased by the salinity of the stored flowback water** (Folkes, 1982). …
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> In addition, **surface ponds can overflow as a result of significant precipitation** (e.g., during heavy rain storms).

The draft paper fails to acknowledge that existing Nova Scotia groundwater regulations and monitoring cover an extremely narrow range of substances.

The draft paper fails follow through with the following conclusion in the paper: "it is too difficult to review the occurrence of all of the possible contaminants in groundwater…" One core topic of this paper should have been to address all the material contaminants in groundwater (naturally occurring and introduced by well operators) that would be released in flowback water, not just a superficial discussion of arsenic. By way of example only, the draft paper fails to consider naturally occurring lead, radon and salts being released.

The paper fails to take into account the public health risk posed by the release of arsenic, with a suggestion that Nova Scotia Environment treatment guidelines for homeowners provide sufficient protection.

Draft paper fails to consider the submission made to the panel by Duncan Keppie, PhD., the leading geologist in Nova Scotia, about natural rock fractures increasing chances and range of escape of fluids and gases.

Available scientific information cited in submissions to the panel was ignored. The draft paper ignores Mark Tipperman's 75 page submission on releases of contaminants and the plethora of authorities cited and almost innumerable occurrences of water contamination arising from hydraulic fracturing. The draft paper also appears to ignore more than 200 references submitted to the panel by Jennifer West. See for example: A 292 page report prepared for and under

contract with European Commission DG Environment, Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe, prepared by AEA Technology, plc, http://ec.europa.eu/environment/integration/energy/pdf/fracking%20study.pdf:

That is a comprehensive analysis of the risks and potential impacts of fracking. The report concludes that:

> 1. **each fracking site presents a high risk of contamination to groundwater and surface water;** and
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> 2. **on a cumulative basis, fracking sites present a high risk to groundwater, surface water, water resources, air quality, biodiversity, noise levels and traffic**. Id. Page vi, Table ES-1

The draft paper fails to take into account the shortages of potable water that will result when contamination does occur and the difficulty and cost of providing alternative water sources.

The draft paper fails to take into account the potential need for water wells tapping into the earth at the deepest levels possible as fresh water sources come under increasing pressure from global warming, agriculture, waste and overpopulation.

The draft paper fails to consider this finding by the Council of Canadian Academies assessment (Page xvii):

> Some of the possible environmental and health effects of shale gas development may take decades to become apparent. These include the creation of subsurface pathways between the shale horizons being fractured and fresh groundwater, gas seepage along abandoned wells.

The draft paper does not cite a recognized authority, let alone an authority familiar with Nova Scotia's geology for its conclusion about the length of hydraulic fractures. Instead, the paper cites a law school article for the following proposition: "fractures generated by hydraulic fracturing typically extend approximately 100 m vertically and approximately 200 – 300 m laterally (King, La Vergne Bryan, & Clark, 2012)." Assuming the law review article is correct, the paper should consider not simply the typical vertical length of fractures but the full range of fracture lengths. One study showed that a fracture extended for 600 meters. Hypothesis was that it connected with a natural fault (and ns shale is highly fractured) http://extension.psu.edu/natural-resources/natural-gas/news/2013/07/initial-findings-of-the-department-of-energy2019s-study-on-groundwater-contamination-from-hydraulic-fracturing

The draft paper fails to consider these related findings in the CCA Report:

> [At Page xii] 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**." [emphasis supplied]
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> [at Pages 80-81] overall, the limited scale of studies that have detected thermogenic gas and other contaminants in drinking water wells near shale gas operations and the particular conditions in the study regions inhibit drawing firm conclusions about contaminant pathways. Even if baseline data did exist, it would not be possible to clearly differentiate contamination through natural pathways from that caused by previous or current drilling activities, leaky well casings, or from active fracturing. Without good baseline data, the task is immensely more difficult. Thus, in most cases, definitive claims in either direction can neither be proven nor disproven without better information from, for example, suitable science-based groundwater monitoring systems and from improved understanding of mechanisms of gas seepage from rigorous site-specific studies.
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> [at Page 77] There is only minimal reference literature and no peer-reviewed literature that assess the potential for the various chemicals in hydraulic fracturing fluids to persist, migrate, and impact the various types of subsurface systems or to discharge to surface waters.

The draft paper leapfrogs from one isolated fact and the existence of regulations to a conclusion unsupported by any authority or logic: "Caustic soda is also used to process drinking water in some facilities in Nova Scotia as it is highly effective at adjusting pH and poses minimal health risks. In the case of the drinking water facilities, regulations and inspections are required by government to ensure that this chemical is safely applied and handled. Therefore, under the assumption of a strong regulatory framework, it would be anticipated that chemical agents could be safely managed and applied for hydraulic fracturing.

The draft paper ignores this finding by the Council: "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 draft paper fails to consider the difficulty if not impracticality of treating hydraulic fracturing flowback water by any method. As the CCA notes (CCA Report at Page 94):

> Minimal research has been conducted on this aspect of shale gas development [treatment of flowback water]. In addition, the costs of treating flowback waters to achieve ecological and human health and safety standards are generally very high with uncertain regulatory outcomes.

The draft paper ignores this finding by the Council (at Page xvii):

> **Full disclosure** of chemicals and the chemical composition of flowback water is a **necessary but insufficient step** in the assessment of the environmental risks associated with drilling and fracturing. Information is also required on potentially hazardous chemicals produced down-hole by chemical interactions under high temperature and pressure. This includes information on concentration, mobility, persistence in groundwater and surface water, and bio-accumulation properties, for each chemical on its own and as a mixture. This represents a major gap in understanding of the potential environmental and human impacts of hydraulic fracturing, and of how to mitigate

> accidental releases of chemicals or flowback water to the environment. [emphasis supplied]

The draft paper more or less assumes that technology or private industry has or will find a means of treating flowback water to a state where it is harmless; and that Nova Scotia standards for water quality take into account the 700 odd contaminants currently known to be employed by the hydraulic fracturing industry as well as the contaminants in the fractured earth that are released by hydraulic fracturing. The draft paper does not even mention some of the contaminants are hazardous at extremely low level concentrations, for example endocrine disruptors.

The draft paper fails to recognize that there is not nearly enough scientific data to adopt an appropriate regulatory scheme or even a safety plan. The CCA concludes (CCA Report at Page 13) that:

> **…well-crafted, rules will not suffice if they are not supported by good quality environmental information and enforcement. As explained above, much of the information required to assess the environmental risks posed by shale gas development either does not currently exist or is not publicly available.** [emphasis supplied]

The draft paper does not address the prospects for treating aquifers and surface water that are contaminated by hydraulic fracturing. That would have to include what is feasible with today's equipment and scientific understanding, what the financial costs are, how much time would be required, how those costs would be paid with solvent and insolvent polluters, how the costs would be paid in those instances in which the identity or liability of the polluter cannot be established to the satisfaction of the courts, and how the costs would be paid before the identity and liability of the polluter is established. Nor does the draft paper address the feasibility and expense of supplying potable water for citizens, agriculture and other industry when their water supplies are contaminated.

The draft paper cannot reasonably rely and does not explain how the authors believe they may rely on an analogy to other industrial uses, to make the assumption that hydraulic fracturing can be done safely with a water safety plan and monitoring. "Water safety plans would ensure that chemicals used by the industry are publicly declared and appropriate monitoring programs and risk mitigation programs are designed and available for public scrutiny. This approach would provide transparency and consistency as exists in other industries and processes such as drinking water treatment practices." Hydraulic fracturing bears no resemblance to the overwhelming bulk of industrial uses. Plans and monitoring that might be adequate for industrial uses within an industrial zone at a limited number of fixed locations, are unsuited for hydraulic fracturing, that do not entail the introduction and release of as many as 700 contaminants, with cumulative effects.

The draft paper asserts "the *Environment Act* is an Act that could be complemented with specific regulations for enforcement and compliance of onshore petroleum resource sector. Further, as per the *Activities Designation Regulations,* the water requirements for hydraulic fracturing would require proponents to provide a comprehensive groundwater and/or surface water technical analysis and would also be required to provide public consultation prior to water withdrawal." But this framework is woefully inadequate. The paper fails to consider that private citizens have no effective means of enforcing the Environment Act or its regulations, the Act and its regulations place the onus on the government to prove a violation in the case of contamination,

enforcement occurs after contamination does, and this does the public very little good. Furthermore, you have failed to consider there is effectively no viable recourse for most private citizens in this Province whose water is contaminated because the Courts in Nova Scotia require a citizen prove negligence, the cost of baseline, ongoing and future testing for potentially 700 or more contaminants is prohibitive and the difficulty of proving which operator caused the contamination will often be insurmountable.

The draft paper fails to consider the extraordinary difficulty or impossibility, and extraordinary decades long expense of monitoring by citizens. Even if ordinary citizens had the financial resources to pay for the required testing the paper fails to consider the technical requirements that are part of EPA and other judicially recognized methods of water contaminant testing, the expense of shipment of samples to EPA or other credible laboratories that perform tests on the 700 odd contaminants, or whether there are any laboratories in the Province or Atlantic Canada who are qualified, equipped and staffed to test for vast numbers of contaminants in samples submitted by 1,000s of Nova Scotians, let alone for 1,000s of wells, on an ongoing basis. Instead, the draft report simply reflect the expectation that the public should bear the expense and burden of testing, to enable the hydraulic fracturing industry to discharge and release its contaminants. "Residents must also play a monitoring role by having their water regularly tested, beginning before any production activity, which should already be a best practice. "

The paper does not consider how expensive and difficult it would be under existing law for ordinary citizens or even the Provincial government, to meet the existing burden of proof to establish liability on the part of well owners and operators for contamination of ground and surface water, including without limitation intended, costs of qualified technicians and equipment to withdraw and handle sample, shipping costs to qualified laboratories, laboratory tests, experts to investigate, evaluate, prepare reports and testify, litigation expenses including lawyers' fees, discovery expenses and expert witness and travel fees.

If hydraulic fracturing is permitted in the Province, it needs to be governed by statutes and regulations that impose: (i) iron clad "no-fault strict liability" upon the operators and owners of the hydraulic fracturing industry, not "best management practices" or voluntary water safety plans that are negotiated on a case by case basis and on insufficient scientific evidence; and (ii) shift the burden of proof from the government and citizens to those engaged in hydraulic fracturing.

In conclusion, the draft paper does not take into account the plethora of scientific research and analyses available that address the risks of hydraulic fracturing on water resources. Neither the draft paper or anything along the lines of the draft should be included in the panel's report. The panel cannot fairly rely upon this draft paper in formulating even draft recommendations to the provincial government.

Dated: June 19, 2014

Respectfully submitted,

Nova Scotia Fracking Resource and Action Coalition Steering Committee

Appendix:
Crucial sources of science missing
from the draft report

2013 Munk School of Global Affairs at the University of Toronto, **Underground Intelligence: The need to map, monitor, and manage Canada's groundwater resources in an era of drought and climate change**
2010 Munk School of Global Affairs at the University of Toronto . Parfitt, Ben. **Fracture Lines**
2014 Ceres **Fracking and water stress: water demand by the numbers**
2013 Hughes, David. **Drill baby drill**
2012 Groundwater **Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers**
2011 Risk Analysis: An International Journal **Water pollution risk associated with natural gas extraction from the Marcellus Shale**
2012 Natural Resources Defense Council **In fracking's wake: New rules are needed to protect our health and environment from contaminated wastewater.**
2012 Baccante **Fisheries Biologist perspective**
2013 Procedia Earth and Planetary Science **The Effects of Shale Gas Exploration and Hydraulic Fracturing on the Quality of Water Resources in the United States**
2007 Maliva, Guo and Missimer **Vertical migration of waste**
2013 Kiviat **Risks to Biodiversity from Hydraulic Fracturing for Natural Gas in the Marcellus and Utica Shales**
2009 Vokoun and Kanno **Evaluating Effects of Water Withdrawals and Impoundments on Fish Assemblages in Connecticut Streams**
2013 Environmental Science and Technology, **Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania**
2013 Southeastern Naturalist, **Histopathological Analysis of Fish from Acorn Fork Creek, Kentucky, Exposed to Hydraulic Fracturing Fluid Releases**
2013 Proceedings of the National Academy of Sciences, **Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction**
2013 Applied Geochemistry **Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas**
2013 Fisheries **Hydraulic Fracturing and Brook Trout Habitat in the Marcellus Shale Region: Potential Impacts and Research Needs**
2013 Journal of the Air & Waste Management Association **Analysis of BTEX groundwater concentration from surface spills associated with hydraulic fracturing operations**
2013 Applied Geochemistry **Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA**
2013 PNAS **Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania**
2011 Frontiers in Ecology & the Environment **Rapid expansion of natural gas development poses a threat to surface waters**
2011 Chemosphere **Chemical and physical characterization of produced waters from conventional and unconventional fossil fuel resources**
2011 Journal of Environmental Quality **Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia**

2011 PNAS **Methane Contamination of Drinking Water Accompanying Gas-Well Drilling and Hydraulic Fracturing**
2013 Pro Publica **Buried Secrets: Is natural gas drilling endangering U.S. water supplies?**
2010 Fisheries Management and Ecology **Evaluating effects of water withdrawals and impoundments on fish assemblages in southern New England streams**
2010 Penn State **Water withdrawals for development of Marcellus Shale gas in Pennsylvania: Introduction to Pennsylvania's water resources**.
2011 Pro Publica **Feds link water contamination to fracking for the first time**
2012 PNAS **Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania**
2009 NY Department of Environmental Protection **Impact assessment of natural gas production in the New York city water supply watershed: Final impact assessment report**
2012 Physicians, Scientists and Engineers for Healthy Energy **Fluid migration mechanisms due to faulty well design and/or construction: An overview and recent experiences in the Pennsylvania Marcellus play**
2013 Environmental Science and Technology **An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation**
2013 Environmental Science and Technology **Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania**
2011 Ecological Society of America **Rapid expansion of natural gas development poses a threat to surface waters**
2013 Environmental Science and Technology **Life Cycle Water Consumption and Wastewater Generation Impacts of a Marcellus Shale Gas Well**
2012 NCBI **Water pollution risk associated with natural gas extraction from the Marcellus Shale.**
2013 Global Water Forum **New perspectives on the effects of natural gas extraction on groundwater quality**
2014 National Geographic **Insatiable thirst**
European Commission DG Environment, Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe, prepared by AEA Technology