Landscape Impacts of Hydraulic Fracturing Development and Operations on Surface Water and Watersheds

A knowledge integration and summary of potential research approaches that could help inform decision-making for hydraulic fracturing and water

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Prepared by:
Michael Quinn, Mary-Ellen Tyler, Emeka Ajaero, Joseph Arvai, Matthew Carlson, Israel Dunmade, Stephen Hill, Jennifer McCallum, Dena McMartin, David Megson, Gwen O'Sullivan, Ryan Parks, Dave Poulton, Brad Stelfox, Judy Stewart, Carlos Serralde Monreal, Stephen Tomblin, Connie Van der Byl

MOUNT ROYAL UNIVERSITY 1910

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NAMES, AFFILIATIONS & CONTRIBUTIONS OF AUTHORS

Michael Quinn, PhD	Institute for Environmental Sustainability, Mount Royal University, Calgary, AB (Project Lead, Chapter 1, 2 and Synthesis)
Mary-Ellen Tyler, PhD	Faculty of Environmental Design, University of Calgary, Calgary, AB (Co-Project Lead & Chapter 8 and Synthesis)
Emeka Ajaero, PhD	University of Regina (Researcher, Chapter 6)
Joseph Arvai, PhD	Department of Geography, University of Calgary (Chapter 10)
Matthew Carlson	ALCES Group (Modeling, Appendix A)
Israel Dunmade, PhD	Department of Environmental Science, Mount Royal University (Chapter 7)
Stephen Hill, PhD	Environmental and Resource Studies Program, Trent University (Chapter 3)
Jennifer McCallum, MSc Cand.	Environmental and Resource Studies Program, Trent University (Chapter 3)
Dena McMartin, PhD	Associate Vice-President (Academic and Research), University of Regina (Chapter 6)
David Megson, PhD	Postdoctoral Fellow, Ryerson University (Chapter 6)
Gwen O'Sullivan, PhD	Department of Environmental Science, Mount Royal University (Chapter 7)
Ryan Parks, PhD	Bissett School of Business, Mount Royal University (Chapter 4)
Dave Poulton, LLM	David W. Poulton Environmental Strategies (Chapter 9)
Carlos Serralde Monreal, PhD	Institute for Environmental Sustainability, Mount Royal University, Calgary, AB (Chapter 5)
Brad Stelfox, PhD	ALCES Group (Modeling, Appendix A)
Judy Stewart, LLM, PhD Cand.	Faculty of Environmental Design, University of Calgary, Calgary, AB (Chapters 5, 8, 9 and Synthesis)
Stephen Tomblin, PhD	Department of Political Science, Memorial University of Newfoundland (Chapter 9)
Connie Van der Byl, PhD	Bissett School of Business, Mount Royal University (Chapter 4)

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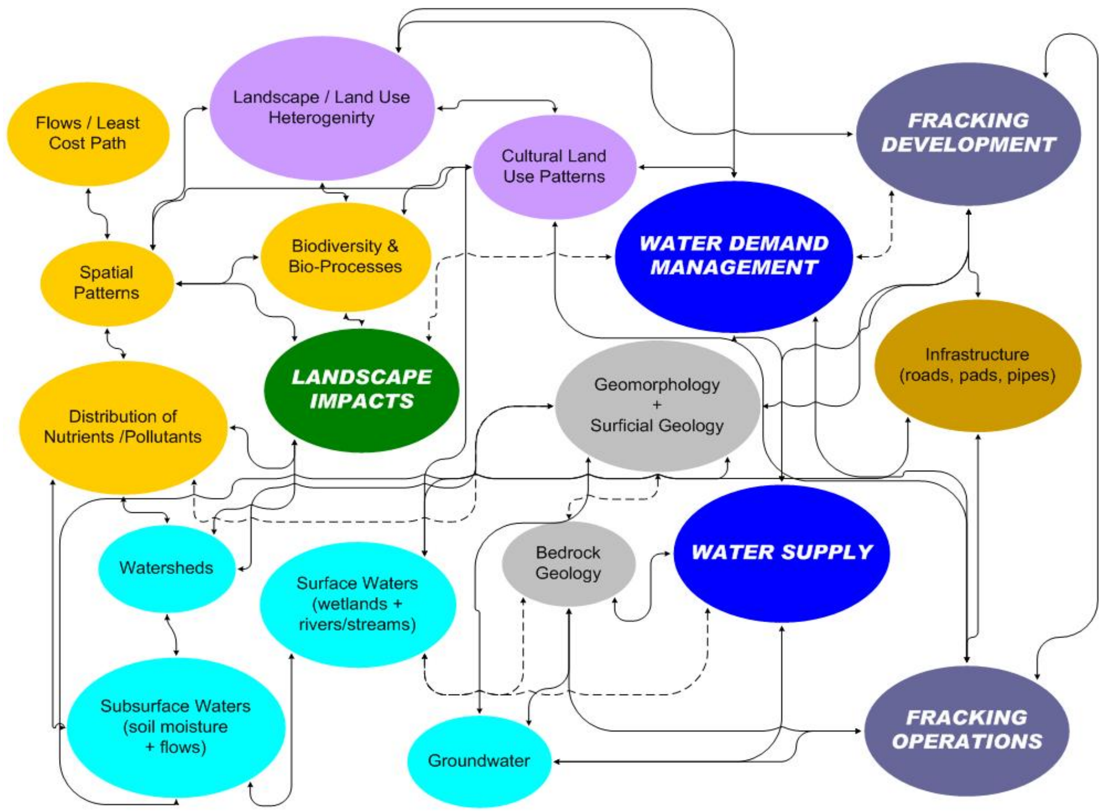
EXECUTIVE SUMMARY

Introduction

Landscapes and watersheds are complex cultural biogeoclimatic systems that are not easily bounded, measured or understood by a single body of expertise. This makes it very challenging to locate and synthesize the best available science to identify what decision-makers need to know about landscape and watershed impacts of hydraulic fracturing. 'Landscape' is not a physical object as much as it is a spatial context for multiple natural processes and human activities. As such, what decision-makers need to know depends upon the specific locations and situational conditions in which hydraulic fracturing is operating. Fracking exists in landscape and watershed contexts that are highly variable at different scales and across different regions. There is a relatively high degree of certainty, within predictable engineered limits, about specific well-based fracking operations. In contrast, there is a lot of uncertainty about how complex social ecological landscape and watershed systems function. Potential landscape and watershed impacts exist in the context of a complex and integrated system of spatial and functional inter-connections and inter-relationships and needs to be understood in this system context (Figure A-1).

We approached landscape and watershed impacts of hydraulic fracturing from a multi-disciplinary social and natural science framework in order to try and capture this complexity. We emerged with common agreement around the difficulties presented by 'silos' of expertise when trying to deal with complex systems. The primary learning from our multidisciplinary approach is the need for greater institutional opportunities to integrate and coordinate a spectrum of approaches to address knowledge gaps in multiple system interactions across scales and involving system threshold effects that may be social in nature as well as biogeochemical.

Figure A-1: Systems Context for Hydraulic Fracturing



Sources

The report relies heavily on the published literature related to hydraulic fracturing. This is a rapidly expanding and evolving body of work. Over 75% of the extant papers and reports on shale gas have been published in the past two years. Despite the proliferation of published material, there has been criticism that the information does not adequately represent the current state of the industry in Canada. We supplemented out data gathering with discussions, interviews and a survey with representatives from industry, government and the affected public.

Social License

Decision-makers need to know more about understanding and establishing a 'social license to operate'. Chapter 3 presents the results of a literature review and content analysis to characterize the range of public response and discourse associated with fracking. There is considerable diversity of response across the country and among different interests, but there is clearly a need to better address the challenges associated with social acceptance. Decision makers are increasingly aware that regulatory approval is necessary, but not sufficient for project success. The expectations of a complex network of stakeholders – local communities, investors, First Nations, industry peers, and so on – need to be continually addressed. A social licence stems from credibility, legitimacy, and trust. There are significant gaps in understanding how public views are shaped and influenced. Likewise there are knowledge and implementation gaps related to understanding the connections between physical and social elements of 'landscape'. Approaches to addressing these issues entail social science research that addresses public perception and knowledge related to fracking and a better understanding of the connections between related issues of energy and the environment. It is often inaccurately assumed that a public misunderstanding or ignorance is a solvable problem, namely that providing more information will somehow move public opinion. New approaches are required to go beyond this 'deficit model' of communication and engagement.

Industry Best Practices

Chapter 4 examines gaps associated with industry best practices to address landscape and watershed issues. The summary was developed through discussions with industry representatives, an analysis of publically available material on petroleum industry best practices, and a review of management literature related to unconventional oil and gas, a media content analysis and a modest industry survey. One of the gaps we identified is associated with achieving a balance between competition and collaboration. How can individual firms benefit from developing innovative strategies for environmental management while helping the overall industry through collaborative improvement? Another theme that emerged in Chapter 4 is shared across all the chapters; the variability in physical, social and regulatory conditions that exist across the country. Approaches are required to better understand and address these differences. The scale of operations and location of activities adds to the challenges of practice across the industry. Building upon the issues raised in the 'social license' chapter (Chapter 3), the effectiveness of the industry to be transparent and communicate regarding stakeholder concerns emerged as a gap. Finally, there is a considerable implementation and institutional gap related to industry efforts to implement best practices beyond regulatory requirements. Approaches for addressing these gaps are largely focused on achieving greater legitimacy and improved reputation in the unconventional oil and gas industry.

Water Use

Most hydraulic fracturing operations require relatively large volumes of water. In many instances, surface water has been the most accessible and economic choice as a fracking fluid. The withdrawal of surface water and the subsequent contamination, treatment and disposal of the water is one of the most significant areas of public concern. Surface water availability varies greatly across the country and even across seasons. Approaches to address surface water usage require region and site specific knowledge of conditions and the potential interactions with other water users. In some regions, there are gaps in basic understanding of hydrologic system function, especially around the interaction between surface water and ground water. Another set of gaps exist around developing and implementing systems for water re-use and recycling and around the potential for use of alternative fracking fluids. Some of the approaches to address the knowledge gaps related to water availability require large scale, systematic research programs to understand regional hydrologic function. This is further addressed in Chapters 8 and 9 with the topics of cumulative effects and the potential for play-based or area-based approaches. Understanding and communicating the effects of surface water removal on aquatic and terrestrial ecosystems will be a critical element in gaining social license. Finally, Chapter 5 identifies another gap that runs through many other topics; the challenges associated with information dissemination and sharing. There is a need for mechanisms to make data more readily accessible for analysis and communication.

Surface Water Contamination

Chapter 6 establishes that there is significant need for research on the potential effects of hydraulic fracturing related activities on surface water quality. There is potential for contamination arising from leaks or spills throughout the full lifecycle of the operation. Contamination may occur due to the introduction of deleterious chemicals associated with unconventional oil and gas development and/or through surface disturbance generated by the operational 'footprint' leading to increased sedimentation to receiving water bodies. Another potential impact that has received comparatively little attention is the removal of surface water leading to altered conditions in the source body (e.g., thermal changes, sediment disruption, concentration increases). Many of the concerns arising in this chapter point to the need for the development and implementation of best practices (see Chapter 4) to prevent and contain spills and to employ less harmful chemicals throughout the development process. In addition, the ability to assess the potential effects of surface water contamination requires the development and implementation of comprehensive monitoring protocols. In many regions, there are significant gaps in baseline data against which to track change. Chapter 6 provides a summary of approaches to address the current knowledge gaps organized around five key issues: understanding fractures and leaks from direct well use, chemical disclosure and characterization of chemicals of concern, efficiency and effectiveness of current legislation relevant to surface water, understanding indirect releases, and understanding the effects on surface water features where water has been removed.

Lifecycle Assessment

One of the central themes of the report is the need to consider the full life cycle of unconventional oil and gas development. Although hydraulic fracturing is not new, the use of high volume, multi-stage, hydraulic fracturing of horizontal wells represents a relatively recent set of techniques. These novel practices do not have enough history to fully understand the long-term implications on the landscape. The use of lifecycle sustainability approaches is ideal to help fill this critical gap. The approaches proposed in Chapter 7 would be an effective way to help organize research to address the gaps raised in the other chapters.

Cumulative Effects

The uncertainty and complexity involved in understanding multiple stressors and valued ecological component thresholds in highly variable and distinct social ecological systems over time and at different spatial scales is highly contextual and cannot be easily measured or 'summed up'. As a result, there are a number of knowledge gaps involved in what both practitioners and decision-makers need to know about the cumulative effects of hydraulic fracturing on regional landscapes and watersheds in a Canadian context. The report identifies four priority CEA knowledge gaps: 1) historical and region specific data gaps, including baseline data about Landscape Impacts and results of monitoring over long periods of time; 2) collaboratively sanctioned systemic approaches and methods for establishing valued ecological components (VECs) needed to set performance objectives and assess Landscape Impacts; 3) inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts; and, 4) integrative and collaborative institutional CEA decision-making frameworks for managing landscape impacts.

There is a lack of operational precedents in Canada for applying a cumulative effects approach to assessment of regional gas extraction from low permeability unconventional geological formations using horizontal wells with multi-stage hydraulic fracturing. Therefore, a demonstration case study was developed for this report and fully presented in Appendix A. The purpose of the case study is to demonstrate how a simulation model, in conjunction with an R-SEA approach, could inform regional management of hydraulic fracturing through the identification of risks and mitigation opportunities, and identify key uncertainties that require further attention. The simulation outcomes were sensitive to uncertainties, emphasizing the importance of improved understanding of hydraulic fracturing's impacts. Addressing other research priorities identified in the report would permit additional indicators to be simulated, most importantly variables related to water availability and water contamination.

Policy, Legal and Regulatory Gaps

Legal, regulatory and policy frameworks for hydraulic fracturing reflect the complex, dynamic social-ecological systems in which they occur. In the Canadian context, the provinces own oil and gas resources and determine when, where, and how energy resources will be developed in the "public interest." Each province regulates hydraulic fracturing according to complex policy and regulatory schemes that reflect their citizens' shared values and desired outcomes for resource extraction. Policies, laws and regulations need to be flexible to address regional variation. Moreover, there are critical influences from practice in the United States and international markets. The fact that various states and provinces have imposed moratoria is a clear sign of policy, legal and regulatory knowledge gaps, because the debate is complicated and cannot be resolved by empirical facts alone.

The report identifies four priority policy, legal and regulatory knowledge gaps that emerged from the literature review and suggested approaches to address them: 1) comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts; 2) knowledge about how legal institutions, governance structures, and decision-making processes can either promote or constrain societal patterns of communication, policy learning, networking, citizens engagement, and knowledge brokering about Landscape Impacts; 3) knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts; and 4) understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

Decision Making and Risk Assessment

When it comes to decision making about unconventional energy development, it is becoming increasingly clear that improved approaches for assessing risks and making decisions (about development initiatives as well as risk management) are required. Improved risk assessments and decisions will arise from a deliberative process designed to guide comprehensive and logical discussions about energy development and delivery. Such processes will encourage involvement from all key stakeholders, and will give them a legitimate voice in the decisions at hand. Moreover, such processes provide a mechanism for organizing information about risks (and benefits), and for dialogue about energy development options and their anticipated consequences. And, such processes provide a mechanism for structuring decision-making about energy choices in a manner that facilitates and easily incorporates learning. The report identifies gaps and approaches to better understand judgement patterns and behaviours that drive decisions about energy development in Canada. There are significant gaps in the implementation of decision frameworks that fully take account of the complex issues such as social license and cumulative effects. In particular, there is a need for approaches that help people confront trade-offs when objectives and alternatives will inevitably lead to conflict.

Summary of Gaps and Approaches

Key issue of relevance to decision makers:

1. Limited understanding of how the public views shale gas development.

Priority knowledge gap to address the issue: There is limited understanding of how the public understands shale gas development, particularly in Canada. Information gaps include explanatory frameworks about how opinions have formed. There is very little academic literature from Canada, examining First Nation views or about environmental stakeholders.

Approaches and strategies

Primary academic research to explore public knowledge and perceptions of shale gas development in Canada. For example, conducting focus groups, surveys, and/or interviews with a variety of groups, such as: Canadians in rural and urban settings, environmental organizations (grassroots, local, regional and national groups), First Nation communities, and energy industry representatives. Ideally, this research would include participants from across Canada, including in Quebec and New Brunswick where there are currently moratoria on shale gas development, and in Alberta and British Columbia where shale gas development has begun.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Robust program of research to examine public attitudes toward shale gas development	Least difficult	Low	High	Moderate	$300k for academic and applied research	2-4 years	Would be most productive with partnerships between universities and industry.

Key issue of relevance to decision makers:

2. Limited tracking of evolving social understanding of shale gas development.

Priority knowledge gap to address the issue: There is limited tracking of how various issues about shale gas development in particular, and energy politics in general, are forming and shaping public opinion. This would be an effort to understand the dynamic aspects of the public understanding regarding shale gas development, particularly at a local and regional scale.

Approaches and strategies:

This research would involve tracking media representations of shale gas development, including through television, radio, newspaper, and via Internet sources, using methods such as following social media discussions surrounding shale gas and using social media analytics. An analysis of how shale gas is framed within the media is also recommended. Additional research could employ focus groups, surveys and/or interviews to further comprehend how Canadians engage with media coverage of shale gas development

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Robust program of research to examine public attitudes toward shale gas development	Least difficult	Low	High	Moderate	$500k per year for academic and applied research	2-4 years to initiate, then ongoing.	Would be most productively undertaken by private sector, with data sharing with universities.

Key issue of relevance to decision makers:

3. Inadequate places and spaces for meaningful dialogue and engagement about shale gas development specifically, and policies surrounding energy development in general.

Priority knowledge gap to address the issue: From a research standpoint, there is limited understanding of how to create the public places, spaces, and processes for effectively engaging local, regional and national publics in a discussion about shale gas development. For example, there are no examples of how to use structured decision making to shape public discussion of values and information. There are no cumulative effects assessments to engage the public in a regional or national discussion of the impacts and benefits of shale gas development.

Approaches and strategies

Energy is central to the Canadian economy yet the way people understand this development is complex and varied. The distribution of risks and benefits surrounding conventional, unconventional and low-carbon projects has created many social conflicts; shale gas is but one actor in a broader play. Nonetheless, the trend in governance of energy development by provinces and the federal government over the past decade has been one of streamlining approval and planning processes. In many ways, Canadian governments are now seen as promoters of energy development, rather than an arbitrator of public interests. Streamlined and centralized approvals have backfired in terms of social acceptance. The need for meaningful and authentic deliberation about these issues is well established in the social science literature, yet contemporary practices by governments and industry seem to ignore this work. The budget for announced energy infrastructure projects in Canada is in the order $62.3 billion (Voshart, 2015). Given the tremendous importance of social licence in moving projects forward; we offer a straw dog argument that an additional modest 1-2% of this be allocated by government and industry to create the spaces and places for authentic public engagement in energy development, an investment of $600 to $1,200 million over the next five years. We don't offer suggestions about the mechanics of the engagement but rather leave this to the various local, provincial and federal governments and responsible authorities. Public engagement approaches might include techniques that:

- Create public interest: animate members of the public to be interested in energy development (i.e., before conflict arises)
- Educate and inform
- Analyse: using approaches such as environmental assessment, modelling tools such as ALCES, or structured decision making to analyse the risks and benefits of energy development.
- Make decisions: the agent and process of making a decision (e.g., decision by government, courts, negotiation (federal-provincial, co-management), by majority, consensus, plebiscite, etc.

The overall point is that a failure by proponents and governments to make significant and sustained investment in mechanisms for public dialogue around energy infrastructure is a sure-fired recipe for prolonged social conflict.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Robust program to create and evaluate the means and mechanisms for effective public deliberation and engagement, at local, regional and national scales, regarding energy policy	Moderate, but essential	High, and this is an extremely difficult collective project	Low, and this will be very challenging to implement	Moderate	millions , perhpas $1 or 2 dollars for engagement & communication for every $100 proposed for capital projects	Five years, then ongoing	Would be most productive with partnerships between universities and industry.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

4. Industry and firm strategies for communication and transparency with the public

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. How effective is the industry at communication, transparency and disclosure in areas of concern to the public?
2. What communication actions yield results for firms in increasing the legitimacy of their operations and the reputation of the industry? While firms are effective at community engagement and stakeholder relations, there seem to be industry challenges in how to effectively communicate with the public and in determining when to be transparent and open. What are the associated risks and benefits? What is the value of independent and third party reviews?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: expand content analysis to identify stakeholder issues and conduct focus group study to assess impact of industry communication approaches	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Local focus groups with potential to extrapolate to wider population.
Qualitative Research study: interview activist groups	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Both national and international groups.
Quantitative Research study: survey of public and NGOs survey	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	National public survey potential and international survey of activists.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

5. Implications of industry best practices exceeding regulations - self-regulation and the potential for free riders, standardization versus customization tensions

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. What are the implications of industry best practices exceeding regulation? How effective is industry self-regulation? What is the risk adverse selection and free riders? Is there a distinction in firm best practices between larger and smaller firms? What are the implications of excess resources: access to capital, expertise, labour, assets? Are larger firms with resources better able to meet and exceed principles versus smaller firms with fewer resources and a business strategy focused on low costs and speed of execution?
2. Is there a correlation between firm size and best practices in operations and/or communication approaches?
3. Do best practices for hydraulic fracturing, acceptable for remote area development, meet stakeholder expectations where development impinges on communities?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: using secondary sources, analyze federal, provincial and local municipality regulations and compare to industry best practices identified via secondary sources and firm interviews	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 year	The expected outcome would be a gap analysis of industry best practices versus regulatory requirements and a critical assessment of the benefits or costs of the gap.
Qualitative Research study: interview community stakeholders	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Targeted communities involved in opposition to hydraulic fracturing.
Quantitative Research study: measure firm size and firm best practices - operational and communication	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	Potential to gather data for various regions of Canada and internationally, and consider the effect of geographical and political context on results.
Quantitative Research study: survey of community, industry and regulator	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	Canadian survey and generalization of results given control variables.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

6. Industry collaboration barriers and enablers and the potential for scale benefits to landscape impact

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. How can the industry capitalize effectively from the benefits of scale and collaboration aimed at reducing landscape impact?
2. What are the barriers and enablers to collaboration - both within and across sectors?
3. How can the industry balance competition and collaboration in the development of best practices?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: expand interviews with industry participants, the regulator and key external stakeholders	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Focus on Alberta with generalizability to other regions in Canada and potentially the United States.
Quantitative Research study: expand existing survey	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

7. Water extraction and use

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. Evaluation of water supply for shale gas developments in Canada according to specific site and region conditions (including seasonal changes).
2. Generation of water availability maps according to Canadian shale plays with emphasis on high water stress categories (i.e. low availability and high demand of fresh water).
3. Evaluation of water recycling and reuse rates in Western Canada where shale gas production is currently operating.
4. Further research on potential use of water with high salt concentrations for shale gas production and identification of potential saline aquifer that may serve as water supply for shale gas developments in Canada.
5. Further research on potential use of alternative components (e.g. CO_2 and N_2) that may be used in the production of hydraulic fracturing fluids and evaluation of current use of low-water hydraulic fracturing fluids in Western Canada.
6. Research of hydrological systems is required to determine how limited supplies of water are allocated or apportioned at low flow periods to all licensed users including shale gas operators.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1. Quantitative Study: Evaluation of source water for hydraulic fracturing across Canada	Moderate	Moderate to High	High	Capacity in Canada: Work groups of 10-20 people for each province where shale gas production is possible.	High – depends on data that is available and costs of creating data sets.	1-2 yrs	The difficulty of this task depends on how much information is available and how reliable is. It is recommended that different institutions integrate groups of work teams (e.g. academic and research institutions, Federal and Provincial Governments agencies, oil producers and third party consultants)
2.Mapping of water availability according to Canadian shale plays	High	Moderate	High	Capacity in Canada – work group of 10 consultants	Moderate – depends on water licensing	6 months	Need to consider trade-offs between competing water users.
3. Quantitative study: Evaluation of water recycling and reuse rates in Canada	High	Low	High	Capacity in Canada – university research project	Low	6 months to 1 year	Depends on producer's willingness to share findings
4. Quantitative study. Research on use of saline waters for shale gas production.	High	High	Moderate	Capacity in Canada – recommended that public and private (oil and gas) research institutions form work teams.	High If using consultant	1-2 years	Depends on current level of research already achieved and owner's willingness to share findings.

5. Research on use of non-water based fluids for shale gas production.	High	High	Low	Capacity in Canada - recommended that public and private (oil and gas) research institutions form work teams.	High if using consultant	1-2 years	
6. Quantitative study: Research of hydrological systems is required to determine how limited supplies of water be allocated or apportioned at low flow periods to all licensed users including shale gas operators.	Moderate	High	Low	Capacity in Alberta	High if consultant is used	2-3 years	Will water withdrawals be licensed from all water sources, or will some streams, creeks, ponds and wetlands etc. be off-limits because the continual depletion of flow may affect the aquatic ecosystem?

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

8. Understanding fractures and leaks from direct well use

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES:

- Are fractures caused by hydraulic fracturing likely to contaminate surface waters?
- Do leaks from wells during use pose a significant risk to surface waters?
- Do leaks from abandoned wells pose a significant risk to surface waters?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Modeling fractures	Least difficult	Moderately difficulty	Least difficult	Least difficult	$1 million for program	1-3 years	Regional differences in geology will lead to a large amount of uncertainty and so modeling and monitoring should be undertaken to encompass different geological areas
2) Develop/ improve existing standards for monitoring leaks during use	Least difficult	Least difficult	Moderately difficulty	Least difficult	$1 million for program	2-5 years	Most of this knowledge already exists and is employed by other disciplines. The results of research could be used to inform future best practice guidance and regulations. (findings may result in extra costs to industry)
3) Develop/ improve existing standards for monitoring leaks from abandoned wells	Moderately difficulty	Least difficult	Moderately difficulty	Least difficult	$500 k for initial desk study	2-5 years	Research could start by considering the best approach to tackle this problem. There are thousands of abandoned wells across Canada and it may be a contentious issue deciding who is responsible for identifying them and monitoring their status.
4) Develop/ improve well design	Moderately difficulty	Moderately difficulty	Least difficult	Least difficult	>$1 million	Ongoing	Much of this work is currently being undertaken by the oil and gas industry anyway

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

9. Chemical disclosure and characterization of chemicals of concern

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES:

- Disclosure by companies of which chemicals they use for hydraulic fracturing
- Which contaminants are present in hydraulic fracturing fluids and waste water
- How do these contaminants behave in the environment
- Do these contaminants pose a significant risk to surface water features

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Develop an initiative for disclosure of chemicals in hydraulic fracturing fluids	Least difficult	Least difficult	Moderately difficulty	Least difficult	$1 million for program	2 years	To be most effective it would require coordination between different provinces to ensure the same requirements are enforced across Canada.
2) Identify contaminants of concern in hydraulic fracturing fluids	Moderately difficulty	Moderately difficulty	Most difficult	Moderately difficulty	$3 million for program	2-5 years	Would require co-operation from industry partners and different land owners to allow collection of samples.
3) Identify contaminants of concern in flowback and produced water	Moderately difficulty	Moderately difficulty	Moderately difficulty	Moderately difficulty	$3 million for program	2-5 years	
4) Identify contaminants of concern in treated waste water, receiving water bodies and biota	Moderately difficulty	Most difficult	Moderately difficulty	Moderately difficulty	$5 million for program	2-5 years	

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

10. Efficiency and effectiveness of current legislation relevant to surface water

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES

- uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation
- Sparseness of baseline surface water quality data
- creating and maintaining robust regulatory infrastructures for surface water monitoring

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Peer review of regulatory activity	Least difficult	Least difficult	Least difficult	Least difficult	$300,000 for program	1 years	The results of research could be used to inform future best practice guidance and regulations.
2) Develop database of baseline water quality and quantity, and geologic information	Moderately difficulty	Moderately difficulty	Moderately difficulty	Least difficult	$2 million for program	2-5 years	Would require co-operation from industry partners to allow access and monitoring
3) Developing appropriate industry practices and Canadian standards for monitoring for surface water impacts	Moderately difficulty	Least difficult	Moderately difficulty	Moderately difficulty	$2 million for program	2-5 years	There may be some issues with regional and national applicability, however if this could be agreed the results could just supplement the existing guidance. Findings may result in extra costs to industry) and it may be difficult and costly to examine the consistency of transposition and implementation of legislation

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

11. Understanding Indirect Releases

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES

- uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation
- Sparseness of baseline surface water quality data
- creating and maintaining robust regulatory infrastructures for surface water monitoring

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Collecting data and monitoring contributions and extent of impact due to aerial deposition	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$500,000 for program	2-3 years	Regional and national activities are required to monitor aerial deposition from source to deposition zone over a few seasons and climatic conditions
2) Quantifying contamination from discharges from treatment plants	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$750,000 for program	2-3 years	A series of monitoring programs across fracking-active regions for development of a comparison and compilation of data is required.
3) Understanding, through both peer reviewed literature review and laboratory-based experimentation, the biochemical alteration and potential bioaccumulation of chemicals used in fracking fluids	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$1 million for program	3-5 years	While it is possible that some of the information and data may be obtained through examination of peer reviewed literature, it will be necessary to respond fully to this data gap through experimentation and analysis, using authentic industrial fracking fluids or simulated fluids based on access to chemical formulae obtained in the gap entitled, "*Chemical disclosure and characterisation of chemicals of concern*"

4) Assessing, through groundwater maps where available and direct monitoring and environmental tracer research, the interactions of groundwater with surface water and potential contamination due to fracking fluids migration of those GUDI systems	Moderately difficult	Most difficult	Most difficult	Moderately difficult	$2 million for program	3-5 years	Groundwater maps are lacking in most regions of Canada; where they exist, they do not necessarily include information about the presence of GUDI. Transportation of fracking fluids between groundwater injection locations and directly linked surface water resources will be very challenging to assess and even more challenging to address or implement solutions for.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

12. Understanding the effects on surface water features where water has been removed

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES

- uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation
- Sparseness of baseline surface water quality data
- creating and maintaining robust regulatory infrastructures for surface water monitoring

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Quantifying water abstraction and the degree of contaminant concentration due to the presence of fracking fluid contamination	Least difficult	Least difficult	Moderately difficult	Least difficult	$300,000 for program	1 year	This research represents a "quick win" in the demonstrated protection of surface water resources in terms of both quality and quantity in relation to hydraulic fracturing activities.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

13. Lifecycle of fracking processes

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES :

1. Determination of the goals and scope of the process lifecycle analysis.
2. Collation and harmonization of new and already identified environmental, economic and social burdens associated with each stage of the fracking process
3. Quantification of the burdens associated with each stage of the fracking process lifecycle
4. Characterization and quantification of the linkage between the fracking process and the attributed impacts.
5. Interpretation of data and analysis of fracking process lifecycle burdens and impacts
6. Identification and experimentation of the "best" sustainable remediation and reclamation process for fracking well site

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1. Goal and Scope definition	Low	Low	Low	Capacity in Canada	Low	Implementable within a very short period	
2. Lifecycle Inventory (Data collection)	Low	Low	Low	Capacity in Canada	Moderate	1-3 years. Progressive updating would also be necessary	The risk involved is in not fully (or completely) identifying all the burdens associated with fracking. The risk may also be in misplacing some identified burdens in the wrong category or overstretching the burdens..
3. Quantitative study: Lifecycle Inventory	Moderate	Moderate- Some of the environmental, and economic burdens are measurable but a number of enviro-economic and social burdens are difficult to quantify.	Moderate-Some level of expertise may be required to quantify some of the identified burdens	Capacity in Canada	Moderate	1-3 years	Could create some rancour and/or stifle economic activities if some burdens are inappropriately quantified.
4. Quantitative study. Lifecycle Impact Analysis	Moderate	High - The characterization process is	Moderate	Capacity in Canada- but greater commitment is	High- significant research infrastructure	Several years	The myriad of incomplete knowledge of correlations of the factors and their potential impacts poses significant risk of making incorrect claims and judgements. In addition,

		scientifically complex as there are many unknowns.		required	and expertise are required		overstretching or underestimating the impacts, double counting or mismatch could cause socio-political backlash.
5. Lifecycle interpretation	Low	Low	Low	Capacity in Canada	Low	short time period	The previous stages of the Lifecycle Sustainability Assessment (LCSA) are needed to be done correctly to avoid risk and uncertainty. In addition, social upheaval could occur if any of the previous steps in the LCSA is incorrectly done.
6. There are many potential mixes of sustainable remediation options that could be experimented. These include oxidation, bioremediation, thermal or a combination of these and other remediation processes.	High	High - depending on the mix of chemicals found in the fracking well site.	Moderate to Low - depending on remediation process.	Capacity in Alberta	High – Remediation and reclamation are expensive	moderate to long	If remediation is difficult, it may confirm the misgivings regarding the impacts of fracking on humans and the ecosystems. This may consequently have socio-political backlash.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

14. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Region-specific valued ecological components (VECs) for Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: 5-10 pilot studies in different regions of Canada that are experiencing rapid growth in hydraulic	High	Needs a qualified coordinator of the 5 -10 pilot	High	High Could be done by provincial regulatory	$25,000 for each project and $50,000 for project	1-2 years	Overall strongest approach for achieving the desired outcome. The results from each region could be analyzed and correlated across the country to find national VECs.

fracturing at the watershed or landscape-scale. Bring together sufficient numbers of region-specific stakeholders to determine valued ecological or ecosystem components of the landscape that could help determine indicators of landscape health and could be monitored over time to detect trends or changes.		projects and qualified facilitators with knowledge of VECs and fracking		bodies	coordination and reporting		Creates places for knowledge sharing and creation through face to face interaction among diverse stakeholders in 5-10 regions in Canada. Weaknesses: it takes time to develop the parameters of the study and to identify the key stakeholders who should be at the table. Costs can escalate if many meetings of stakeholders are required to finalize region-specific reports.
Qualitative research: national online survey targeting 5-10 regions where fracking is a growing industry	Moderate	Low – moderate Needs qualified survey design and analysis	High	High University programs or professional consultants could work with provincial regulatory agencies to design, administer and analyze results	$100,000.00	6 months-1 year	Strengths: Easy to administer and no need for meetings. Tools exist for achieving desired outcome and just need to be applied. Professionally designed and conducted survey with analysis and report comparing region-specific VECs across the country.
Qualitative research: regional scale facilitated workshops in 5-10 locations in Canada to develop region-specific VECs for fracking impacts on the landscape.	Moderate May not have enough time	Low	High	Workshops could be conducted by provincial department or by governance networks or consultants.	$15,000 per workshop and $50,000 for project coordination and final reports.	6 months-1 year	Strengths: relationship building and knowledge sharing at the regional scale. Less costly than pilot projects. Less time needed to organize and develop the program to achieve outcome. Weaknesses: identifying workshop participants may take time. Not enough time in one workshop to fully develop concepts of VECs or cumulative effects of fracking on landscape. Would require some time before and after the workshops by professional workshop facilitators.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

15. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Region-specific indicators of landscape health based on VECs for managing Landscape Impacts

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Quantitative research: 5-10 pilot studies in watersheds/landscapes in different regions of Canada: based on region-specific data and using best available science and software modeling programs like BASINS, set baseline "reference condition" of landscape/ Watershed.	High	High	Low	High	$250,000 Depends on who does the work and how many pilots are conducted to achieve outcomes	2-3 years to establish pilots, develop conceptual framework and principles and 2-3 years to develop set of indicators for use across Canada. Given the variety of landscapes, watersheds in Canada, this may not be possible, but may need to be region specific.	Strongest research approach using science to establish reference condition of landscape/watershed in 5 regions of the country to establish similarities and differences in national "indicators" of landscape or watershed health. Weaknesses are that there are few agreed upon conceptual frameworks or principles and processes to develop indicators of landscape health and the indicators of watershed health are usually related to surface flowing water bodies. Also, costs would be extensive to establish
Quantitative research: 5-10 pilot studies in different regions of Canada using VECs and baseline of landscape or watershed, set indicators of landscape health that can be monitored over long periods of time. Use modeling programs such as ALCES (see appendices) or watershed health assessment tool like THREATS. (see Squires et al.., 2012.)	HIGH	High	Low	High	$200,000	2 years	Strength is that indicators would be developed by experts and put in place in different river basins and landscapes and monitoring could begin right away. Weakness is that indicators would be based on current knowledge from pilot projects and might not be transferrable from one model river system to another. Also, there is very knowledge about indicators of landscape health and how to detect and make predictions, except possibly ALCES model.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

16. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing and testing region-specific monitoring and modeling programs of indicators for performance objectives of managing Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Quantitative research: 5-10 pilot studies in different regions of Canada. Test existing monitoring and modeling programs for a set of landscape health indicators relevant to all the 5 regions that could be used as predictive models, scenario description and selecting management objectives to achieved preferred future states. Need to move from project to project (stressor) studies to (effects-based) R-SEA approaches.	High	High Would need to be national study with scientific coordinator of the pilot projects	Low	High	Unknown- depends on who does the research	4-5 years	Strong approach to developing scientific tools. Would be expensive and take a long time to develop and test monitoring and modeling programs and processes for reliability and robustness as predictive tools for managing Landscape Impacts over time. Would move toward R-SEA approach.
Quantitative research: 5-10 regions in Canada on a "paired-watershed" basis (Squires et al., 2012). Develop region-specific monitoring and modeling programs to determine if the models can be rolled up to be used in other regions. Would require R-SEA approach to CEA.	High	High Requires experts in landscape dynamics and complex system dynamics	Low	High Models already exist as prototypes	$250,000	2-3 years	Strong approach based on existing research literature, models and methodologies for watershed assessment of model rivers in Canada. Weakness is that current models etc, are all based on flowing surface waters and are not landscape based. Would need to develop indicators of landscape health based on reference conditions before hydraulic fracturing and then compile large amounts of data over large time scales to create models and predict scenarios. See ALCES model and Human Footprint models that do not consider flowing surface water, but other land use impacts.
PhD research: literature and on-line, conference attendance and interview research with experts to compile a compendium of best known monitoring and modeling programs for detecting and	Moderate Based on what is known and no new knowledge created	Moderate Student would need to understand monitoring and modeling	High	High	$45,000 - $80.000	2-5 years	Strength is that the PHD student would compile all existing models and programs for decision-makers and explain the design strengths and weaknesses for each model. Major weakness is that this is compiling what is

predicting Landscape Impacts. Would explain purpose, application and strengths and weaknesses of each model or program.		programs and how they are developed and for what purpose.					known and no new knowledge would emerge. Could design the project to propose a "best" model for certain regions and Landscape Impacts.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

17. CEA: Collaboratively sanctioned systematic approaches and methods for establishing valued ecological components (VECs) for setting performance objectives and assessing Landscape Impacts

Developing collaboratively sanctioned systematic approaches and methods for establishing valued ecological components (VECs) and setting performance objectives for managing Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: Literature and online research with interview input from government departments across Canada to develop summary of systematic approaches and methods for establishing valued ecological components (VECs) and setting performance objectives for managing Landscape Impacts. Summary would need to be tested with experts in a collaborative process –see approach below	High	High	High	High	$50,000-80,000 Depends who does the research	2-3 years	Strong research to create a compilation of methodologies used across Canada and potential for peer review and testing. VEC development requires knowledge of communities at a regional scale, and when working on a national project to design the "best" approach for developing VECs to inform selection of indicators and performance outcomes could be expensive and time consuming. Weakness: this is an emerging field of knowledge and requires expert knowledge of system dynamics and collaborative processes during crisis or change scenarios. Not much is known about Landscape Impacts, but new knowledge is emerging.
Qualitative research informed by experts. Expert panel or workshop to review the summary of VEC setting processes and collaborate to design a sanctioned process that may work in different regions.	High	High	High	High Could be done through gov't depart.	$100,000 - 200,000	1 year	Strength would be to create a collaborative process for experts to design a system for establishing VECs that would be sanctioned by scientists at a national scale as a "best practice."

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

18. CEA: Inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts (see Chapter 9)

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: Graduate student using this report as a baseline of current literature on inter-jurisdictional and trans-boundary regulatory frameworks and non-regulatory approaches to CEA of Landscape Impacts compile and analyze a "state of report" to inform decision-makers of what is currently being done.	Moderate	Low	High	High	$45,000-85,000 Depends on who does the study.	1-5 years	Strong approach for creating baseline of information. Would be least expensive and fastest option for informing decision-makers about regulatory and non-regulatory systems that are already being used in Canada. Comparative analysis of provincial systems would be of benefit to understand regional disparities and needs for resources, data, etc. Weakness: There is very little literature or knowledge specific to CEA in Canada because this is an emergent field of study.
Qualitative research informed by experts: An expert panel could be assembled to collaborate and sanction a "best" approach for regulating or implementing CEA through R-SEA or other similar approaches	High Based on existing or baseline knowledge	High	High	High	$100,000 Should be federal gov't Program to learn more about CEA and R-SEA and how to regulate processes or support non-regulated processes	2 years	Would be integrative, collaborative and would create public space for co-creation of new knowledge or advancing knowledge about regulations for CEA or R-SEA approaches. Research and expert review would flow from this report ensuring benefit from investment.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

19. CEA: Integrative and collaborative institutional CEA decision-making frameworks for managing Landscape Impacts

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing integrative and collaborative institutional CEA decision-making frameworks for managing Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: using this report as a baseline of current literature for decision-making frameworks in Canada, Graduate level study to compile and analyze how CEA of Landscape Impacts is currently being used by decision-makers to regulate hydraulic fracturing. Study could propose a "best" CEA decision-making framework based on the literature to be tested by experts.	Moderate	Low	High	High	$45,000-85,000 Depends on who does the study.	1-5 years	Strong approach for creating baseline of information about CEA decision-making frameworks to be tested with experts. Would be least expensive and fastest option for informing decision-makers about processes that are already being used in Canada. Weakness: There is very little literature or knowledge specific to CEA decision-making frameworks in Canada because this is an emergent field of study.
Qualitative research informed by experts: An expert panel could be assembled to collaborate and sanction a "best" CEA decision-making framework for Canadian decision-makers when regulating hydraulic fracturing.	High Based on existing or baseline knowledge of CEA decision-making frameworks in Canada	High	High	High	$100,000 Should be federal gov't Initiative	2 years	Would develop some systematic decision-making frameworks for use by decision-makers. Would be integrative, collaborative and would create public space for co-creation of new knowledge or advancing knowledge for decision-makers.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

20. Policy, Legal and Regulatory Knowledge Gaps1

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts.

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research of literature and on-line resources to compile a summary of provincial approaches to regulation, and perform a comparative analysis through university graduate program, consultant, or government regulatory body.	**High** To fully understand how policy is driving legislative change across Canada, comparing regulatory differences is required. Why is Western Canada leading the way while Eastern Canada and Territories are still engaged in studies?	**Low**	**High**	**High** Most post-graduate programs in Canada have capacity to conduct this research. Gov't department could also commission the work or complete in-house. Use of consultants could be costly	**$20-25,000**	**6 month-1 year**	Strong approach for creating a baseline of current knowledge in order to track changes over time. Each province/territory has its own regulatory system for regulating hydraulic fracturing, and a compilation and analysis of the legal systems would inform decision-makers. Codes of practices and BMPs could be compared across the country to determine if there is a possible national code. A major weakness is that the research would present a snapshot in time that would need to be redone when regulatory systems change in each province. However, most qualitative research involving legal systems requires period revisiting and future review. Most efficient and least expensive approach, but may not be thorough.
Qualitative research through online survey of provincial government department decision-makers to compile knowledge and then conduct comparative analysis. Would require pre-survey interview with selected government department respondents	**High** – would require cooperation among government departments across the country	**Low - moderate**	**High** – depends on who does the research and how it is funded.	**High** Most law or science graduate programs in Canada have capacity to perform the survey, but may need multi-disciplinary approach with	**$100.000 - $150,000** Requires comparative analysis of large amounts of survey data by expert analysts.	**1-2 years-** phased approach as survey design would not be completed until interviews with department respondents is complete. Admin., data collection,	Overall the strongest research approach including design of survey materials and communication with government experts engaged in regulation and decision-making with the industry. Multi-stage aspect provides opportunities for research refinement at every stage. Ensures that information provided is from best known respondent and therefore reliable information for creating the baseline data set to monitor over time. Would represent only a snapshot in time and would require future review**.**

				computer technology and social sciences for design and administer		interpretation and data analysis would all require further phases.	Strongest approach to create thorough and robust knowledge.
Qualitative research: national symposium on regulation of the hydraulic fracturing industry in Canada.	**Moderate** Would create baseline or reference condition from which to test or conduct further qualitative research	**Low**	**High**	**High** National ENGOs and symposium organizers could be employed to develop the symposium agenda and find expert speakers and facilitators of workshop component.	**$100,000-200,000 b**ut could be sponsored by gov't and industry to break even	**1 year to organize** 1 year to create symposium proceedings and peer review before publication.	Symposium proceedings would provide baseline materials to inform decision-makers about the diversity, opportunities and barriers to regulation of the industry in Canada. Would provide opportunities to network and dialogue on important matters of regional-scale policy development, national policy development and social learning.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

21. Policy, Legal and Regulatory Knowledge Gaps 2

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative research of literature and on-line resources to create a compilation of all existing regional and provincial "public spaces" currently funding wholly or in part by provincial and federal governments that	**High** There are few public spaces in Canada where stake-holders with diverse interests are	**Low**	**High**	**High** Government departments	**$20,000** Depends on whether it is done by an industry member or gov't	**6 month-1 year**	Strong approach for creating compilation tool for decision-makers and other researchers. Tool could be used to understand how these public places emerge and how they partner and co-create knowledge to inform decision-making processes.

are actively engaged in multi-stakeholder processes of governance with respect to Landscape Impacts	actively engaged in dialogue to build trust and relation-ships necessary to create recommend policy or legislative amendments or BMPs				department		
Qualitative research: national symposium to facilitate discussion and creating of new knowledge about the need for public spaces, and to stimulate development of regional scale governance networks to inform decision-makers about Landscape Impacts	**Moderate**	**Low**	**High**	**High** National ENGOs and professional symposium organizers could be employed to develop the symposium agenda and find expert speakers and facilitators of workshop component.	**$100,000-200,000** but could be sponsored by government and industry to break even	**1 year to organize** 1 year to create symposium proceedings and peer review before publication.	Symposium proceedings would provide baseline knowledge of the "current state" of public spaces in Canada. Opportunities to network and dialogue on important matters of regional-scale policy development, national policy development and social learning.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

22. Policy, Legal and Regulatory Knowledge Gaps 3

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES
Understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative research of literature and online	**High**	**Low**	**High**	**High** Most post-	**$30,000.00**	**2 years**	Strong approach for creating a baseline of current knowledge.

resources from government departments and municipal governments, and other hydraulic fracturing managers and decision-makers to identify needs and costs associated with meeting those needs.				graduate programs in Canada have capacity to conduct this research. Government departments could also commission the work or complete in-house.			Would need follow-up interviews to test or ratify the results of the study. Cost estimation would inform decision-makers of the extent of budget required to fund needed processes for regulatory design, implementation, and monitoring and trend analysis for recommending new approaches. Weakness would be that study design might not create an accurate representation of true costs because governance structures, regulatory institutions and decision-making processes are currently considered public goods with very little attention paid to input costs to design, implement, monitor and enforce.
Qualitative research through online survey of provincial government department decision-makers to compile knowledge about needs and then conduct comparative analysis. Would require pre-survey interview with selected government department respondents	**High –** would require cooperation among government departments across the country	**Low - moderate**	**High –** depends on who does the research and how it is funded.	**High** Most law or science graduate programs in Canada have capacity to perform the survey, but may need multi-disciplinary approach with computer technologist and social sciences for design and administer	**$100.000 - $150,000** Requires comparative analysis of large amounts of survey data by expert analysts.	**1-2 years-** phased approach as survey design would not be completed until interviews with department respondents is complete. Admin., data collection, interpretation and data analysis would all require further phases.	Overall the strongest research approach including design of survey materials and communication with government experts engaged in regulation and decision-making with the industry. Multi-stage aspect provides opportunities for research refinement at every stage. Ensures that information provided is from best known respondent and therefore reliable information for creating the baseline data set to monitor over time. Would represent only a snapshot in time and would require future review. Strongest approach to create thorough and robust knowledge.
Qualitative research: expert panel Developing the panel and providing space and time for creating panel findings for decision-makers.	**Moderate** Would create baseline or reference condition	**Low**	**High**	**High**	**$50,000**	**1 year** to organize and report on findings of the panel	An expert panel of consultants and industry specialists who work in regulating Landscape Impacts for municipalities, provincials, provincial agencies and others would help determine the state of the industry and provide advise as to capacity of current agencies and identify needed resources. Weakness would be that need the right experts to ensure the accuracy of the panel proceedings.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

23. Research and Development of Decision-Support Tools

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. What are the underlying judgmental patterns and behaviours (i.e., "heuristics") that drive decisions about energy development in Canada? To what extent to representatives of industry and the public differ in terms of their intuitive approaches to decision-making.
2. How can industry better understand the range of objectives that guide decisions about energy development?
3. How can industry better model alternative development and management scenarios in a manner that is responsive to the multitude of stakeholder objectives?
4. To what extent can decision-support tools be developed to help people confront tradeoffs when objectives and alternatives will inevitably conflict?
5. To what extent might improved decision-support approaches, that involve multiple stakeholders, contribute to the development of "social license" for energy development initiatives?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Experimental work to addresses Priority Knowledge Gaps 1 and 5. Experiments to address these gaps would follow established quantitative methods in the cognitive sciences.	High potential to fully address these gaps.	Standard and accepted experimental (quant.) research methods.	Moderate	Capacity in Canada and internationally.	$100-200K	2 to 3 years of initial work, with the potential for ongoing research if necessary.	Focus on Canada with generalizability to other countries.
Qualitative research study to elicit objectives and performance measures (Gap 3).	This will be context specific. Gaps may be fully addressed in each context for which the research is undertaken.	Standard and accepted qualitative research methods in the decision sciences.	Moderate	Capacity in Canada and internationally.	$50-100K per resource development context.	1 year per resource development context.	The focus would be context-specific within Canada. Elicitation approaches for this kind of work are already well-established. The focus would be on expanding context-specific knowledge (vs. methods development).
Quantitative Research study to develop and test tradeoff support tools (Gap 4).	Valuable but Partial	Standard and accepted quantitative research methods.	Low. This would be challenging work requiring a dedicated and knowledgeable team.	Limited Capacity in Canada; greater capacity in US.	$250-400K	3 to 4 years	Focus would be on developing computational tools (which may be automated) so that decision-makers and stakeholders could confront challenging tradeoffs. Work would build in existing research and development (e.g., Bessette et al. 2014). Benefits from this work would be internationally applicable and would span multiple resource development (and risk management) contexts

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

24. Training and capacity building within industry.

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. There is a need for industry to develop and maintain capacity in the arena of decision-support. Too often, industry relies on consultants with little or no understanding of the decision-support capabilities that are required. The strategy, therefore, would be to the industry to become more sophisticated in their understanding of decision-making, as well as in terms of decision-support.

ADDITIONAL CONSIDERATIONS INCLUDING RISK OF UNCERTAINTY OR LACK OF AGREEMENT ON RESEARCH RESULTS, REGIONAL VS. NATIONAL APPLICABILITY, SPECIFIC SOCIOPOLITICAL CONSIDERATIONS, ETC.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Rather than pure research, the emphasis here would be on developing and testing a series of training modules that could be provided to industry.	Significant on a "client-by-client" basis.	Standard and accepted training and evaluation methods.	Moderate	Capacity in Canada	$50-100K per industry "client"	6-12 months per industry "client"	Local training sessions for industry clients. Modeled after work by Arvai and colleagues for EcoCanada, as well on a bespoke basis through university executive education programs.

1 INTRODUCTION

1.1 HYDRAULIC FRACTURING OPERATIONS IN UNCONVENTIONAL HYDROCARBON DEVELOPMENT

North America is in the midst of a 'fracking boom' (Ewert 2014, Gold 2014). More specifically, the novel and evolving combination of horizontal drilling and multi-stage hydraulic fracturing (along with improved earth imaging) has increased exponentially in North America over the past decade. The depletion of conventional oil and gas reserves from highly permeable formations (i.e., where the oil and/or gas readily flows from the rock formation to the well bore without additional stimulation) has compelled development of these new techniques to coax oil and gas from shale and other 'tight' formations (i.e., geologic materials with significantly lower permeability). The technology has made it possible to extract hydrocarbons from many previously uneconomic or inaccessible reservoirs (National Energy Board 2013).

Contemporary hydraulic fracturing is often discussed in the context of the shale gas revolution that has occurred in the United States and more recently spread to Canada. It is important, however, to recognize the use of this technology in the production of tight oil (from very low permeability shale, sandstone, and carbonate geologic formations) and natural gas liquids (i.e., ethane, propane, butanes and pentanes plus). Throughout this report we use the terms 'hydrocarbons', 'petroleum' and 'shale gas/oil' to collectively refer to these unconventional resources. In addition, when discussing hydraulic fracturing ***we are referring to the full life cycle process of accessing these resources and not solely to the brief stage of completion when the target formation is fractured***. In other words, this report focuses on the field currently referred to as 'unconventional oil and gas'.

The first stage of the unconventional oil and gas process (directional / horizontal drilling) involves drilling down vertically to the target formation and then 'bending' the well bore so that it tracks within the target zone to maximize contact with the reservoir for distances up to several kilometers. Hydraulic fracturing is then accomplished by perforating the horizontal leg of the well (often in several stages) and injecting a fluid at high pressure to open up fractures in the rock and stimulate a flow of oil or gas from the reservoir to the well bore. The fractures are held open by specific size particles called 'proppant' (often natural sand, but also engineered materials such as resin-coated sand or ceramic beads) injected along with the fracking fluid. The pressure is then released allowing much of the fracking fluid to return to the surface (flowback). The target petroleum product(s) is then able to flow to the well bore and be pumped to the surface. The method allows for the efficient placement of several wells on a single pad each accessing a different portion of the reservoir.

Hydraulic fracturing has been used for over 60 years to stimulate well production, but it was Mitchell Energy's pioneering efforts in the Texas Barnett shale formations that proved to be the 'game changer' in the 1990's. Subsequent growth has been dramatic in the U.S. For example, led by Texas, Pennsylvania, Louisiana and Arkansas, natural gas withdrawals from U.S. shale formations increased 660% from 5 billion cubic feet per day (Bcf/d) (141,000 m3/d) in 2007 to 33 Bcf/d (930,000 m3/day) in 2013 (U.S. Energy Information Administration, 2014). In the Texas Barnett shale formation near

Dallas/Fort Worth, the number of producing horizontal wells increased from less than 400 in 2004 to over 10,000 in 2010.

Although the current boom has been more modest in Canada, approximately 171,000 wells have been fracked in Alberta since the 1950's (primarily in vertical wells and in a single stage; Alberta Energy Regulator 2014). In the first quarter of 2014, 73% of all wells in Canada were horizontal and included hydraulic fracturing. Furthermore, projections and land sales indicate significant growth in horizontal drilling and hydraulic fracturing in the near future, particularly in large plays such as the Horn River, Liard Basin, Cordova Embayment and Montney basins in northeast B.C. and the Montney and Duvernay basins in Alberta. As an example, the 130,000 km^2 Montney is one of the most active natural gas plays in North America and one of the larger natural gas resources in the world with siltstones, shales and fine-grained sandstones producing natural gas, natural gas liquids and condensates.

> *The ultimate potential for unconventional petroleum in the Montney Formation is estimated to be very large… with expected volumes of 12,719 billion m3 (449 Tcf) of marketable natural gas, 2,308 million m3 (14,521 million barrels) of marketable NGLs, and 179 million m3 (1,125 million barrels) of marketable oil (NEB, BCO&GC, AER, BCMNGD 2013, p. 3).*

Beyond the large resources identified in B.C. and Alberta, the new technology has also spawned exploration across the rest of the country. Fracking in Saskatchewan and Manitoba is mainly associated with shale oil in the Bakken formation along the U.S. border. There is little marketable gas production expected in Ontario. Exploration and some initial production in the St Lawrence River Lowlands of Quebec (Utica shale) included fracking, but has recently ceased due to the imposition of a moratorium (BAPE 2014). The maritime provinces of New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland & Labrador all have shale gas potential (including off shore), but all except PEI have fracking moratoria in place. There are also considerable reserves in the off shore zone of the Arctic. The National Energy Board (2013) estimated that there was $3.10\ 10^{12}\ m^3$ (530 Tcf) of marketable tight gas resources available in Canada at the end of 2012. For reference, that equates to more than 150 years of Canadian natural gas at current consumption levels.

1.2 Sources of Controversy

Horizontal drilling and hydraulic fracturing represent a new phase in the development of petroleum resources. Many of the same environmental concerns and considerations exist as for conventional oil and gas production, especially with respect to the landscape 'footprint' of associated infrastructure and its operation. A significant difference in unconventional petroleum development is the use of high volumes of hydraulic fracturing fluid. The primary elements to be considered include:

- Source – what is the fluid being used and where is it coming from?
    - If it's water, what are the impacts of withdrawal on surface and groundwater?
    - If it's another fluid, where is it being sourced and what are the effects?
- Additives – what is being added to the fluid to make it most effective for fracking?
    - What are the risks and consequences of a spill or release of these fluids? (in transport, on site and in the re-use or disposal phase)

- Flowback and Produced Water – what is the nature and toxicity of the materials that return to the surface at the well site?
    - How are the fluids collected, stored, treated, disposed of, transported, etc.?
- Drilling technology and management
    - What technology and methods are used to isolate the well bore from surrounding aquifers?
    - What is the long term integrity of these structures?
    - What is the risk and potential of communication with pre-existing wells and naturally existing fractures/faults?
    - What are the risks and consequences of surface and groundwater contamination?
- Geophysical consequences of hydraulic fracturing
    - What is the potential and consequences of seismic activity being transferred from the active fracturing zone?
- Air emissions – what is the nature of materials released to the atmosphere from all of the activities associated with this form of petroleum development
- Landscape effects of the hydrocarbon development footprint
    - How do seismic lines, multi-well pads, roads, pipelines, electrical transmission utilities, etc. affect the ecological function of the local area and region?
    - What are the impacts associated with transporting all of the necessary materials to and from a well site?
- Cumulative effects - how does unconventional oil and gas activity interact with pre-existing and future land-uses in time and space?
- Cultural landscape – what is the public understanding and acceptance of these new and evolving technologies and practices? And how do these activities affect the cultural landscape?

The preceding list could certainly be expanded and refined, but the central message remains the same; this is a highly complex activity taking place in a highly complex social-ecological system. It is also occurring in a time where there is increasing attention being paid to issues such as climate change and a transition to a lower carbon energy future. It is not surprising that the rapid and extensive expansion of unconventional hydrocarbon development has generated such a considerable response by the general public and decision-makers. It is essential that hydraulic fracturing be explored and understood in its full context. This is much more than a technical, site-specific issue. Finally, it is critical to recognize that there is significant variation across the geographic, geological, jurisdictional and political landscapes of Canada. Understanding regional context is absolutely essential to addressing gaps in our understanding of unconventional tight hydrocarbon development.

1.3 Recent Relevant Reviews and Analyses

The interest and concern over the potential effects arising from hydraulic fracturing activities has resulted in a significant number of research projects, review studies and meta-analyses. A database maintained by Physicians, Scientists and Engineers for Healthy Energy (http://www.psehealthy energy.org/site/view/1180) is one of the most comprehensive collections of references pertaining to the effects of shale gas and tight oil development. The database indicates the number of peer reviewed papers doubled in 2012 and doubled again in 2013. Over 150 peer-reviewed publications pertaining to the impacts of hydraulic fracturing were released in 2014. In fact, approximately 75% of all studies published on the impacts of shale gas development have been in the past two years (Concerned Health Professionals of New York 2014, 2). We provide an annotated bibliography of some of this literature (emphasis on surface water, watershed and landscape impacts) in Appendix B.

The studies included below were recently conducted by expert panels to provide high level evaluation of the state-of-knowledge and research needs related to hydraulic fracturing and associated activities. The summaries below focus on the topics most germane to our focus on surface water and watersheds and landscapes. Many of the findings from these reports are addressed further in the body of our report.

1.3.1 Council of Canadian Academies

The Council of Canadian Academies (CCA), at the request of The Government of Canada (Minster of Environment), convened a multidisciplinary panel of experts to address the following question:

> *What is the state of knowledge of potential environmental impacts from the exploration, extraction, and development of Canada's shale gas resources, and what is the state of knowledge of associated mitigation options?*

The final report was released in 2014 and encompassed a range of potential impacts including effects on: surface water, ground water, greenhouse gas emissions, landscapes, human health and social conditions, air quality and seismic activity. The main findings of the CCA report that may have direct or indirect effects on surface waters, watersheds and landscapes are summarized below.

The panel recognized that issues associated with potential environmental impacts of hydraulic fracturing on groundwater have received more attention than the surface waters issues. However, the final report describes three primary hazards where shale gas developments may pose a direct risk to surface waters, these include: (i) accidental spills, (ii) spills of condensates or flowback water from the production well, and (iii) inadequate storage, treatment or disposal of residual liquids. Surface disturbance by well pads, roads, pipelines and associated infrastructure is also a source of increased sediment loading to surface waters. The report stresses the need for greater understanding of the landscape-scale cumulative effects of all associated shale gas activities.

The panel concludes that there is scientific evidence to suggest a range of potential negative effects on surface waters and watersheds, but the authors stated that there was insufficient scientific data and understanding to evaluate accurately the magnitude of these risks. "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" (p. 96). The expert panel also concluded that more field research was needed in order to more fully evaluate the environmental impacts on ground and surface waters. This conclusion is echoed by other national panels on hydraulic fracturing in the United States, United Kingdom and Australia. The panel suggested that this research should also be supported by laboratory and modeling efforts. The report stresses the need for effective scientific baseline studies and long-term monitoring. A full chapter is dedicated to monitoring and research needs. The panel states, “It is particularly challenging to implement a monitoring program for the cumulative effects of shale gas development that is sensitive to the watershed-scale. The cumulative effects are most significant at this geographic scale” (p. 185).

The panel notes that the amount of water required for shale gas development is relatively small in the context of overall Canadian water usage. However, the volume and intensity of water use in dry areas or during dry seasons may pose significant local surface hydrology impacts. The availability of source water varies significantly across both regions and seasons, pointing to the need for the development of site-specific water management plans. In addition, the panel notes efforts by the industry to implement water recycling, use of saline water and the use of alternative fluids.

1.3.2 United States Environmental Protection Agency

The United States Environmental Protection Agency (EPA) is currently working on a project related to the potential impacts of hydraulic fracturing on drinking water resources; a progress report was released in late 2012. The research is structured around the five phases of the hydraulic fracturing water cycle: water acquisition, chemical mixing, well injection, flowback and produced water, and wastewater treatment and waste disposal.

Stage 1 (water acquisition) will evaluate the potential impacts of water withdrawals from ground and surface sources. Stage 2 (chemical mixing) will improve EPA’s understanding on possible adverse effects of hydraulic fracturing fluids if surface spills occur. The possible impacts of chemical injection and fracturing process are being examined in Stage 3 (well injection). Stages 4 and 5 evaluate the impacts that may be generated from surface spills of flowback/produced waters and inadequate treatment of wastewaters originated from shale gas developments respectively.

The research approach used by EPA for this project is mainly composed of analysis of existing data, scenario evaluations, laboratory studies, toxicity assessment, and case studies activities. Specific research projects were assigned to evaluate hydraulic fracturing impacts on drinking water quality and were accommodated according to the research activities. Table 1.1 indicates the research projects that EPA is currently carrying out and that are more directly related to the evaluation of potential impacts on surface waters. A draft of the full report was expected to be released in 2014, but the work is still ongoing.

Table 1.1 EPA research projects that are directly connected to the evaluation of environmental impacts on surface waters (EPA 2012).

Research Project	Description
Surface water modelling	Simulation of chemicals concentrations present in public water sources downstream from wastewater treatment plants that discharge treated hydraulic fracturing wastewater to surface waters
Source appointment studies	Identification and quantification of bromide and chloride concentrations and sources at public water supply intakes downstream from wastewater treatment plants discharging treated hydraulic fracturing wastewater to surface waters
Wastewater treatability studies	Evaluation of the ability of common wastewater treatment systems to eliminate chemicals found in hydraulic fracturing wastewater
Br-DBP precursor studies	Evaluation of the potential generation of byproducts as brominated disinfection byproducts (Br-DBP) originated from bromide and brominated compounds present in hydraulic fracturing wastewater in drinking water treatment processes
Toxicity assessment	Toxicity evaluation of chemicals commonly reported in hydraulic fracturing fluids and hydraulic fracturing wastewaters
Retrospective Studies	Reported cases where impacts on drinking waters may be related to hydraulic fracturing activities

1.3.3 Expert Panel on Hydraulic Fracturing in Nova Scotia

The Province of Nova Scotia and the Nova Scotia Department of Energy commissioned an expert panel under the leadership of Dr. David Wheeler, Cape Breton University, to conduct an external review on the environmental, socio-economic, and health impacts of hydraulic fracturing. The panel report stated that the principal risks to water quality from hydraulic fracturing developments are more linked to operational practices rather than the fracturing process itself. Their work reported that many chemicals used in the hydraulic fracturing fluid, as well as natural occurring compounds present in produced water, may contaminate water supplies when they are managed incorrectly.

The Nova Scotia report agreed with the conclusions of the Council of Canadian Academies in the fact that risks to surface water and groundwater originate mainly from three different sources:

- Accidental spills of chemicals, hydrocarbons and hydraulic fracturing fluids during the transportation, storage and use stages.
- Spills of condensates and/or flowback water.
- Inappropriate storage, treatment, or disposal of flowback water and produced water.

An uncertainty that was identified and reported by the Nova Scotia panel is that the future disposal of wastewater from shale gas developments needs to be carried out adequately. The authors highlighted that the Government of Nova Scotia had not approved any deep well injection project yet, mainly because this activity is not regarded as a best management practice for formation waters from coal bed methane activities and because the potential of unsuitable geology sites.

The report provided a case study where Encana and Apache, currently carrying out hydraulic fracturing operations in the Horn River Basin, are using a proprietary system where it is possible to use saline water from deep aquifers and treat it before injecting it back into the same aquifer. The authors recommended evaluating whether this approach could be used in the geologic formations of Nova Scotia. The panel also reported on a pilot project where wastewater is being used as a coolant at a cement plant kiln and subsequently evaporated. The main objective of this research is to evaluate whether this practice may be applied as a disposal method for hydraulic fracturing wastewater.

Other suggestions made by the expert panel members include that baseline conditions must be generated for water levels, flow and quality before shale gas production starts in Nova Scotia. The panel also suggested that sampling, when obtaining baseline conditions, should be conducted in all seasons to account for annual variation. Beyond the technical issues related to water use and treatment, the panel was clear in calling for implementing cumulative effects approaches to the range of activities associated with shale has exploration and development.

1.3.4 New Brunswick Department of Health

The New Brunswick Department of Health released a report in 2012 providing recommendations related to future shale gas developments in the province (NB Department of Health, 2012). The authors concluded that there are still important knowledge gaps concerning the potential environmental impacts from shale gas production through hydraulic fracturing operations. The researchers also recommended that further research should be implemented to address these gaps as this sort of information is relevant for the evaluation of public health risks.

The main knowledge gaps that were identified by the NB Department of Health, in areas where shale gas developments are in operation, that are closely linked to hydraulic fracturing impacts on surface water were:

- **Lack of public health studies**. Nonexistent application of monitoring systems to evaluate health status of the population, before or during hydraulic fracturing operations.
- **Lack of Health Impact Assessments**. The document reported a constant lack of extensive studies regarding potential health effects of nearby communities from shale gas developments. The authors recommended the use of Health Impact Assessments to overtake this potential gap.
- **Lack of information regarding toxicity of hydraulic fracturing chemicals**. Relevant information on the chemicals found in hydraulic fracturing fluids is commonly missing (e.g. nature of chemicals, concentrations, volumes used and their toxicological information).
- **Lack of enough information regarding toxicity of hydraulic fracturing wastes**. Full characterization of liquid and solid wastes generated in shale gas developments is commonly

omitted, resulting in inappropriate risk assessments and toxicological profiles. Additionally, New Brunswick Department of Health recognized that conventional waste water treatment may not be adequate for the treatment of these wastes. For all these reasons, the authors recommended that full characterization of solid and liquid wastes for each well should be conducted.

- **Lack of accurate exposure data**. Not enough or absent data from air, liquid and waste monitoring has resulted in inaccurate exposure assessments. Also, different locations and conditions implicate that chemical emissions may vary from time to time and from place to place. Once again, researchers noted the need for information related to chemicals identification and quantities (used and/or emitted), identification of potential exposure routes (air, water and wastes) and exposure times.
- **Lack of estimates of well pad densities**. There is not information about well pad density values that may occur in New Brunswick or their possible locations. This makes more difficult to evaluate potential cumulative health effects in the region.

1.3.5 Health Canada

Health Canada also conducted research on identifying the potential hazards from shale gas developments. This work aimed to present all the different sources of contamination of drinking water and air that may arise from hydraulic fracturing operations. The study reported their findings on contaminant sources at each step of shale gas production and concluded that all processes in this technique were potential sources of water pollution (e.g. exploration, extraction, transport and wastewater treatment).

The following is a list of potential health hazards that were identified by Health Canada for surface and groundwater, according to different activities in shale gas developments:

<u>Direct sources</u>

- **Drilling**. Well blowouts, fluid migration from the borehole to the surface or groundwater, drilling fluid spills, improper drilling operations.
- **Hydraulic fracturing.**
    - **Hydraulic fracturing fluid and flow back water**. Accidents and spills by truck transport, leaks of wastewater ponds and storage containers, spills from on-site accidents, damage to the cementation and casing, and migration through artificial or natural formations.
    - **Production brine**. Transport of brine (produced water) to the surface during the hydraulic fracturing operations, spills and leaks, migration through artificial or natural formations
    - **Shale gas production**. Rising of natural gas and produced water to the surface.

<u>Indirect sources</u>

- **Wastewater treatment and disposal**. Containment and transport leaks, deep well injection leaks, and inappropriate treatment.
- **Spills and releases**. Releases occurring on-site and off-site activities and operations.
- **Well and rock integrity**

- o **Well casing and cementing**. Gas migration occurring along active/inactive wells.
  - o **Rock integrity**. Contaminant flow through cracks in the rock originated from hydraulic fracturing.
- **Well blowout and stormwater runoff**. Uncontrolled releases of oil and natural gases (blowout). Soil erosion and runoff generation from initial land clearing, steep access roads, well pads on hill slopes, on-site drilling pit.

The report also highlighted the potential data gaps that were identified at each of the activities; these are listed in Table 1.2.

Table 1.2 Potential data gaps identified by Health Canada concerning environmental impacts on surface water sources at different activities observed at shale gas developments.

Shale Gas Activity	Identified data gaps
Drilling	It is currently not possible to know whether drinking water contamination events reported in the literature (linked to gas-well drilling) were specifically related to drilling processes.
Hydraulic fracturing fluid and flow back water	No exhaustive list of all chemicals used in the hydraulic fracturing process. Companies often do not have to disclosure chemicals. Chemicals may have different names or may not have chemical registry number (CAS). Communication events between wells are not commonly reported. Quantities of chemical additives are regularly unknown. Composition of flowback water is generally incomplete. Possible generation of unknown compounds due to mixture of chemicals and flowback with natural components. No toxicological evaluation available of hydraulic fracturing fluids thus health risks are not known. Data gaps regarding chemical fate and transport overtime of hydraulic fracturing fluids.
Waste water treatment and disposal	Lack of knowledge related to final disposal and characterization of wastewater (e.g. volumes, disposal methods, contaminant concentrations, salinity). Lack of information concerning membrane integrity, storage installations and duration of wastewater storage. Lack of information respecting the ability of wastewater treatment plants to treat shale gas wastewaters (e.g. high salt concentrations, radioactive materials, organic and inorganic materials) and to manage large volumes of wastewaters. Lack of monitoring data regarding groundwater quality nearby deep injection wells. Health risks associated to hydraulic fracturing wastewaters is not very well documented.
Well casing and cementing	Limited data on well integrity. It is possible that the number of water contamination events related to well casing and cementing is underestimated.

Rock integrity	Poor understanding of fluid movement through fractures. Potential for water contamination events in the coming years or decades and after the well was constructed. Fracture behaviour is also poorly understood.

1.3.6 Quebec Bureau d'Audiences Publiques sur l'Environment (BAPE)

The Quebec BAPE completed a report in November 2014 to examine issues relating to shale gas exploration in the St. Lawrence Lowlands. The report is the result of an inquiry and public hearings following earlier work completed by the Strategic Environmental Assessment Committee on Shale Gas. Issues of water use and water management were predominant in the hearings. Of primary concern was the prediction that the water required for hydraulic fracturing of Utica Shales in the St. Lawrence Lowlands would "place significant pressure on watercourses... in terms of both water withdrawal and wastewater disposal" (p. 2, English Summary). More information on the spatial and temporal distribution of wells and the actual water withdrawals are need before and informed decision can be made on future hydraulic fracturing activity. The commission recommended further exploration of the potential to re-use frack water. The risk to ground water contamination arising from the migration of fracking fluids through natural faults was deemed to be low, but with considerable uncertainty. Likewise, the commission stated that too much uncertainty exists to adequately ass the risk of wastewater-related contamination and the impacts on health and the environment.

The Quebec report, like the Nova Scotia process, included extensive public consultation. Comments made by member of the public reflected a "sense of powerlessness and dispossession" and a "sense of loss of control over their own space or territory was shared by a number of municipal and regional officers" (p. 9, English Summary). The commission recommended the government develop clear definitions for 'social acceptability' in determining if and how shale gas development is to occur.

Finally, the report stresses the importance considering shale gas development as one of many regional land uses. The commission recognized the challenge that this creates for local and regional municipalities as their jurisdiction is superseded by the Mining Act. The report recommends that the "shale gas industry should not be developed in Quebec until and appropriate legislative framework, which also includes local and regional authorities, has been adopted" (p. 11, English Summary).

1.3.7 Report Prepared for Petroleum Technology Alliance Canada (PTAC) and the Science and Community Environmental Knowledge Fund (SCEK) by ALL Consulting

A report titled *The Modern Practices of Hydraulic Fracturing: A Focus on Canadian Resources* was finalized in 2012 (ALL Consulting 2012). In comparison to the other reviews summarized here, this report is the most technical with respect to hydraulic fracturing practices and provides an excellent primary on hydraulic fracturing. The information in the document comes from the most current information available from industry at the time of writing. Although the authors recognize the many activities associated with the production of tight oil and gas, the report is primarily focused on the phase of well completion when hydraulic fracturing occurs. This is important in the context of the finding we report because

> *Many of the concerns raised about hydraulic fracturing are related to the production of oil and gas and can be associated with the development of a well, but are not directly related to the act of hydraulically fracturing a well. It is important to distinguish those impacts that can potentially be attributed to hydraulic fracturing from those that cannot so that mitigation measures and regulatory requirements can be directed towards the proper activities and responsible parties* (ALL 2012, 1).

The report stresses that every play is unique and will require information specific to the particular geological, social and regulatory conditions.

The ALL report is particularly strong in examining the pathways through which potential contamination could occur: vertical fractures created during fracking, existing conduits (natural fractures or abandoned welbores), intrusion into fresh water zones through poor well construction, operating practices during well injection and migration of fracking fluids from the fracture zone to a fresh water zone. The authors conclude that existing technologies and best practices make it highly improbable that fracture or reservoir fluids would contaminate fresh water and, based on research previously conducted by the American Petroleum Institute, state:

> *The probability for a groundwater source used as drinking water to be impacted by the pumping of fluids during hydraulic fracture treatments in a properly constructed well using the latest regulations on well construction and permit requirements and when a high level of monitoring is performed would be even less than the one well in 200,000,000 (2 x 10-8) estimated in the study* (ALL 2012, 98).

The report includes an examination of 30 cases where water contamination was alleged to have been caused by hydraulic fracturing. The analysis shows that none of the cases were a direct result of hydraulic fracturing, but were caused by “poor execution of other parts of the drilling, development, and production process” (ALL 2012, 103).

1.3.8 New York State Department of Health

In 2012, the New York State Department of Environmental Conservation requested the Department of Health to assess the potential health impacts of high volume hydraulic fracturing. The review included a review of the literature, input from public health experts, field visits with health and environmental authorities and communication with a wide variety of experts and stakeholders. The primary conclusion of the final report (2014) was that substantial gaps remain in understanding the effects of fracking and that more research is needed. In particular, the report notes “Well-designed, prospective, longitudinal studies are lacking that evaluate the overall effect of HVHF shale-gas development on public health outcomes” (p. 85). With respect to surface water and watershed impacts, the report highlights the potential for spills and inadequate treatment of contaminated or radioactive waste.

In his letter of submission for the final report, the Acting Commissioner of Health concludes:

> *As with most complex human activities in modern societies, absolute scientific certainty regarding the relative contributions of positive and negative impacts of HVHF on public health is unlikely to ever be attained. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF to all New Yorkers and whether the risks can be adequately managed, DOH recommends that HVHF should not proceed in NYS* (New York State Department of Health 2014, i).

The Governor of New York subsequently imposed a ban on hydraulic fracturing in the state.

1.3.9 Report to the South Africa Water Commission

An academic review report was completed for the South Africa Water Commission in 2012 (Steyl, van Tonder and Chevaliier 2012). The report noted that there was little information available in the public domain to fully assess the risks of potential surface or groundwater contamination in a South Africa context. Much of the literature reviewed for the report came from the U.S. and is included in the previous summaries above. The issues identified as being the most probable points of impact included: migration of fracking fluid, surface spills and water use. The focus of the inquiry was the organic rich shales of specified deposits in the Ecca Group and Bokkeveld Group. The report suggests that migration of hydraulic fluid from the fractured zone is highly unlikely due to the confining geology that overlies the reservoirs of interest. There are, however, dolerite dykes that intrude the gas basins within 300 m of the surface (little information is available for deeper zones) and the report raises questions about the potential of these features to act as vertical conduits for fracking fluid migration. Likewise, there are deep faults that intersect the basin and could play a role in fluid migration. The report stresses the importance of having good baseline data on surface and groundwater quality before drilling begins.

1.3.10 European Union

There has been a significant amount of background research and discussion for policy development as it relates the unconventional oil has development in the European Union (EU). This work has been completed under the European Commission Energy and Environment group. Current information indicates that shale gas is the unconventional hydrocarbon with the most potential for development in the EU with potential in France (5.1 Tcm) and Poland (5.3 Tcm) and an additional 3.1 Tcm in Germany, the Netherlands, United Kingdom, Denmark and Sweden. There is great deal of uncertainty around shale gas development due to the lack experience across the EU. The impact assessment document completed by the European Commission on hydraulic fracturing states (EU 2014, 18):

This combination of techniques high volume (hydraulic fracturing and directional drilling) and the fact that shale gas extraction requires the drilling of numerous wells, high use of water and significant land take, the injection of volumes of chemical additives underground and the production of large quantities of wastewater, combined with the public perception that the disclosed information is too little and not enough verified, have raised significant public concerns as to the related environmental, climate and related health impacts and risks of the practice (e.g. water and air emissions, cumulative impacts on water and land use, induced seismicity, …).

These concerns have led to the imposition of legal bans on hydraulic fracturing (France and Bulgaria) and temporary moratoria (United Kingdom, Netherlands, North Rhine Westfalia (Germany), Cantabria and La Rioja (Spain), Romania and Denmark). The lack of public acceptance is the primary driver of these bans on hydraulic fracturing. Public complaints about insufficient consultation and information sharing, along with doubts about the effectiveness of existing policy and legislation to protect human and environmental health, are recognized as significant barriers to unconventional hydrocarbon development. The most common environmental concerns raised by the public during impact assessment related to risks of water contamination and air pollution through releases of fracking fluids and through methane and VOC emissions.

At the time of writing, the EU is discussing the potential for developing specific policy and regulations for tight oil and gas development. The recommendations from the Commission include the need for: strategic planning and environmental impact assessment, risk assessment to identify all potential exposure pathways, comprehensive baseline studies on all environmental facets, comprehensive operational guidelines to ensure best practices, efforts to minimize water use and fracking fluid additives, detailed monitored during and after well completion, full disclosure of information regarding chemical and water use, reporting of all spills and accidents (EU 2014b).

The EU Impact Assessment (2014a) suggests that many of the identified risks associated with shale gas development can be addressed through careful management. The report includes a very useful table that identifies current approaches to managing the impacts of shale has development as well as remaining gaps and uncertainties.

1.3.11 Overall Review Trends

All of the reviews summarized above communicate significant concerns about the current level of uncertainty associated with evaluating the potential social, economic, health and environmental effects of unconventional gas and oil development that includes hydraulic fracturing.

A consensus exists over the main risks associated to fracking. Despite uncertainties, a broad consensus exists, with some risks systematically either ranked high or consistently evoked by scientific experts and sources. These risks relate mainly to risks of water pollution, in particular stemming from the use of chemicals in the fracking process, insufficient underground characterisation and well casing, air emissions (including GHG), as well as local impacts linked to transport and land and water use in particular. Other risks are not necessarily ranked high by *experts but are high in the public perception. This is for instance the case of induced seismicity risks and issues related to the asymmetry of information about the chemicals used* (EU 2014a, 23).

Decision makers need to have robust frameworks to evaluate these uncertainties. It is clear from our analysis that more (and better) science is necessary, but not entirely sufficient to address the issues surrounding this topic. In other words, this is much more than a technical issue to be solved with the comforting absolutes of statistics, graphs and tables. Certainly more research, especially longitudinal studies, will assist in understanding the immediate and longer term landscape effects of hydraulic fracturing development on surface water and watersheds. In addition, such research will need to be conducted in a broad sample of areas to address the significant regional variation in surface and geologic conditions. However, much of the critical decision making will need to make sense of the 'messy' world of societal beliefs and values. In particular, understanding and communicating about risk and uncertainty is essential. It is a mistake to believe that the facts will speak for themselves. A poignant and current example comes from the recent imposition of a fracking ban in the State of New York. Two quotes highlight how two community leaders can arrive at very different conclusions when they both have access to the same information as relates the ban imposed by the Governor:

> ***American Petroleum Institute, New York State Petroleum Council Executive Director – "****Today's action by Governor Cuomo shows that New York families, teachers, roads and good-paying jobs have lost out to political gamesmanship. This is the wrong direction for New York. Robust regulations exist at the federal and state levels nationwide for natural gas development and environmental protection. A politically motivated and equally misinformed ban on a proven technology used for over 60 years – throughout the country to great success – is short-sighted and reckless, particularly when New York depends on safely produced natural gas just over the border in Pennsylvania"* (API 2014).
>
> ***Acting New York Health Commissioner – "****The potential risks are too great. In fact, they are not even fully known. Relying upon the limited data that is presently available to answer the public health risks would be negligent on my part. I have identified significant public health risks in the current data. And until the public health red flags are answered by valid evidence through longitudinal long-term studies, prospective analysis, patient surveys with large population pools showing that the risk for impact on public health are avoidable or sufficiently low, I cannot support high-volume hydraulic fracturing in the great state of New York"* (Democracy Now 2014).

In this report we include a spectrum of information and implementation gaps that will need to be addressed to improve the quality of decision making as it relates to horizontal drilling and multi-stage hydraulic fracturing.

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2 APPROACH

2.1 PURPOSE AND MANDATE

This report was compiled in response to a call from the Canadian Water Network (CWN) to provide a summary of potential research approaches to inform decision-making for hydraulic fracturing and water. We were selected by the CWN as one of the national, university-based teams to conduct a one-year "knowledge integration" project. Specifically, our team addressed the issue of ***landscape impacts of hydraulic fracturing development/operations on surface water/watersheds***. We were also asked to include information on water use and demand as there was not a team selected to address this issue.

The mandate of the exercise was to integrate leading international research from across relevant disciplines to:

- **Summarize current research approaches and knowledge relevant to the issue area.**

  Integrate leading research and approaches from relevant disciplines to frame a clear understanding of how and where advancing knowledge through research could meaningfully support decision-making in this area.

- **Identify key knowledge gaps in the issue area that are being clearly articulated as priorities for decision-makers.**

  Based on credible studies and sources reflecting consultations with groups participating in the decision-making process, clarify the knowledge gaps that exist for decision makers which could be addressed by further research.

- **Present the range of practical research approaches that could be used to address these priority knowledge gaps.**

  Describe what research approaches and options are practical and could be implemented to meaningfully advance knowledge in the gap areas identified to support improved decision-making.

- **Discuss the potential strengths and weaknesses of the research approaches identified for informing decision-making knowledge gaps in the Canadian context.**

  For each research approach identified within the priority knowledge gap areas, provide an assessment of the relative strengths and weaknesses of each approach in terms of its ability to meaningfully inform the decision-making process. This analysis should focus on the expected efficacy of the research approaches in the Canadian context and should include, but not be limited to: scientific complexity, risk and uncertainty, timeframe, cost, capacity, ease of implementation, socio-political or other concerns, and what is likely to be achieved.

2.2 GAPS AND UNCERTAINTIES

It rapidly became clear to our team that there is a spectrum of gaps and uncertainties associated with the overall research topic. The following is a list of the 'type' of gaps that we address in the report:

- **Knowledge Gaps** – these are areas/topics where additional quantitative studies will provide more, better, and new information that improve our knowledge of impacts associated with hydraulic fracturing. Approaches to addressing these gaps include conventional scientific research, including longitudinal studies.
- **Information Sharing Gaps** – these gaps are characterized by information that is held by one or more parties, but not readily available to everyone who may have an interest. In some cases information is not sharable due to non-disclosure agreements between companies and land-owners. In other cases there is a 'silo effect' where different authorities or ministries have information, but it is not effectively shared. Approaches to addressing these gaps require the development of comprehensive, neutral party, data repositories (FrackFocus is a good example here).
- **Understanding and Trust Gaps** – these are significant gaps that exist because of deep-rooted and value-based positions that are held by competing interests. Approaches to addressing understanding and trust gaps include breaking down communication barriers and seeking dialogue. There is no 'quick fix' here.
- **Implementation Gaps** – are situations where knowledge and capacity exist, but where there are operational barriers to implementing the desired activity. For example, there is a growing understanding of the need to address cumulative effects, but significant challenges in doing so. There can also be implementation gaps related to the adoption of best practices. Approaching implementation gaps includes looking for successful precedents, adaptive learning and strong political will. Demonstration research and scenario planning / modeling can also be very effective here.
- **Institutional or Framework Gaps** – the integration required to address complex social-ecological issues (such as those associated with unconventional hydrocarbon development) require not only new and better techniques and information, but new institutional and organizational structures. Approaches to addressing these gaps include the consideration and implementation of more integrated forms of government and governance.

2.3 APPROACH

2.3.1 Guiding Principles

A foundational premise for our work is that 'landscapes' are more than static, physical entities. We view 'landscapes' as the product of relationships between natural and human processes over time. Identifying and assessing approaches to understand landscape impacts on surface water/watersheds (and water demand) requires a systems view founded on understanding the valued environmental components and the interrelationships between them.

Understanding and managing the effects of unconventional oil and gas on landscapes and watersheds requires and integrative, cumulative, landscape approach. Sayer et al. (2015, p. 345) conclude that a landscape approach provides “an organising framework for disentangling the complexity of the landscape and facilitating the investigation of impacts of different courses of action.” The authors to on to suggest a list of preconditions for success:

1. Inspired leadership is essential.
2. Long-term, adaptive commitment.
3. Facilitation is necessary but not sufficient to achieve landscape-scale outcomes.
4. Value propositions will motivate engagement.
5. Conflict and entrenched views must be openly addressed.
6. Strong systemic governance is essential.
7. Private sector engagement is a key element of success.
8. Policies without budgets and implementation commitments do not work.
9. Formalisation and monitoring of process outcomes is eventually needed.
10. Metrics must be developed to establish values, track progress and enable adaptive management.

We also recognize that meanings of landscape vary in different regional, jurisdictional and institutional contexts (i.e., across Canada). Therefore, we convened a national team with relevant and diverse disciplinary skills, but also with demonstrated commitment to transdisciplinarity (which we define as the co-creation of knowledge through integration and synthesis across disciplines and with the engagement of stakeholders – i.e., decision-makers, regulators and interested members of the public).

Our approach is guided by the methods of regional strategic environmental assessment (R-SEA) with an emphasis on cumulative effects. We believe that a cumulative effects regional scale focus has the potential to offer the best framework for: 1) understanding the complexity of decision-making in the face operational risk and uncertainty, 2) assessing knowledge gaps in the science-policy-management interface for decision makers and, 3) identifying key factors involved in creating and maintaining ‘social license to operate’ as it relates to landscape impacts of hydraulic fracturing on surface water/ watersheds and water demand management.

We began with a scoping exercise and identifying current knowledge and information gaps from multiple disciplinary perspectives. This process included conventional literature review, but also consultation with representatives from industry, government regulators and the public. The information from discussions with decision-makers and stakeholders is incorporated into the report chapters. For example, consultation and surveys with industry are included in Chapter 4. Chapter 9 includes information based on discussions and interviews with relevant government representatives from both the U.S. and Canada.

A modified R-SEA approach provided a compatible guiding methodology for dealing with cumulative effects at a regional environment scale. Specifically, R-SEA enabled social, ecological and economic values to be integrated into understanding landscape impacts, watershed, surface water and water supply/demand management concerns related to hydraulic fracturing. R-SEA has been applied to watersheds, river systems and wetlands as well as with landscape impacts. It has also been applied in Canadian federal and provincial projects with major energy development projects in sector specific and multi-sector situations. Both government and industry are familiar with an R-SEA approach as a decision support tool. The benefit of an R-SEA approach to our case is its procedural adaptability to different application contexts (landscape impact, watershed, wetland, water demand/supply management and regional energy development) and its ability to provide a common framework for knowledge integration. This approach combines expert-based and data-driven techniques. It is also provided the opportunity for members of our team with expertise in legal, stakeholder, regulatory, decision-making, risk assessment and social science to examine regional development and stakeholder debate as an opportunity to identify approaches for the creation or modification of institutional arrangements to improve environmental management related to hydraulic fracturing, water and landscape impacts.

Our approach was nested within the context of multifunctional/multipurpose decision-making. The volatility existing in this field and the fact the decision-makers have responded very differently to the issue suggests that many of these challenges are connected with governance and are not simply technical in nature. Much of the story is connected with social-ecological factors and the mechanisms and processes we rely upon to make sense of the world around us. As a result, there much pressure to better understand these different systems, comparing the forces that have shaped divergent patterns of technical-political decision making and knowledge sharing (or lack thereof). We purposely included considerable expertise on our team in the areas of legal, policy and decision making to insure the integration of these issues. The approach contrasted policy, management and best practices across the industry, between Canadian jurisdictions and between Canada and the U.S.

We brought our full team together in a workshop setting (one full 'in-person' meeting in Calgary in October 2014) and made use of conference calls and project management software for ongoing communication.

2.3.2 Field Visit

We conducted a field visit to view the 'Lochend Play' (a Cardium tight oil production area just northwest of Calgary). This was an opportunity for team members to gain first-hand exposure to active drilling operations. Lightstream Energy graciously hosted us on two of their active well-sites. The company was open to demonstrating their best practices for protecting the environment and addressing the many questions raised by the group.

The fieldtrip also included a visit with a ranching family and some of their neighbours within the active drilling region. These individuals were members of a local landowners association with significant concerns about the use of hydraulic fracturing. Their membership includes long-time ranchers, science professionals and people with extensive experience in the petroleum industry. They described a litany of health issues experienced by both humans and livestock in the area. They are particularly concerned about the effects on their drinking water and on air emissions. Their story and that of other concerned landowners in Alberta can be found at: www.albertavoices.ca. It is their belief that the onset of these effects coincided with hydraulic fracturing in the area and they are opposed to the activity. Their preference would be for a moratorium until more information is known about the potential effects. Many of the landowners in this area are not satisfied with the information that is being provided to them. In addition, they feel that their concerns are not being adequately addressed. They would like to see:

- Onus on the industry to prove safety rather than on residents to prove harm;
- Transparency regarding all chemicals and combinations of chemicals to be used before any operation commences, including amounts of each and possible interactions;
- Development of protocols for testing for all chemicals to be used, and free testing of surrounding water wells for all of these ingredients to be provided by industry and/or government;
- Use of tracers in the fracking fluids to allow determination of the source should contaminants appear in surrounding water wells;
- Requirement for zero flaring or venting of gases and well effluent;
- Presence of independent monitors on site during fracking and flowback operations;
- Testing of drilling solids and flowback for radioactivity;
- No spreading of drilling solids or liquids on farmland.

The landowners have requested information and research from the regulator, but we were unable to locate any site specific information arising from their call for research.

Understanding and addressing public concerns related to the development of unconventional hydrocarbons and the use of hydraulic fracturing needs to be an essential part of the decision making process. We deal with these issues in Chapters 3 and 4.

3 Public Understanding of Shale Gas Development and the Social License to Operate

3.1 Public understanding of hydraulic fracturing

There has been limited research to explore how various publics understand and react to shale gas development in Canada. This is a major knowledge gap with respect to social acceptance and licence to operate. We searched for articles using Google Scholar and then articles referenced within those found articles to locate the existing academic research regarding public understanding of shale gas development. We identified fourteen highly relevant articles, most published in 2014 and all published since 2011. The Center for Local, State, and Urban Policy (CLOSUP) at the University of Michigan has been pursuing a research agenda around this topic.

Research to date suggests that the general public has only limited knowledge of fracking, and that opinions about shale gas development are in the early stages of formation. Boudet and colleagues surveyed 1060 Americans about their perception of fracking (Boudet, Clarke, Bugden, Maibach, Roser-Renouf, & Leiserowitz, 2014). Most (52%) were uninformed about fracking and more (58%) were unsure whether they supported or opposed it. Of those who were aware of fracking, there was an even split between support (22%) or opposition (20%).

In a similar study, Davis and Fisk (2014) surveyed 765 Americans who were aware of fracking. Again, respondents roughly equally supported (45%) or opposed (40%) fracking, with the rest being undecided. Women and African-Americans were more likely to oppose fracking (statistically significant). They did not find that age, income or employment were related to one's fracking stance. Among those who do have opinions about fracking, the topic is often polarized along political lines, with Democrats more likely to oppose it on environmental grounds, and Republicans more likely to support it for economic development (Davis & Fisk, 2014; Mazur, 2014).

Theodori et al. studied the views of the public in Pennsylvania (Theodori, Luloff, Willits, & Burnett, 2014). Respondents in the high-density fracking areas were significantly more familiar with fracking than those in low-density areas. Respondents were largely unaware of how frack flowback water is managed, although this may reflect limited knowledge of wastewater treatment in general.

Although Canadian studies on this topic are limited, CLOSUP released two reports in 2014 comparing Canadian and American perceptions of fracking. The first report involved a survey of 1247 residents in the Great Lakes Basin, and compared how Ontario residents view fracking as compared to Americans in eight states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin). As compared to their American counterparts, Ontarians were less knowledgeable about fracking (Brown, Borick, Gore, Banas Mills, & Rabe, 2014). Despite their limited knowledge about fracking, Ontarians were more likely to favour federal authority over fracking decisions than were Americans. In this study, Americans were more likely to favour increased fracking activities in the Great Lakes Region than were Ontarians. However, political worldviews were more important for determining perceptions of fracking than nationality. Liberal-minded respondents were more likely to favour government regulation over fracking and to be concerned about potential risks to human health and the environment. Conservatives showed higher support for increasing fracking activities in the Great Lakes Region for economic development (Brown et al., 2014).

In the second CLOSUP report, Lachapelle and Montpetit (2014) explored Quebec, Michigan and Pennsylvania residents' perceptions of fracking. Quebeckers were significantly more likely to oppose fracking operations than were their American counterparts (62% versus 40% in Pennsylvania, and 35% in Michigan). Furthermore, Quebeckers perceived higher health and environmental risks from fracking and lower potential for economic development than did residents of Pennsylvania and Michigan. Nearly two-thirds (63%) of Quebeckers thought the risks of fracking outweighed the benefits in the long term, while both Michigan and Pennsylvania residents viewed benefits as outweighing risks (53% and 54%, respectively). When asked about their views on politics and society, Quebeckers' cultural attitude was more 'egalitarian' than Michigan and Pennsylvanian residents, who measured more frequently as 'individualists'. This egalitarian worldview, along with being female, was correlated with opposition to fracking. The measure for individualism was not a significant factor in determining one's stance on fracking. Meanwhile, conservative respondents from all three regions were more likely to support fracking operations.

3.1.1 Communicating Shale Gas Development

While many members of the public remain ill-informed about shale gas development, it is often inaccurately assumed that a public misunderstanding or ignorance is a solvable problem, namely that providing more information will somehow move public opinion. Bubela et al. (2009) have written about the deficit model of communication and engagement:

> *"Despite increasing attention to new directions in public engagement, a still-dominant assumption among many scientists and policy-makers is that when controversies over science occur, ignorance is at the root of public opposition…. (C)ommunication initiatives are therefore directed at filling in the 'deficit' in knowledge, with the hope that if members of the public only understood the scientific facts, they would be more likely to see the issues as experts do…. Yet the narrow emphasis of the deficit approach does not recognize that knowledge is only one factor among many influences that are likely to guide how individuals reach judgments, with ideology, social identity and trust often having stronger impacts" (p. 515).*

The Canadian Academies of Sciences expert panel report on the environmental impacts of shale gas extraction suggest that public engagement "encompasses two distinct sets of activities: (i) information and consultation; and (ii) good neighbour practices" (p. 209). These are important activities in that they may assist in shaping public trust in industry and government to manage the risks of shale gas development, but they miss larger challenges in engaging the public around shale gas development: building the governance frameworks and institutions that enable various publics to help co-create, shape and design the development. This is critically important for First Nations consultation but also for engaging effectively with local communities. Effective regional governance and institutions are also important for nurturing trust. One can imagine regional strategic environmental assessment as a potentially helpful tool in this regard. In short, public communication and information about shale gas development is critically important for ensuring a social licence to operate, but far from sufficient.

3.1.1.1 Media Representations of Shale Gas Development

The media play critical role in shaping public expectations about the important issues of the day, but are much less able to tell the public what to think about these issues (McCombs & Shaw, 1972). Nonetheless, research can trace the role in media representation of shale gas development in public concern.

One study, about how fracking has been represented in the media, found that two major events created negative media coverage about fracking: the explosion of the *Deepwater Horizon* in the Gulf of Mexico in 2010, and the release of the film *Gasland* in 2010 (Mazur, 2014). The *Deepwater Horizon* explosion led to a 10-part series in *The New York Times* called Drilling Down, from 2011 until 2012. The release of *Gasland* in 2010 prompted coverage in September 2010 in *The Sydney Morning Herald*. This coverage subsequently decreased, then increased again following the Drilling Down series in *The New York Times*.

In contrast, Theodori et al. (2014) found that the film *Gasland* was not very influential in Pennsylvania, where most of their survey respondents viewed both it and fracking industry information as untrustworthy. Yet, in areas with high densities of shale gas wells, both regulatory agencies and the fracking industry were viewed as important and credible information sources.

Evensen et al. used surveys to compare public reaction to the phrase “fracking” versus the phrase “shale gas development” (Evensen, Jacquet, Clarke & Stedman, 2014). They found that shale gas development was seen much more positively than fracking, with the latter being a more polarizing term. Even respondents who’d never heard of fracking saw it as bad, relating it to something that was obscene, negative, violent and weird.

A key message or take away point from this is that the nature of the messenger, the nature of the receiver, and the nature of the message framing are all important in shale gas communications.

3.1.1.2 The notion of ‘social license to operate’ and the connection to decision-making processes

The idea of a “social licence to operate” expands upon regulatory approval considerably. Rather than gaining government consent at the outset of a project, the expectations of a complex network of stakeholders – local communities, investors, First Nations, industry peers, and so on – need to be continually addressed. A social licence stems from credibility, legitimacy, and trust (Thomson & Boutilier, 2011). Each of these components are:

- <u>asymmetrical</u>, that is tough to earn and easily lost;
- <u>collectively held</u>, that is your credibility can be influenced by others in your sector or region;
- <u>contextually</u> determined, that is every project is different and locally dependent; and
- <u>historically</u> dependent, that is, past actions.

There are varying degrees of social licence: attachment for any project or proponent, and approval, acceptance and withdrawal. In short, a social licence is an ambiguous concept. In our view, it stems from a long-term decline in the trust of government and industry to properly manage the technological and social risks for the public good. While we are encountering the term 'social license to operate' more and more often, it may not be terribly useful in shaping the governance arrangements, process for public engagement and dialogue, or decision making beyond conveying the complexity and difficulty in meeting public and community expectations.

3.1.2 Typology of public perceptions

A broad typology of the typical supporter or opponent to fracking can be hypothesized from the survey work of Boudet et al. (2014), Davis and Fisk (2014) and Theodori et al. (2014). While there remain significant gaps in our understanding of how the public understands shale gas development, and some inconsistencies between the findings, a useful representative picture can be hypothesized (Figure 3.1). A key point to draw from this is the significant potential for fracking to become a divisive political issue, with probable lines drawn between political parties, urban and rural residents, race, and so on.

3.2 Perceptions, positions and activities of environmental stakeholders

To begin to understand the position and perception of environmental stakeholders toward shale gas development, we undertook a systematic review of their public websites (in October 2014, using search terms "frac" and "shale"). Overall, our review suggests that most environmental stakeholders are opposed to shale gas development, but there are nuances to this generalization. In particular, many environmental organizations (e.g., many conservation organizations, such as Greenpeace and WWF) have not taken any formal position on shale gas development. Others (e.g., Pembina and David Suzuki Foundation) have a position that in many ways acknowledges the complex uncertainties surrounding the environmental impacts of shale gas development and are advocating for careful and thoughtful regulatory oversight of these potential impacts. Nationally, the Council of Canadians has taken the strongest stance against shale gas development, likely in connection to their long history of water advocacy. In addition, many local organizations have taken a strong stance against shale gas development, although no national coalition of opposition groups has yet formed, but this is something to watch carefully for in the future. Table 3.1 summarizes the review of environmental organization websites.

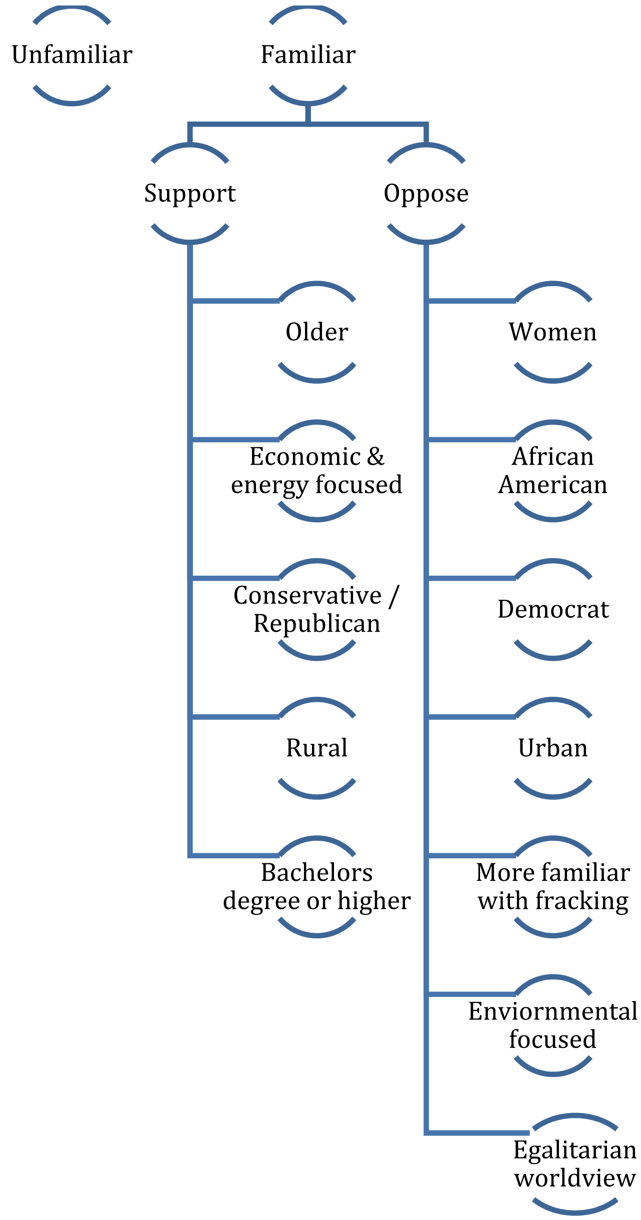

Figure 3.1. **A representative picture of supporters and opponents of fracking.**

TABLE 3.1 A Summary Of The Review Of Environmental Stakeholders Public Websites To Understand Their Positions On Shale Gas Development.

Environmental Stakeholder	Comments
Conservation Organizations	Canadian Boreal Initiative, CPAWS, Canadian Wildlife Federation, Ducks Unlimited, Land Trust Alliance, and Nature Conservancy of Canada o Generally have limited, if any, communications about fracking
Canadian Youth Climate Coalition	No communications about fracking or connection between shale gas and climate risks.
Greenpeace Canada	Limited communications about fracking. Focus is on broad rejection of fossil fuels.
WWF	Limited communications about fracking. Focus is on broad rejection of fossil fuels.
Environmental advocacy/legal organizations	Canadian Environmental Law Association, Council of Canadians, Ecojustice, Environmental Defence. o These organizations are generally against shale gas development. Council of Canadians hosts a petition, *Ban Fracking Now.*
David Suzuki Foundation, Sierra Club, Pembina	These organizations present a number of articles analyzing shale gas development, including the negative impacts on water resources.
Regional NGOs	Ontario: websites contain little to no information about shale gas development. Alberta, BC, Nova Scotia, New Brunswick, Saskatchewan, and Yukon all have local organizations arguing against shale gas development. It strikes the authors that a national coalition of anti-fracking organizations could emerge in the future, although we found no evidence of this as of yet.

In the academic literature, we found only one article that addressed stakeholder views of shale gas. Using interviews with people in the Marcellus and Utica regions, Willow et al. investigated how grassroots activists, non-profit organizations, and government representatives perceived shale gas development (Willow, Zak, Vilaplana, & Sheeley, 2014). The authors repeatedly attempted to contact gas industry representatives for interviews without success, and decided instead to perform content analysis on publicly accessible documents that address corporate social and environmental responsibility. In general, grassroots organizations saw fracking as having negative social and environmental impacts. Non-profit representatives wanted to learn from past mistakes in moving forward on shale gas development, which was seen as inevitable. Representatives from regulatory agencies highlighted the importance of developing regulations to protect people and the environment while pursuing economic development. Finally, industry documents promoted the economic benefits that Ohio can experience through shale gas development, while also being good stewards of the environment and protecting people.

3.2.1 First Nations responses to hydraulic fracturing

We initially sought to understand the range of First Nations perspectives on shale gas development using similar methods as the environmental stakeholders above. We found only limited formal statements about fracking on First Nations websites and came to the realization during this research that much of the First Nation opposition to shale gas development parallels the Idle No More movement, which had a strong social media presence. As such, we began a systematic search of Facebook and Twitter for “#idlenomore #fracking”; “#frack #indigenous” and used NCapture to import these to Nvivo 10 for Windows for review and analysis. Methodologically, while content can be located, it was challenging to identify social media posts/tweets as originating from First Nation peoples. Identity can often be ascribed when individual First Nation communities use their name, e.g., Mi’kmaq or Uni’stot’en Camp or when some First Nation posters/tweeters include a label such as “native” in their username.

On the whole, First Nations’ discussion on social media reflects opposition to fracking, and there is evidence of this through original tweets and retweets, Facebook postings, and links to websites and newspaper articles. The Elsipogtog First Nation in New Brunswick has been especially active and recognized in their opposition to fracking, and BC groups have been very active in opposing pipelines. There is strong solidarity and support between First Nation communities in opposing development projects for the protection of their communities and for the environment.

In general, First Nation postings about fracking appear to be from individuals rather than organized groups. There also does not appear to be a coordinated effort among First Nations to communicate about fracking using social media. Facebook seems to be more commonly used than Twitter for social media discussions about shale gas development.

Often, First Nation communications about fracking are part of a wider discussion of other environmental, health and rights issues as manifested in, for example, the Idle No More movement. This is an expected phenomenon, namely that a single issue becomes part of a larger constellation of issues, grievances and controversies.

Elsipogtog First Nations and SWN Resources fracking proposal in New Brunswick

In the summer and fall of 2013, the Elsipogtog First Nation protested against a shale gas project, blocking SWN Resources from conducting seismic testing, despite it having permission to explore from the New Brunswick government in 2010. In October 2013, a court injunction against the blockade led the RCMP to arrest over 40 protestors. The Elsipogtog protests and arrests took place at the same time as the grassroots Idle No More movement was gaining steam. Idle No More was initially a response to a December 2012 federal government omnibus budget act (Bill C-45) that overhauled the Navigable Waters Protection Act, including vastly removing the need to consult with First Nations about construction and projects on waterways that passed through traditional First Nations territory. Bill C-45 was seen as one among a long list of actions that threatened Treaties and Indigenous sovereignty.

The Elsipogtog protests present a valuable example of the power of social media to create networks of resistance to, in this case, shale gas development. The iconic October 17, 2013 photo of Amanda Polchies holding an eagle feather on her knees in front of a team of RCMP officers circulated widely on social media. It became a powerful tool for quickly communicating the story of Elsipogtog and painted fracking as a clear and present danger to First Nations sovereignty and the environment. Shale gas development was a central issue in the fall 2014 New Brunswick election and new Premier Brian Gallant put a shale gas moratorium in place in December 2014. The lesson here is that fundamentally different strategies and approaches are needed by government and industry as they interact with public and stakeholders about energy development.

3.2.2 Understanding the connections between physical and cultural landscapes

It is our view that landscape identity – the interdependent relationship between landscape and people that leads to a "perceived uniqueness of place" (Stobbelaar & Pedroli, 2011) – is a central vehicle for engaging local knowledge in energy planning processes, such as shale gas development. Landscape identity has biophysical, cultural, and practical components (Stephenson, 2008, see Figure 3.2) that can guide how the public engages with and assesses the social and environmental impacts of energy deployment. Paramount in this type of process is recognizing that local authorities and community members – supported by provincial and federal experts – are often best positioned to make the ultimate decisions about the acceptability of social and environmental impacts within their local community.

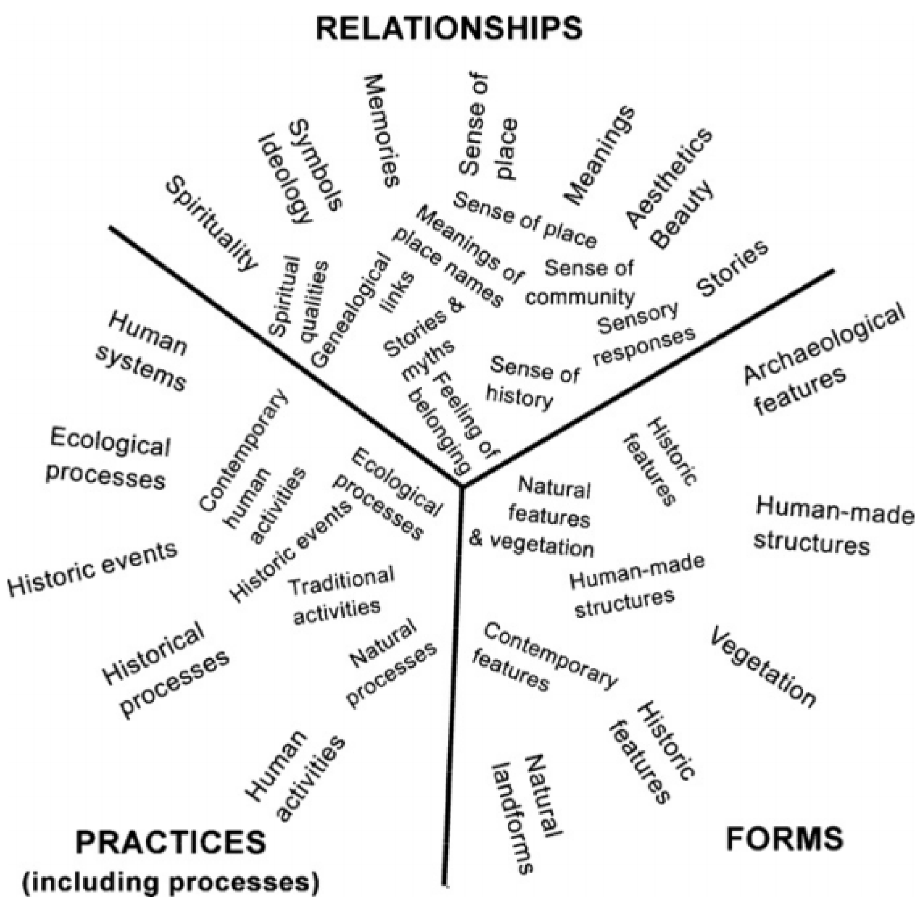

Figure 3.2 Showing the Connections Between Cultural And Physical Landscapes (Stephenson, 2008)

Community members may not have formal planning or engineering expertise, but they understand the area in which they live, and can give voice to the landscapes they care about. Designing public engagement and planning processes that allow meaningful discussion of the co-evolutionary nature of landscape and culture is vitally important if we are to succeed in designing a sustainable and resilient energy system.

While economic expediency will push regulators toward streamlined planning and approval processes for energy development (Oles & Hammarlund 2011), it may also alienate local communities and exacerbate conflict (Hill & Knott, 2010; Owens & Driffill, 2008).

Authentic discussion about the potential local impacts of a development, such as the impact on landscape identity, alongside empathy for the burden that energy developments might place on some local stakeholders, is central to building trust, sharing risks and benefits, and addressing opposition.

Nonetheless, there are significant challenges in designing effective public engagement processes that both enable communities to become more involved in energy projects, and shift local controversies "from conflict between enemies to constructive controversies among adversaries who have opposing matters of concern but also accept other views as legitimate" (Björgvinsson, Ehn & Hillgren, 2012). The difficulty, then, is to design participatory approaches that can achieve a fair negotiation around values. Certainly, the chapter on structured decision making provides a number of useful ideas for eliciting values in a systematic manner in decision making. The work of ALCES in creating dynamic models for understanding cumulative effects across a region is also important in that it allows the public to contribute to the analytical process.

Thus, the governance surrounding the intersections between land and energy planning, the contested views and social controversies surrounding land use and energy planning, and the role of knowledge-based authority in shaping these issues, whether through scientific expertise or local knowledge are critically important.

3.3 INFORMATION GAPS

Key issue of relevance to decision makers: ***1. Limited understanding of how the public views shale gas development.***
Priority knowledge gap to address the issue: There is limited understanding of how the public understands shale gas development, particularly in Canada. Information gaps include explanatory frameworks about how opinions have formed. There is very little academic literature from Canada, examining First Nation views or about environmental stakeholders.
Approaches and strategies Primary academic research to explore public knowledge and perceptions of shale gas development in Canada. For example, conducting focus groups, surveys, and/or interviews with a variety of groups, such as: Canadians in rural and urban settings, environmental organizations (grassroots, local, regional and national groups), First Nation communities, and energy industry representatives. Ideally, this research would include participants from across Canada, including in Quebec and New Brunswick where there are currently moratoria on shale gas development, and in Alberta and British Columbia where shale gas development has begun.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Robust program of research to examine public attitudes toward shale gas development	Least difficult	Low	High	Moderate	$300k for academic and applied research	2-4 years	Would be most productive with partnerships between universities and industry.

Key issue of relevance to decision makers:

2. Limited tracking of evolving social understanding of shale gas development.

Priority knowledge gap to address the issue: There is limited tracking of how various issues about shale gas development in particular, and energy politics in general, are forming and shaping public opinion. This would be an effort to understand the dynamic aspects of the public understanding regarding shale gas development, particularly at a local and regional scale.

Approaches and strategies:

This research would involve tracking media representations of shale gas development, including through television, radio, newspaper, and via Internet sources, using methods such as following social media discussions surrounding shale gas and using social media analytics. An analysis of how shale gas is framed within the media is also recommended. Additional research could employ focus groups, surveys and/or interviews to further comprehend how Canadians engage with media coverage of shale gas development

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Robust program of research to examine public attitudes toward shale gas development	Least difficult	Low	High	Moderate	$500k per year for academic and applied research	2-4 years to initiate, then ongoing.	Would be most productively undertaken by private sector, with data sharing with universities.

Key issue of relevance to decision makers:

3. Inadequate places and spaces for meaningful dialogue and engagement about shale gas development specifically, and policies surrounding energy development in general.

Priority knowledge gap to address the issue: From a research standpoint, there is limited understanding of how to create the public places, spaces, and processes for effectively engaging local, regional and national publics in a discussion about shale gas development. For example, there are no examples of how to use structured decision making to shape public discussion of values and information. There are no cumulative effects assessments to engage the public in a regional or national discussion of the impacts and benefits of shale gas development.

Approaches and strategies

Energy is central to the Canadian economy yet the way people understand this development is complex and varied. The distribution of risks and benefits surrounding conventional, unconventional and low-carbon projects has created many social conflicts; shale gas is but one actor in a broader play. Nonetheless, the trend in governance of energy development by provinces and the federal government over the past decade has been one of streamlining approval and planning processes. In many ways, Canadian governments are now seen as promoters of energy development, rather than an arbitrator of public interests. Streamlined and centralized approvals have backfired in terms of social acceptance. The need for meaningful and authentic deliberation about these issues is well established in the social science literature, yet contemporary practices by governments and industry seem to ignore this work. The budget for announced energy infrastructure projects in Canada is in the order $62.3 billion (Voshart, 2015). Given the tremendous importance of social licence in moving projects forward; we offer a straw dog argument that an additional modest 1-2% of this be allocated by government and industry to create the spaces and places for authentic public engagement in energy development, an investment of $600 to $1,200 million over the next five years. We don't offer suggestions about the mechanics of the engagement but rather leave this to the various local, provincial and federal governments and responsible authorities. Public engagement approaches might include techniques that:

- Create public interest: animate members of the public to be interested in energy development (i.e., before conflict arises)
- Educate and inform
- Analyse: using approaches such as environmental assessment, modelling tools such as ALCES, or structured decision making to analyse the risks and benefits of energy development.
- Make decisions: the agent and process of making a decision (e.g., decision by government, courts, negotiation (federal-provincial, co-management), by majority, consensus, plebiscite, etc.

The overall point is that a failure by proponents and governments to make significant and sustained investment in mechanisms for public dialogue around energy infrastructure is a sure-fired recipe for prolonged social conflict.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Robust program to create and evaluate the means and mechanisms for effective public deliberation and engagement, at local, regional and national scales, regarding energy policy	Moderate, but essential	High, and this is an extremely difficult collective project	Low, and this will be very challenging to implement	Moderate	millions , perhpas $1 or 2 dollars for engagement & communication for every $100 proposed for capital projects	Five years, then ongoing	Would be most productive with partnerships between universities and industry.

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4 Industry Best Management Practices

4.1 Introduction

Business managers in firms that conduct hydraulic fracturing consider the issue of landscape effects on water and watersheds from various perspectives. In this chapter, we move beyond the technical details of fracking operations and identify gaps in our knowledge of how managers in the oil and gas industry approach strategic decision making around best practices, collaboration and management of nonfinancial risk, in particular reputation. Our focus is the North American oil and gas industry, with particular attention given to Western Canada. The scope of research was defined by our expertise and our relationships with firms headquartered in Calgary.

4.2 Approach

To identify gaps in the existing management literature and managerial knowledge, we have undertaken a three-pronged approach. First, we evaluated a sample of firm websites and public material to identify best practices. We interviewed a small number of industry experts to test our findings and garner further insights. To define industry best practices and collaborations, we reviewed public materials to determine industry associations that exist in consideration of hydraulic fracturing and if those associations address best practices for firms. Second, we conducted a review of the management literature to understand the current academic conversation on hydraulic fracturing. Third, we conducted a content analysis of media sources for the past 5 years to examine the nature of stakeholder concerns and hydraulic fracturing issues. Our goal in analysing data collected via these primary and secondary methods was to identify gaps in the literature and managerial knowledge. In support of this initiative, we conducted a survey of companies through the Canadian Society for Unconventional Resources (CSUR) to assess managerial perspective and validate our findings.

Dr. Parks and Dr. Van der Byl included three undergraduate students in their data collection and analysis. The Canadian Water Network funded two of these students. We used the software program NVIVO for our content analysis of the media dataset.

4.3 Findings

In the following sections, we outline our findings. We show what information exists, that is what we know, and what we do not know or potential knowledge gaps. From this foundation, we summarize and identify gaps in our current understanding of landscape impacts of hydraulic fracturing and business decision making (see Appendix 4-A to this chapter).

4.3.1 Firm Best Practices

Public documents, predominantly websites, of sixteen oil and gas firms with operations in North America were reviewed to determine best practices related to surface water impacts.

4.3.1.1 Overview

Overall, each company researched has a water program in place and all address the concern of possible contamination of groundwater. As well, companies are involved in projects to reuse and recycle water from unconventional sources and the produced water in an effort to decrease their use of fresh water and environmental impact. All companies researched are also involved in disclosures about fracking fluids used in their processes. A gap in best practice reporting by firms seems to be disposal of produced water. There is a large focus on the reuse and recycling of water, but there is very little known about the amount of water disposed of or the way in which this water is disposed. This is one area in which firms can be more transparent.

4.3.1.2 Competitive Issues

Although all companies have best practices in place, there are companies which are visibly more involved in water initiatives. Many of the front-runner companies in terms of water policy have been pioneers on water projects and are taking initiative to be more involved in water related programs. An issue throughout the research tends to be proprietary technology. Many aspects of the industry are new, as demonstrated through the variety of programs and initiatives. There is no single way to address the water issues of the industry (see the following section for expansion on this point). The industry remains in the technology development and optimization phase and, therefore, competitive advantages derived through proprietary processes are important. The proprietary nature of this technology is potentially keeping any single initiative by one company from becoming standard within the industry. Drawing on the management literature on collaboration versus competition (Chen, 2008; Das & Teng, 2000; Davis & Eisenhardt, 2011; Raza-Ullah, Bengtsson & Kock, 2014), we identify an opportunity to explore both barriers and enablers to deeper industry collaboration on landscape and watershed practices.

Potential Knowledge Gap: How can the industry balance competition and collaboration in development of best practices?

4.3.1.3 Standardization versus customization

In addition to competitive pressures, another barrier to the development of best practices may lie in the unique nature of the business itself. Since reservoirs differ and since development occurs in vastly different geographic locations, firms must adjust to varying conditions for production and water management. In some cases, regions benefit from the use of surface water in operations; however, in others this is not acceptable. One size does not fit all and water is a local issue with specific issues to the watershed. One interview participant noted the encouraged use of surface water in areas like Louisiana compared with strict surface water regulations in other jurisdictions. Our site tour in the Cochrane area demonstrated the mutual benefit to industry and community of surface water usage in local flooding areas. Water management, unlike air emissions, demonstrates variability based on geographic location and water availability. This results in adjustments and customization to best practices when necessary. However, despite this element, firms and the industry develop best practices to provide a foundation from which adjustment can occur. While customization occurs when needed in operation practices, some firms contend that practices remain consistent regardless of whether development occurs in more remote or more populated regions. The underlying sentiment here is that practices in remote areas are of such integrity that they can be equally applied in operations that impinge on communities. Is this valid? Are best practices developed to account for differences in impact of operations when local communities might be affected? For example, issues of road use and noise levels. This is particularly salient given how development, especially in the United States, is impinging more and more on populated areas and with longer timeframes. Much of the stakeholder concerns in recent years come from more populated areas. While the industry prides itself on compliance and adherence to regulations wherever activity occurs, even in remote areas, the question becomes: Are best practices adequate where industry and society meet?

Potential Knowledge Gap: Do best practices for hydraulic fracturing that are acceptable for remote area development meet stakeholder expectations where development impinges on communities?

4.3.1.4 Transparency and Disclosure

Only one company in our sample of public document analysis explicitly addressed the issue of onsite spill prevention and control. In our interviews with decision makers, we determined that firms do not state this practice as it is 'taken for granted'. Spill prevention and control in hydraulic fracturing operations are considered part of normal best practices and have been required of the industry for decades. Surface spills are not considered an issue to industry because firms must prevent and manage this in all facets of their business. However, one interview participant questioned how effectively the industry is communicating this established practice. Similarly, the public does not believe that firms do not know how big a field will eventually become. It is a function of the industry that the exact size of a play is not known until exploration is complete. Can the industry better communicate the evolution of a field to build trust with the public?

We did notice a variation in disclosed best practices by the firms in our study. Some companies, typically larger more established firms with a strong operational or sustainability reputation, tended to disclose more detailed best practices. We are unable to determine whether this is because of more advanced practices or because of more developed approaches to transparency and communications.

We identify an opportunity to contribute to the limited management literature on transparency and communication from firms to stakeholders on issues of corporate responsibility (Augustine, 2012; Dawkins & Fraas, 2009; Rainey, 2008). Research in this area has the potential to inform oil and gas industry practices.

Potential Knowledge Gaps: How effective is the industry at communication, transparency and disclosure in areas of concern to the public? Is there a correlation between firm size and best practices in operations and/or approach to communication?

4.3.1.5 Benefits of Scale

All the companies in our sample addressed the need to find new water sources other than fresh water. Many companies address water issues and sourcing, but are in the beginning stages of making changes or are not yet involved in actual projects. Some firms are progressive in their approach, partnering with municipalities for use of wastewater and non-potable ground water. All sample firms note that the construction of pipes and wells meets and exceeds regulations. Where the scale of development allows, firms see benefit in transporting water to and from site via pipelines versus trucks. There is also an environmental and cost advantage to using centralized facilities and approaches when scaled to a certain size. However, prior to achieving exploitation of the resource and the associated scale, firms must conduct exploration activity which has a surface disturbance. As the industry and the regulator move to play based approaches it is unclear, in our review of secondary data, the positive effect of this development. An opportunity exists to identify the benefits stemming from a play based approach.

Potential Knowledge Gap: How is the industry capitalizing effectively on the benefits of scale and collaboration to reduce landscape and watershed impact?

4.3.1.6 Industry Collaborations

Beyond firm best practices, there are also Oil and Gas Associations that promote many guidelines in order to mitigate the risk of environmental and social impact to the environment and community. For instance, according to the Canadian Association of Petroleum Producers (CAPP), the Guiding Principles for Hydraulic Fracturing involves the following (CAPP website, 2012):

1. Safeguarding the quality and quantity water in the surface and groundwater resources by maintaining construction practices, sourcing fresh water and recycling water for reuse in operations.
2. Measuring and disclosing water usage.
3. Supporting the development of fracturing fluid additives with the least environmental impact.
4. Supporting the disclosure of fracturing fluid additives. However, it is an Operating Practice but it is not mandatory by law. CAPP strongly recommends that Oil and Gas “companies disclose, either on their websites or on a third-party website, those chemical ingredients in their fracturing fluid additives,” which are identified on the Material Safety Data Sheet (MSDS) by federal law.
5. Continuing to develop technologies and best practices that reduce the potential of environmental risk of hydraulic fracturing.

According to CAPP’s website (2012), there are seven Operating Practices that include the following:

1. Fracturing Fluid Additive Disclosure
2. Fracturing Fluid Additive Risk Assessment and Management
3. Baseline Groundwater Testing
4. Wellbore Construction and Quality Assurance
5. Water Sourcing, Measurement and Reuse
6. Fluid Transport Handling, Storage and Disposal

7. Anomalous Induced Seismicity: Assessment, Monitoring, Mitigation and Response.

Industry interview participants point to the clarity and relevance of CAPP's guiding principles. According to our interviewees, these principles exceed current regulations.

Another Canadian Association is the Petroleum Services Association of Canada (PSAC). Their website contains a *Hydraulic Fracturing Code of Conduct*. It says that their efforts are focused in five areas:

1. Water and the environment
2. Fracturing Fluid Disclosure
3. Technology Development
4. Health, Safety and Training
5. Community Engagement.

In addition, some of the PSAC member companies founded the Working Energy Commitment and they have agreed to this *Statement of Principles* that consists of the following:

1. Operate safely and responsibly
2. Meet or exceed all environmental standards
3. Act with integrity
4. Continually improve our practices and services
5. Treat all members of the community with respect, dignity and trust.

In the United States, standards and regulations for hydraulic fracturing vary from state to state. There are many American Associations such as the American Gas Association (AGA) and the American Petroleum Institute (API). The API states that there are three main principles, which are Integrity, Safety and Environmental Responsibility and Communicating Effectively. One interview participant suggests that collaboration in the United States is complicated by greater diversity in that industry. Similar industry guidelines to those established in Canada do not seem to exist in the United States.

This review of industry standards and guidelines is not exhaustive and could be expanded to include other industry professional associations like AAPG, SPE or standards associations that might include ANSI, ASME etc.

4.3.2 Management Literature, Content Analysis and Stakeholder Management

The subject of hydraulic fracturing is not addressed extensively in the management literature. Where it is explicitly considered is in what we refer to as "niche" sustainability or energy journals. These would be considered second-tier journals in our field. Papers are typically focused on the American industry and are dominated by scientific research that begins with questions of concern regarding the impact of hydraulic fracturing. On the subject of landscape and watershed impact, the limited relevant management literature considers the infrastructure necessary to support hydraulic fracturing activity and its landscape impact (Dana & Wiseman, 2014; Jain, 2015; Racicot, 2014; Smith, 2012) as well as the potential impacts of spills, leaks and equipment malfunctions (Jain, 2015; Siegel, 2014). More generally, topics include: water contamination, flowback water testing, aquatic impact, additives, spills and discharges and water disposal. There are also journal articles that consider American hydraulic fracturing regulations and the distinction between federal and state jurisdiction. Finally, a number of papers consider stakeholder perception, including: the public, communities, shareholders and the aboriginal community.

Beyond journal articles that explicitly address the issue of hydraulic fracturing, we consider the broader management literature. Some of the issues affecting firms using hydraulic fracturing technology can also be found in contexts that vary from oil and gas in general to the chemical or forestry industries, for example. Theories used in this research might include: efficiency theories like the resource based view of the firm (Sharma & Vredenburg, 1998) and transaction cost economics (Williamson, 1989); institutional theory is used to examine regulated industries and the potential for self-regulation (Hoffman, 2001; King and Lenox, 2000); stakeholder theory to consider firm impact on stakeholders and stakeholder impact on firms (Freeman, 2010; Mitchell, Agle & Wood, 1997) - this literature is connected to firm reputation (Eccles, Newquist & Schatz, 2007) and a small literature on transparency and openness (noted earlier).

As part of our research, a content analysis of media articles from the past five years was conducted to define key stakeholder issues and their associated rhetoric in opposition to hydraulic fracturing practices. The top ten Canadian English-language newspapers, by circulation, and media releases from the five most vocal ENGOs were searched for relevant data. Computer assisted, textual analysis was completed using NVIVO. Our key finding is that two broad themes of de-legitimization discourse emerge from the data: appeal to fear (uncertainty) and appeal to fairness (flawed process). Stakeholders demonstrate fear of: disease or death, the unknown, technology, pollution and depleting resources. They also show concern for a lack of: government regulation, transparency, information/knowledge, and trust in industry.

Given these preliminary findings and our review of the extant literature, as well as consideration of secondary and primary data in this investigation, we identify the following potential knowledge gaps:

1. What communication actions yield results for firms to increase the legitimacy of their operations and the reputation of the industry? While firms are effective at community engagement and stakeholder relations, there seem to be industry challenges in how to effectively communicate with the public and in determining when to be transparent and open. What are the associated risks and benefits? What is the value of independent, third-party reviews?

2. What are the implications of industry best practices exceeding regulation? How effective is industry self-regulation? What are the risks of adverse selection and free riders? Is there a distinction in firm best practices between larger and smaller firms? What are the implications of excess resources: access to capital, expertise, labour, assets? Are larger firms with resources better able to meet and exceed principles versus smaller firms with fewer resources and a business strategy focused on low costs and speed of execution? Is there a need to exceed regulation and customize practices to meet stakeholder expectations where activity impinges closely on society?

3. What are the barriers and enablers to collaboration on stakeholder issues related to hydraulic fracturing - both within and across sectors? How can the benefits of scale best be achieved via collaboration to enhance or augment existing regulation?

4.3.3 Validation of Potential Knowledge Gaps

In our survey, conducted through CSUR, the respondent rate was low with only 12 participants meeting completion. However, even with that low sample size, some interesting insights exist and provide a litmus test for the gaps identified through interviews, literature review and content and secondary source data analysis. While the majority of respondents agree that industry is effectively sharing best practices, there is less consensus on effective collaboration on stakeholder engagement and elevating industry reputation. The data suggests that while firms assess their individual stakeholder engagement as adequate, that of the industry is deficient. This validates our identified knowledge gap regarding industry effectiveness in communication and transparency on stakeholder concerns. The sample confirms our finding that industry best practices are exceeding government regulations. Contrastingly, and in opposition to our expectation, respondents did not feel competitive issues created a barrier to sharing best practices.

Material in this chapter of the report was shared with a key industry decision maker to test validity of the findings. This is consistent with our engaged scholarship approach. The decision maker did validate our findings and expressed enthusiasm for moving the research agenda to address these knowledge gaps.

4.4 Conclusion

We have amalgamated the gaps identified in this chapter based on synergies and have provided them in table format below. The three knowledge gaps, related to industry best practices, concern:

1. Industry and firm strategies for communication and transparency with the public.
2. Implications of industry best practices exceeding regulations - self-regulation and the potential for free riders, standardization versus customization tensions.
3. Industry collaboration barriers and enablers and potential benefits, including issues of scale and landscape impact.

As outlined below, and based on our analysis, we have identified three gaps in knowledge specific managerial decision making in addressing landscape water impacts of hydraulic fracturing. In addition, we have proposed research study approaches that would address these gaps.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

4. Industry and firm strategies for communication and transparency with the public

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. How effective is the industry at communication, transparency and disclosure in areas of concern to the public?
2. What communication actions yield results for firms in increasing the legitimacy of their operations and the reputation of the industry? While firms are effective at community engagement and stakeholder relations, there seem to be industry challenges in how to effectively communicate with the public and in determining when to be transparent and open. What are the associated risks and benefits? What is the value of independent and third party reviews?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: expand content analysis to identify stakeholder issues and conduct focus group study to assess impact of industry communication approaches	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Local focus groups with potential to extrapolate to wider population.
Qualitative Research study: interview activist groups	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Both national and international groups.
Quantitative Research study: survey of public and NGOs survey	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	National public survey potential and international survey of activists.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

5. Implications of industry best practices exceeding regulations - self-regulation and the potential for free riders, standardization versus customization tensions

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. What are the implications of industry best practices exceeding regulation? How effective is industry self-regulation? What is the risk adverse selection and free riders? Is there a distinction in firm best practices between larger and smaller firms? What are the implications of excess resources: access to capital, expertise, labour, assets? Are larger firms with resources better able to meet and exceed principles versus smaller firms with fewer resources and a business strategy focused on low costs and speed of execution?
2. Is there a correlation between firm size and best practices in operations and/or communication approaches?
3. Do best practices for hydraulic fracturing, acceptable for remote area development, meet stakeholder expectations where development impinges on communities?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: using secondary sources, analyze federal, provincial and local municipality regulations and compare to industry best practices identified via secondary sources and firm interviews	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 year	The expected outcome would be a gap analysis of industry best practices versus regulatory requirements and a critical assessment of the benefits or costs of the gap.
Qualitative Research study: interview community stakeholders	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Targeted communities involved in opposition to hydraulic fracturing.
Quantitative Research study: measure firm size and firm best practices - operational and communication	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	Potential to gather data for various regions of Canada and internationally, and consider the effect of geographical and political context on results.
Quantitative Research study: survey of community, industry and regulator	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	Canadian survey and generalization of results given control variables.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

6. Industry collaboration barriers and enablers and the potential for scale benefits to landscape impact

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. How can the industry capitalize effectively from the benefits of scale and collaboration aimed at reducing landscape impact?
2. What are the barriers and enablers to collaboration - both within and across sectors?
3. How can the industry balance competition and collaboration in the development of best practices?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative Research study: expand interviews with industry participants, the regulator and key external stakeholders	Valuable but Partial	Standard and accepted qualitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 3 years	Focus on Alberta with generalizability to other regions in Canada and potentially the United States.
Quantitative Research study: expand existing survey	Valuable but Partial	Standard and accepted quantitative research methods.	Moderate	Capacity in Canada	$50-100K	1 to 2 years	

4.5 References

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5 WATER EXTRACTION AND USE

5.1 INTRODUCTION

Shale gas development in Canada requires significant amounts of water if current production technologies are applied. Several Canadian provinces have acknowledged that hydraulic fracturing operations may need to be regulated differently to avoid cumulative impacts on both water supply and quality (BCOGC, 2010; ERCB, 2012 and AER, 2014). Furthermore, in order to address the challenges related to water supply, the Canadian Association of Petroleum Producers (CAPP) has stated that "*protecting water during sourcing, use and handling is a priority for our industry*" and has adopted both guiding principles for hydraulic fracturing, and operating practices (CAPP, 2012).

Swanson (2014) identified "management and protection of water" activities as the primary challenge of unconventional oil and gas developments. This was also identified as the priority resource management issue by researchers studying the willingness of provincial governments to allow and regulate hydraulic fracturing operations in the Marcellus shale play (Rahm and Riha, 2012; Parfitt, 2010; and ERCB, 2012).

In 2011, the Energy Resources Conservation Board (now the Alberta Energy Regulator; ERCB, 2011) conducted a jurisdictional review of regulations for shale gas production across North America and identified shared water management issues across jurisdictions, as follows:

- Very large volumes of water, tens of thousands of cubic meters per well, are needed to hydraulically fracture shale gas wells using current technology.
- Most of the water used in shale gas development to date has been from fresh surface water or groundwater.
- Access to sufficient water is critical to development, but cumulative effects on the sources of large water withdrawals must be managed.
- Transporting large volumes of water by truck or pipeline presents challenges.
- On-site containment and the transport and disposal of large volumes of used hydraulic fracture fluid must be carefully managed.
- Limiting overall and water use, especially of fresh water, by using water with higher total dissolved solids and by reusing and recycling hydraulic fracture fluid is being promoted.

As hydraulic fracturing requires large volumes of water, the distribution of shale gas developments in a region is a key factor and requires the identification of multiple locations for water withdrawals (Rahm and Riha, 2012). Provincial governments are aware of the importance of achieving a higher level of understanding of the total amount of water available (surface water, shallow water aquifers, and deep saline aquifers) across watersheds and that could be allocated for industry expansion (BCOGC, 2010; AER, 2014). For this reason, Canada's western provinces are currently engaged in generating scientific reports about water availability (Integrated Water Resources, 2013; Geoscience BC, 2015a and Geoscience BC, 2015b), developing policies for water-use and water re-use; creating "new" area-based (BCOGC,2010) and play-based (AER, 2014) regulations, and developing good engineering practices.

The predominant cross-cutting water supply management issues identified are, as follows:

- sufficient water supply and timing of withdrawals,
- water scarcity and competing interests for the same water supply,
- uncertainty around the potential effects of climate change on water supply,
- water storage and water reuse,
- potential for using alternative hydraulic fracturing fluids.

Sufficient freshwater supply is not always readily available to support the significant water requirements for hydraulic fracturing operations. For this reason, the need to understand the total freshwater inventory on a provincial, regional, “area-based” (BCOGC, 2010) or “play-based” (ERCB, 2012; AER, 2014) scale that could be allocated for shale gas production is of utmost concern.

Seasonal and inter-annual variation in the hydrological system is complex and not well understood in many systems. The impact of timing on water withdrawals is not addressed in the literature; however, water allocations are based on seasonal and measured data and existing water permits and licenses account for these variations. Additionally, competing interests (existing approvals, licenses and temporary permits or licenses) may exist to withdraw fresh water from the same sources and may result in some water sources not being available for hydraulic fracturing purposes in some regions. Special attention is needed in some regions in Canada where water scarcity may exist for municipalities and irrigation districts that rely on surface water supplies for domestic uses and food production, freeing up surface water in large quantities to support increased hydraulic fracturing operations may not be possible.

Water storage, either onsite or piped in from a central reservoir, and water reuse is an emerging solution for water needs; however, provincial regulatory systems are not always in alignment with technological advances. In addition, there may be unintended consequences associated with novel solutions. For example, water storage onsite may create opportunities for surface and groundwater contamination from runoff associated with extreme climate events, and during heavy precipitation (e.g., spring flood events in recent years) and snowmelt.

With hundreds of wells to be drilled over large gas plays, water management warrants considerable regulatory attention and could limit where, when and how fast shale gas development occurs (ERCB, 2011). In some provinces, like British Columbia and Alberta, water availability for hydraulic fracturing is currently being investigated on a regional scale (Integrated Water Resources, 2013). Water sourcing and mapping of surface water, fresh groundwater from shallow aquifers, and deep saline aquifers in West-Central Alberta is underway by a three-party consultant firm known as Integrated Water Resources. This research is funded by industry in partnership with government and supports CAPP’s guiding principles and operating practices for water sourcing and measurement. Alberta’s water sourcing knowledge in one part of the province is currently being co-created in support of industry and the provincial play-based regulatory scheme (independent third party water inventory information).

In its second year of the project, Alberta’s Integrated Water Resources (2013) will continue hydrologic analysis and will characterize regional and seasonal patterns of water availability at the watershed scale for four main watersheds in Alberta: Peace; Athabasca; North Saskatchewan; and South Saskatchewan. Since 2012, British Columbia has had an online water sourcing tool in place for the northeast region of the province to enable industry, decision-makers and the general public to understand the sources of fresh and saline water that may be used for hydraulic fracturing. The NorthEast Water Tool (NEWT) and NorthWest Water Tool (NWWT) are currently in use as a decision-making support tool for guidance on water availability in north eastern and western British Columbia respectively. Finding sufficient water supply to support increased shale gas production is of great economic importance to provincial governments and industry alike in western Canada. Operators and regulators are increasingly considering moving away from freshwater surface water for injection for oil and gas production and toward increased use of saline groundwater.

5.2 Water extraction requirements and potential effects – review of literature

5.2.1 Water use rates in Alberta

In 2012, horizontal hydraulic fracturing activities accelerated in the following shale formations or "plays" in Alberta: Cardium; Viking; Glauconitic; Montney; Duvernay; and Beaverhill Lake (George, 2012). One example of this is the Cardium Play, which runs parallel to the foothills of the Rocky Mountains. The Cardium Play lies directly below the Paskapoo Aquifer, which supplies the majority of fresh groundwater of drinking or domestic quality to Albertans who live in towns and rural areas in Alberta's foothills. There is a significant concern among Albertans that groundwater used for oil and shale gas development will affect water supplies (e.g. Paskapoo Aquifer) such that water needed for domestic, agricultural, and existing industrial and commercial uses will be depleted. A secondary concern is that shale gas development operations will contaminate fresh water aquifers due to introduction of contaminants through faulty surface operations or poorly sealed wellhead and borehole casings.

Hydraulic fracturing of shale formations for production of oil and gas has occurred in Alberta since the 1950s, with horizontal drilling and fracturing operations starting in the late 1980s. In 2008, approximately 70% of the wells licensed in Alberta were horizontal, and most of these used multi-stage horizontal hydraulic fracturing processes. In 2008, most of the wells were oil wells, and the previous regulator, the ERCB had not documented any cases of groundwater contamination as a direct result of oil or shale gas development. According to George (2012), by 2008 three major issues had already been identified that would affect future regulation of shale gas development and operations: water management and protection; fracturing fluids and processes; and increased commercial development and cumulative impacts.

George (2008) reported that the use of fresh water for hydraulic fracturing ranged between 60,000-80,000 cubic meters of freshwater was required to fracture stimulate one gas well. As far as supply issues, George (2012) also identified that during high peak use periods during fracturing, surface storage of water for fracturing was always required. He stated that "groundwater yields are low relative to peak use (well, pad, or "play" development). George identified that sustainable water supplies were a necessary component for planning commercial play-based development because commercial development is not short-term one-time water use. Full "play" development continues for decades over an extensive geographical area. It was also estimated that multiple sources of water, saline groundwater and fresh water were needed for most commercial scale development; however, total saline groundwater and fresh groundwater sources are not sufficiently known.

While a license is required to divert and use fresh water at the surface, or groundwater that is hydraulically connected to fresh surface water, there is no requirement under Alberta's *Water Act* for licensing "saline"[1] groundwater for shale gas development. Until recently, commercial shale gas development operations were regularly issued temporary water diversion and use licenses for fresh water, as hydraulic fracturing apparently worked best using fresh water.

Recently, the Alberta Energy Regulator issued a Directive, requiring that applicants for fresh water diversion and use licenses explain that there is no saline or other supply of water before they issue a temporary water diversion and use license.

Freshwater supplies that are currently used in shale gas development come from many sources: fresh groundwater, treated water from municipal water treatment facilities, water from wetlands and storm drainage collection and treatment ponds. As yet, it was not possible to find examples in Alberta of shale gas development using treated wastewater in the literature, such as from municipal wastewater treatment facilities. There is a gap in current knowledge around the feasibility of constructing pipelines for moving vast quantities of freshwater from municipal treatment facilities and river systems to provide sufficient quantities for play-scale commercial operations.

5.2.2 Water use rates in northeast British Columbia

From a Canadian perspective, the information related to the water use in hydraulic fracturing activities reported in the literature has been obtained mainly from two shale plays Montney Basin and Horn River Basin, located in northeast British Columbia. Dunk (2010) and Burke et al. (2011) reported that at shale gas production sites at Montney Basin, a fracture stage needed between 200 m^3 and 4,600 m^3 of water representing 800 m^3 to 13,000 m^3 of water per well. Moreover, the water consumption values observed at Horn River Basin increased considerably according to Horn River Producers Group (2011) as they stated that a fracture stage in this play required 2,500 m^3 to 5,000 m^3 of water; leading to a 10,000 m^3 to 70,000 m^3 rate of water consumption per well.

There is an important difference between the water consumption rates obtained in the two shale plays evaluated (i.e., the upper limits of water use per well had a 1:5 ratio). There are several factors that may have an effect on water use rates in shale gas developments, including: site geology, depth of target formation, mix and constituents of the hydraulic fracturing fluid, number of fractures per well, horizontal length of the wells to be fractured, and water returns. The difference in water use rates found in these two plays reveal the need of further research on the assessment of water needs in northeast British Columbia. Further studies may confirm whether the water use rates found at Montney Basin and Horn River basin can be applicable to other areas in the region or in the country. Complementary and supportive information on water use in Canadian shale gas developments will add relevant knowledge that may clarify whether important changes in water estimates in this region are common.

Johnson and Johnson (2012) reported that the application of different fracturing methods in shale plays in northeast British Columbia also led to considerable differences in water use rates. Their research

[1] According to the US Geological Survey (USGS, 2015), *saline water* is defined as water that contains significant amounts of dissolved solids and can be classified as: slightly saline water (1,000 ppm to 3,000 ppm), moderately saline water (3,000 to 10,000 ppm) and highly saline water (10,000 ppm to 35,000 ppm).

evaluated three different forms of hydraulic fracturing fluids: (i) energized, (ii) energized slickwater and (iii) slickwater. The “energyzed” stimulation category consisted of using CO_2, N_2 or CO_2-N_2 as the main fracturing fluid whereas the “energized slickwater” option was composed of a mixture of these three components with water. Finally, only water was used in the “slickwater” option. The investigators found that the slickwater treatment consumed the highest rate of water use, up to 5 times more water was needed than the rates observed for the “energized” option. On average, slickwater and energized treatments used 2,100 m3 and 155 m3 per fracture (CO_2) respectively. The hybrid option, a mixture between water and energized-compounds, showed a value of 800 m3 according to the author’s findings. The difference of water use rates found among these three treatment possibilities emphasizes the need of further research on alternative fluids to fresh or saline waters.

5.2.3 Water use in the United States

Two of the largest shale plays in North America are Marcellus (New York and Pennsylvania) and Barnett shales (Texas). The water sources in the Marcellus region are predominantly surface waters whereas groundwater is the main water source for shale gas activities in Texas. Estimated water requirements (drilling and fracturing) for some shale gas developments in the United States include 10 million liters (Barnett Shale) and 14.68 million liters (Marcellus Shale) per well. Additionally, Mitchell et al. (2013) reported that 39 million liters of water per day were used in the Marcellus shale between June 2008 and the end of 2012. Other fresh water requirement estimate for the Marcellus region states that 32 millions of liters per day may be needed at the expected peak activity (Gaudlip et al., 2008).

The Marcellus case is also a good example of how regional conditions define the magnitude of potential water effects. The expected water volume required for shale gas production in the Marcellus is relatively small in relation to available water sources. Furthermore, the water demand in a region changes according to the specific water needs in that specific region. Even though the Marcellus region has good water resources, operators are recommended to make withdrawals from multiple sources to avoid negatively impacting a single water source.

5.3 EMERGING TECHNOLOGIES FOR WATER RE-USE AND RECYCLING

A full scale water supply and water management system is required for play-based commercial shale gas development. Technology exists for water re-use and recycling in the shale gas development industry; however, as was pointed out by George, (2012) flowback from fracturing operations is highly saline, depending on the shale formation being fractured. To reuse flowback, dilution with large quantities of fresh water may be required[2]. As well, the reuse of flowback water requires surface storage facilities that in themselves increase the risks of runoff and contamination of adjacent surface water supplies during extreme weather events. Another need associated with flowback recycling and reuse is the generation of deep well disposal sites, industrial flowback treatment facilities, and pipeline transport of flowback water to municipal wastewater treatment facilities.

[2] This practice is changing rapidly as new fracturing chemicals are developed which allows more saline water to be used.

Treatment of saline water for use in shale gas development is already common. Industrial saline water treatment facilities could be developed on a play-based scale so that a pool of operators would contribute to treating sufficient water supplies for commercial operations.

A further consideration is whether water is always the best medium for fracturing shale formations. Researchers are currently exploring use of other media. In relation to Alberta's shift to cumulative effects management and play-based regulation of shale gas development, George (2012) highlights the importance of applying the following considerations:

- A play-based water management and cumulative effects planning approach is fundamental to improved outcomes for future large-scale hydraulic fracturing operations.
- An escalating scale of development and increased water use will be matched with escalating regulatory requirements.
- Industry must lead, and collaborate with other stakeholders, on water management plans and infrastructure to minimize development footprints and ecosystem/community impacts.
- GOA agencies (AESRD, DoE, AER) are collaborating to ensure that hydraulic fracturing proceeds in a safe, orderly and environmentally sustainable manner.
- Watershed Planning and Advisory Councils will play an important role in integrating plans from industry with watershed, basin and regional plans (water management plan review, advice, collaboration, synergy groups, advice to AESRD).

In southern Alberta, the implications of low water availability may include higher costs to producers, seasonal limitations or avoiding some areas altogether. Finding sustainable water supplies will continue to be problematic. As shale gas development opens up areas that were previously not developed, communities and other industries will spring up alongside. This will lead to more and more competition for limited supplies of fresh water necessary for all uses.

5.3.1 Current practices of water reuse and recycling

CAPP released recommended operating practice on water sourcing, measurement and reuse. The intent of these practices is to minimize the negative effects on water systems and watersheds. CAPP advises that the practice of recycling water for reuse should be carried out when possible; however, research found no data on recycling rates or volumes of reused water in shale gas developments in western Canada where shale gas production is currently taken place.

The British Columbia Oil and Gas Commission (2013) reported that hydraulic fracturing activities represented the largest petroleum-related use of water in the province and that 31 companies used more than 5.3 million m^3 of water to fracture 433 wells between 2012 and 2013. Table 5.1 presents the different sources of water used in hydraulic fracturing operations reported in B.C. for 2012/13. These values indicate that 15% of the total water use in these activities in 2012 and 2013 was obtained from flowback sources and 10.6% was obtained from private acquisition/produced waters.

Table 5.1 Sources for water acquisition for hydraulic fracturing purposes in British Columbia in 2012-2013.

Water source	%
Section 8*	48.8
Water License	13.5
Water Source Wells-fresh	7
Water Source Well-Saline	0.8
Flowback (estimate)	15
Municipal Waste	4.3
Private Acquisition/Produced Water	10.6

* Section 8 of Water Act allows permits for short-term water use (2 years maximum period)

Source: BCOGC, 2013.

As shale gas developments in Canada start growing, the lack of detailed information related to current and future recycling and water reuse rates may represent a potential gap that may affect the overall evaluation of this form to reduce use of fresh water. Furthermore, future shale gas operators could use existing data when developing their water management plans and when evaluating water needs before applying for water permits to the corresponding authorities.

Shale plays in Texas and Pennsylvania indicate that there is a trend in recycling water and reuse it (DOBb, 2014) where more companies are now developing and implementing more water management plans.

5.3.2 Use of other fluids as an alternative for reducing fresh water consumption

One of the most controversial topics when talking about hydraulic fracturing is the large quantities of water to support the production of shale gas. The potential of a future replacement of water with different alternatives will not only support reducing negative effects on water resources but could also improve social opinion on this controversial issue.

Some alternatives to water use have been tried in hydraulic fracturing operations; for example, Johnson & Johnson (2012) reported that CO_2 and N_2 have been used fracture treatment methods in northeast British Columbia. These researchers observed an important decrease in water use when CO_2 and N_2 were used in comparison to water-based methods. Unfortunately, there are still considerable technical challenges and lack of infrastructure that create barriers to these methods being applied more widely. The supercritical state of CO_2, a state where CO_2 behaves as a fluid that is neither a liquid nor a solid at high pressure conditions, may be used as a proppant carrier for the rock-fracturing process. Moreover, there is a possibility that the high pressure conditions of supercritical form of CO_2 may increase the rates of shale gas production because the higher pressure conditions. One example of the trend observed in this topic of research was reported by the news agency Reuters (2014) last year; the note stated that the company General Electric is researching how CO_2 could be used as a new industry standard for hydraulic fracturing, however, the note also claims that is unlikely that this activity will be implemented in the short term.

Saline water obtained from deep aquifers or residual waters from shale gas development operations may serve as a potential source of water. Paktinat et al. (2011) reported experimental and case studies of the performance of friction reducers in high salinity waters obtained from produced waters and deep groundwater. Their work documented that the evaluated friction reducers showed performance levels similar to those observed when using fresh waters. Further research of this kind may support the optimization of slickwater fracturing treatments based on high salt concentration waters (e.g. produced waters and/or deep aquifers).

There is a need for complementary research to evaluate alternative fluids that may substitute water in hydraulic fracturing operations (e.g. CO_2 and N_2). Additionally, this research also needs to evaluate potential sources of these alternate fluids that are relatively close to shale gas fields.

5.4 Regional differences in water availability and its implications

Overall, the water used by the oil and gas industry is relatively small in comparison to other uses. In 2009, the petroleum industry was responsible for the withdrawal of 223 million m^3 (0.59%) of the 38 billion m^3 of water that was withdrawn from Canadian surface and ground water sources (Environment Canada, 2014). Although Canada has relatively large sources of fresh water, there are some regions in the country that are considered to be under water stress due to significant withdrawals in response to water needs. Water impacts will be defined by water availability and water needs in a given specific region (e.g. most of the water use in some regions in Alberta is for irrigation purposes). The relationship of hydraulic fracturing operations with this issue was described by Daily Oil Bulletin (DOBa, 2014) in a news note, the energy magazine expressed that water shortages observed in USA could also be observed in some regions in Canada and that regulatory and technology challenges may be expected in the coming years. On the other hand, water supply will also depend on the specific characteristics of the region of interest.

A document released by the World Resources Institute (WRI, 2014) presents global shale gas plays in relation to water stress regions (Figure 5.4.1). Accordingly to WRI, approximately 80% of the shale plays in Canada are located in regions considered as “low” or “low to medium” water stress zones.

Figure 5.1 shows that there are significant regional differences in surface water availability in Alberta. As an example of how water demand-availability may change in Canada, we can highlight that an important part of the Colorado Group play (Cardium play), province of Alberta, is located in an area with a high water demand and scarce water resources, mainly due to semi-arid conditions and existing water use for agriculture. In southern Alberta, the South Saskatchewan River system is already fully allocated, and there is a moratorium on licensing from surface water supplies from all of its tributaries.

In other examples, the Cordova Embayment play (northeast British Columbia) is located in an area where fresh water levels are influenced highly on season variability (e.g. low levels in rivers) whereas the Utica play (Quebec) is situated in a very high populated region.

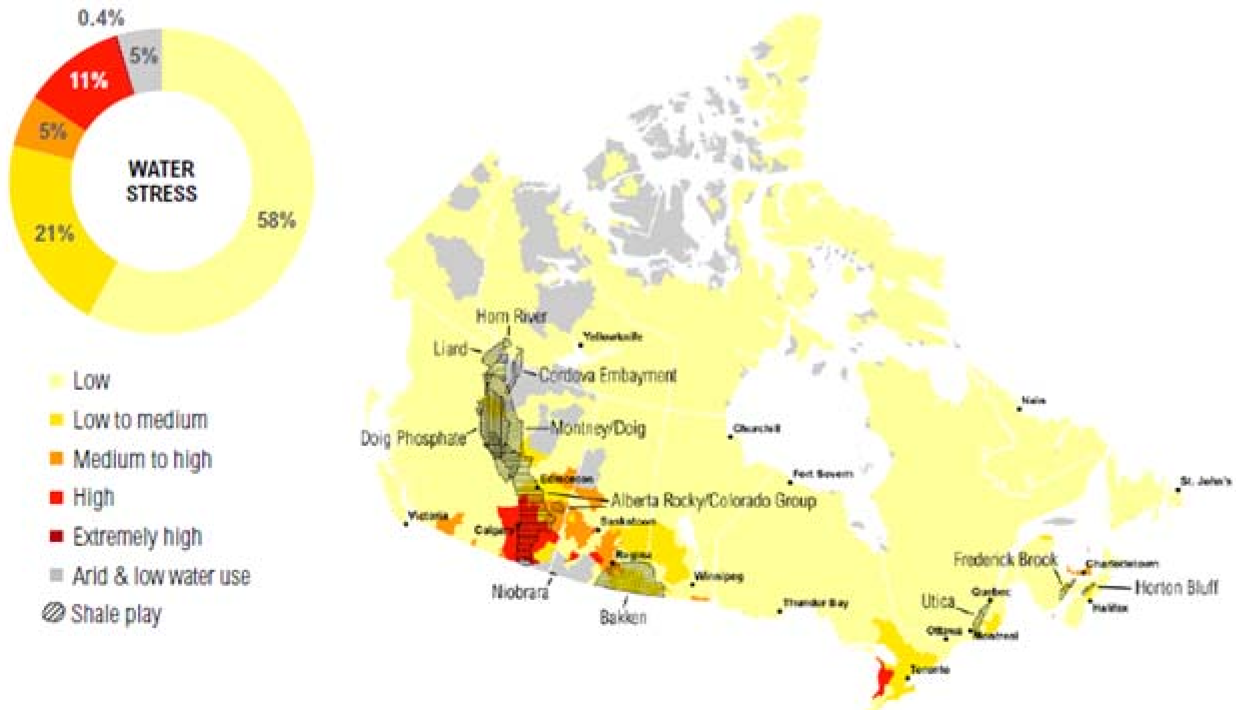

Figure 5.1 **Canadian shale plays and water stress categories (WRI, 2014).**

Water supply for shale gas development must be evaluated individually according to the specific conditions of the site and region and the potential water needs. Examples of these evaluations are the NorthEast Water Tool (NEWT) and the NorthWest Water Tool (NWWT)[3] in British Columbia used to provide guidance on water availability across northern BC, these tools offer real-time information to support decision-makers and inform the local public. Similar water availability evaluations would be convenient at places where shale gas may be produced in areas with high water demand and low presence of water resources in other Canadian regions (e.g. Cardium Play in Alberta).

If play-based shale gas development proceeds in Canada in the near future, more research is needed to achieve a comprehensive understanding of water availability on a play-based scale for all licensed users and at different times of year. Plays do not follow watersheds or surface water features; for example, in Alberta, all the shale gas plays currently under rapid development run northwest-southeast, not west-east like most of the large river systems. In play-based regulatory systems, the supply of fresh water may open up debates about inter- basin transfers, surface reservoirs for storage, and the need to construct pipelines to move large amounts of water from one river basin to another to provide sufficient water for play-based commercial scale fracturing operations.

Other research of hydrological systems is required to determine how limited supplies of water be allocated or apportioned at low flow periods to all licensed users including shale gas operators. Will water withdrawals be licensed from all water sources, or will some streams, creeks, ponds and wetlands etc. be off-limits because the continual depletion of flow may affect the aquatic ecosystem?

[3] NEWT and NWWT were developed by the BC Oil and Gas Commission and the BC BC Ministry of Forest, Lands and Natural Resources Operations.

Where competition for water supply exists, the timing of large withdrawals needed for shale gas development becomes important. Seasonal variation of supply also needs consideration. To continue to develop shale gas at the current rate in the Cardium Play, research is necessary to understand and regulate for periods of low flows in the system.

5.5 GAPS AND APPROACHES FOR WATER SUPPLY

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

7. Water extraction and use

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. Evaluation of water supply for shale gas developments in Canada according to specific site and region conditions (including seasonal changes).
2. Generation of water availability maps according to Canadian shale plays with emphasis on high water stress categories (i.e. low availability and high demand of fresh water).
3. Evaluation of water recycling and reuse rates in Western Canada where shale gas production is currently operating.
4. Further research on potential use of water with high salt concentrations for shale gas production and identification of potential saline aquifer that may serve as water supply for shale gas developments in Canada.
5. Further research on potential use of alternative components (e.g. CO_2 and N_2) that may be used in the production of hydraulic fracturing fluids and evaluation of current use of low-water hydraulic fracturing fluids in Western Canada.
6. Research of hydrological systems is required to determine how limited supplies of water are allocated or apportioned at low flow periods to all licensed users including shale gas operators.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1. Quantitative Study: Evaluation of source water for hydraulic fracturing across Canada	Moderate	Moderate to High	High	Capacity in Canada: Work groups of 10-20 people for each province where shale gas production is possible.	High – depends on data that is available and costs of creating data sets.	1-2 yrs	The difficulty of this task depends on how much information is available and how reliable is. It is recommended that different institutions integrate groups of work teams (e.g. academic and research institutions, Federal and Provincial Governments agencies, oil producers and third party consultants)
2.Mapping of water availability according to Canadian shale plays	High	Moderate	High	Capacity in Canada – work group of 10 consultants	Moderate – depends on water licensing	6 months	Need to consider trade-offs between competing water users.
3. Quantitative study: Evaluation of water recycling and reuse rates in Canada	High	Low	High	Capacity in Canada – university	Low	6 months to 1 year	Depends on producer's willingness to share findings

				research project			
4. Quantitative study. Research on use of saline waters for shale gas production.	High	High	Moderate	Capacity in Canada – recommended that public and private (oil and gas) research institutions form work teams.	High If using consultant	1-2 years	Depends on current level of research already achieved and owner's willingness to share findings.
5. Research on use of non-water based fluids for shale gas production.	High	High	Low	Capacity in Canada - recommended that public and private (oil and gas) research institutions form work teams.	High if using consultant	1-2 years	
6. Quantitative study: Research of hydrological systems is required to determine how limited supplies of water be allocated or apportioned at low flow periods to all licensed users including shale gas operators.	Moderate	High	Low	Capacity in Alberta	High if consultant is used	2-3 years	Will water withdrawals be licensed from all water sources, or will some streams, creeks, ponds and wetlands etc. be off-limits because the continual depletion of flow may affect the aquatic ecosystem?

5.6 FURTHER COMMENTS ON GAPS AND APPROACHES FOR WATER SUPPLY

5.6.1 Knowledge Gap 1

“Evaluation of water supply for shale gas developments in Canada according to specific site and region conditions (including seasonal changes)”

An approach to address this gap is to undertake quantitative studies for the evaluation of water sources in places where shale gas development is or might be taking place. Such studies should be carried out in a regional basis and according to different Canadian shale plays. One good example of this sort of studies is the “*Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta Project*” currently being undertaken by Integrated Water Resources (IWR, 2013). The main objective of this study is to evaluate all potential water sources in a selected region in Alberta. Figure 5.2 shows the area of study delineated by a blue line and identified as “West central Alberta Project”. The project includes the assessment of surface waters, shallow aquifers and deep saline aquifers. The project also addresses the potential of the identified saline aquifers as deep disposal zones for residual waters (i.e. flowback and produced water). The findings obtained in this project will permit the establishment of collaborative regional water projects. Furthermore, the final product will gather valuable information available for decision-makers.

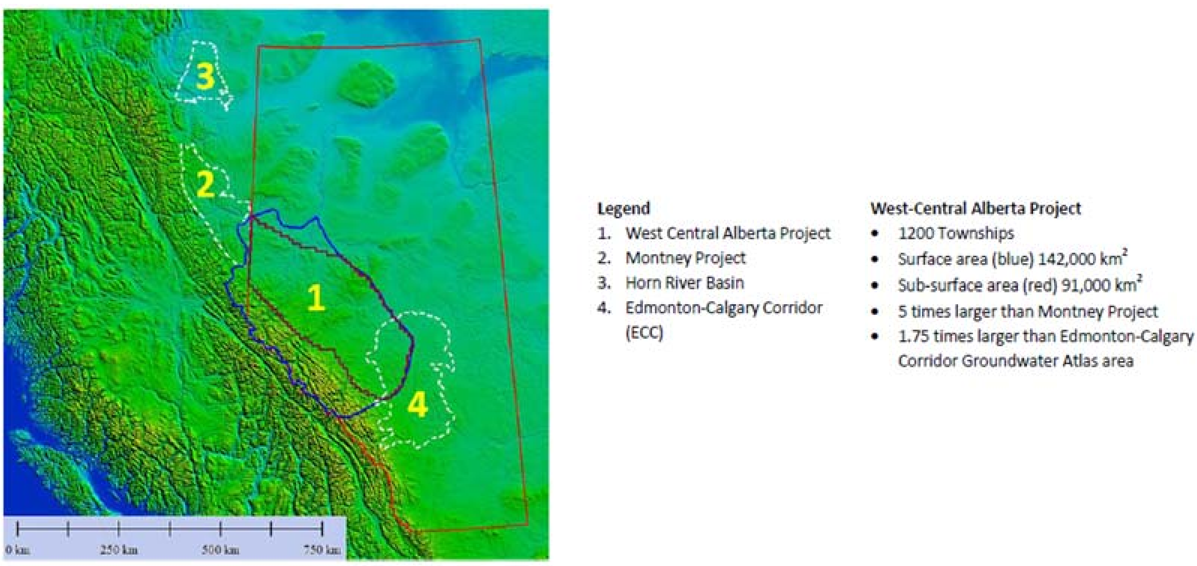

Figure 5.2 Study area for the “Integrated Assessment of Water Resources for Unconventional Oil and Gas Plays, West-Central Alberta Project” (IWR, 2013)

If we observe Figure 5.2, we can notice the extra value of running similar studies for the “Montney Project”, “Horn River Basin” and “Edmonton-Calgary corridor” areas. The West-Central Alberta Project is being carried out by three private consultant companies[4] as requested by the Petroleum Technology

[4] These companies joined efforts to create Integrated Water Resources.

Alliance of Canada (PTAC), at the same time, PTAC acts as the manager of the Alberta Upstream Petroleum Research Fund (AUPRF).

We suggest that a study of this nature could be carried out for each of the shale plays in Canada where federal or provincial authorities have identified potential for shale gas development in the coming years. We strongly believe that the outcome obtained from this research approach can serve as an important milestone in overtaking “Knowledge Gap 1” successfully. This research team believes that the timeframe for this kind of studies should be around a period of two years.

If all the water sources close to a shale play are identified and evaluated, operators and regulators will have a more solid background to make decisions and to support these decisions when looking for social license. Additionally, the information gathered in this sort of studies will permit evaluating how water use in shale gas developments may impact other important water consumers in the region (e.g. agriculture, food, manufacturing and other industries). We believe that human capacity in Canada for undertaking this sort of studies should not be a barrier for the implementation of this approach; however, the complexity of the task can be relevant due to the amount of information that needs to be generated and managed if previous studies are nonexistent, not available or not reliable.

5.6.2 Knowledge Gap 2

“*Generation of water availability maps according to Canadian shale plays with emphasis on high water stress categories (i.e. low availability and high demand of fresh water)*”

The generation of water availability maps, including Canadian shale plays and water demand in the regions close to shale plays, will complement the evaluation of water supply and addressed in Knowledge Gap 1. The information obtained from the evaluation of water sources studies (knowledge Gap 1) would collect the data necessary for the generation of water availability maps. These maps will also serve as an important tool when decision-makers when evaluating the amount of water available in a region at or close to a shale play and when evaluating regional water demand.

The information related to water use and availability in regions of shale plays in Canada may also be presented in a digital format. One example of this is the NorthEast Water Tool (NEWT) and the NorthWest Water Tool (NWWT) tools developed by the British Columbia Oil and Gas Commission and the Ministry of Forest, Lands and Natural Resource Operations. These systems are GIS-based hydrology decision-support tools aimed at guiding decision-makers on water availability across northern BC when granting water use approvals and licenses. The scientific complexity for this task is directly related to the outcome obtained from the studies carried out when developing knowledge Gap 1.

5.6.3 Knowledge Gap 3

“Evaluation of water recycling and reuse rates in Western Canada where shale gas production is currently operating”

We have identified that there is a significant gap related to current information about water recycling and reuse rates in locations where shale developments are taking place in western Canada. We believe that this gap could be initially addressed by undertaking a quantitative study approach. We suggest that this approach is focused on western Canada cases where unconventional production is already taking place. There are operators that are already applying water management methods as suggested by CAPP in their "Guiding Principles of Hydraulic Fracturing". It is important to evaluate how these water management practices, including water recycling and reuse, are reducing the use of fresh water in all the different regions where shale gas developments are located.

One of the main objectives of a quantitative study related to this topic would be to identify water recycling and reuse rates. Producers are familiar with the application of water management practices and they can tell whether these practices are being effective or not. Producers could provide additional and relevant information such as how much water is being recycled and reused in each site, how much fresh water is being avoided after implementing these practices and what are the main barriers identified when applying the water management methods.

5.6.4 Knowledge Gap 4

"*Further research on potential use of water with high salt concentrations for shale gas production and identification of potential saline aquifer that may serve as water supply for shale gas developments in Canada*"

Another important gap that is also linked to water management practices aimed at reducing fresh water use is the identification of saline aquifers that may serve as water source and the current rates of this activity in western Canada. As in the previous case (Knowledge Gap 3), we propose that a quantitative study approach can be used to address this lack of knowledge. We also consider that the study should also be focused on western Canada as there are companies that are already using saline aquifers as an important water source for shale gas developments. To our knowledge, there is not much information available in the literature concerning the current rates of use of saline aquifers as water sources. Nevertheless, the BCOGC (2013) already included saline groundwater as a source for water acquisition for hydraulic fracturing purposes as noted in Table 5.1.

One of the principal aims for this quantitative study case is to identify the current rates of saline groundwater used for hydraulic operations in western Canada. In addition, the study will also assist in identifying the principal barriers that could prevent this activity to be applied more widely. This information may serve in the near future as an important basis when considering implementing the use of deep saline groundwater as a technique for the production of shale gas and oil while reducing fresh water consumption. Again, the level of cooperation from oil and gas companies willing to share their experience will dictate the success of this quantitative study.

We consider that the level of scientific complexity for this activity is high given the nature of necessary studies to corroborate the availability of saline aquifers as a water source and as an injection point for residual waters. As deep saline groundwater is used in western Canada only in specific locations and according to specific conditions; the information observed in those locations will be very relevant when addressing this information gap. Another point to keep in mind is that there are studies that evaluate deep groundwater sources in western Canada that are still being carried out or are currently inconclusive (e.g. IWR, 2013). A more inclusive evaluation of the use of saline aquifers for shale gas developments needs to be complemented by studies similar to the IWR study.

5.6.5 Knowledge Gap 5

"Further research on potential use of alternative components (e.g. CO_2 and N_2) that may be used in the production of hydraulic fracturing fluids and evaluation of current use of low-water hydraulic fracturing fluids in Western Canada"

The use of non-water fluids for fracturing operations is still not very well developed and on-going research is currently taking place. We believe that further research is still necessary to explore the effectiveness of different fracturing fluids when used for the production of unconventional oil and gas. The continuous investigation of alternatives to fresh water can lead us to reduce significantly the use of fresh water sources, for this reason, it is important that the Canadian energy sector evaluates other fracturing fluids such as CO_2, N_2, propane and other components that might appear as research develops. Johnson and Johnson (2012) reported that there are companies in northeastern BC that are already using CO_2 and N_2 in their treatments for shale gas production, complementary research will provide further details on the effectiveness of these methods and the availability of alternative fluids[5].

We consider that the scientific complexity for this approach is high due to the complex variables involved in this task (e.g. time consuming, high costs, laboratory research, field research, availability of fluids close to existing or potential shale gas developments). We identify that one of the risks involved when working on this knowledge gap is the imminent higher costs of these alternatives, i.e. higher costs than obtaining water from available surface water sources. This fact can influence producers to be reluctant to invest in this topic. For this reason, this research should be focused initially in regions where water supply is scarce, water demand is high and sources for other fracturing fluids are not difficult to find. We believe that the timeframe for this sort of investigation can vary from 1 to 2 years.

As the case addressed in Knowledge Gap 4, the implementation of the use of non-water alternatives for shale gas and oil production will depend on specific conditions and regional characteristics. For this reason, we recognize that the level of implementation of this method is low as it will be significantly site specific.

[5] For example, Alberta is internationally known for supporting projects on Carbon Capture and Storage (CCS) hence industrial CO_2 sources are already identified within the province. These emission points may be considered as CO_2 sources for the production of unconventional oil and gas.

5.6.6 Knowledge Gap 6

"*Research of hydrological systems is required to determine how limited supplies of water are allocated or apportioned at low flow periods to all licensed users including shale gas operators*"

One of the main concerns regarding places with low water availability is the abrupt fluctuations that can be present in low flow periods in regions where water is scarce. We recommend further research on hydrological systems that can support decision-makers when allocating water licenses in the periods of low flow. First, it is necessary to identify current and potential shale gas operations located in regions where these characteristics occur. Hydrological studies, including low flow seasons, will provide relevant information on the amount of water that is available in the evaluated system and will support regulators when granting water licenses in a sustainable way.

One of the complications that can appear when undertaking this research is the reliability that can exist in the results. Weather conditions may not be necessarily similar from year to year making more difficult to obtain parameters that will behave steadily. We do not know whether hydrological studies have been carried out in the regions of interests and whether they are available or reliable. It is worth mentioning that this sort of research will need to use approximations and assumptions that will need to be fully understood and supported as they may add bias to the findings. We consider an initial timeframe of 1 to 2 years; however, constant hydrological monitoring in the future will help building a more reliable data set.

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6 RISK OF SURFACE WATER CONTAMINATION

6.1 INTRODUCTION

Hydraulic fracturing and horizontal drilling are the principal methods in the production of shale gas and other 'tight' petroleum resources. The development of shale resources has had positive impacts such as increasing the availability of natural gas and providing jobs. However, the potential environmental impacts such as the risk to surface waters should also be considered.

There are many potential ways that surface water resources may be contaminated both directly and indirectly by hydraulic fracturing activities, these include:

- Contamination of surface water features due to the removal of water,
- Contamination from fractures / fluids rising to the surface,
- Contamination from leaks from the well during construction,
- Contamination from leaks from the well during use ,
- Contamination from leaks from the well post decommission,
- Contamination from process water transport and storage,
- Contamination from discharges from treatment plants,
- Contamination during transport/construction,
- Contamination from aerial deposition.

All of these potential risks will be discussed in this chapter; Section 2 presents a literature review on the risks to surface water from hydraulic fracturing, Section 3 lists the major knowledge gaps in understanding deleterious effects to water quality, and Section 4 discusses a number of approaches which may be used to fill information gaps.

6.2 LITERATURE REVIEW

The use of hydraulic fracturing, or fracking, has raised important environmental concerns among the public, regulators, producers and academic sectors. Special emphasis has been put on impact on ground waters and some researchers have stated that fracking may cause contamination of these water sources. Unfortunately, the potential environmental impacts of hydraulic fracturing on surface waters have not received an equal attention and thus more research is needed to investigate how shale gas development activities affect surface water quality.

Vengosh et al. (2014) considered three principal forms of impact on surface waters: (i) surface leaks and spills of flowback and produced water, (ii) disposal of untreated wastewater (e.g. direct or illegal disposals), and (iii) inadequate treatment and discharge of wastewater (e.g. municipal wastewater treatment plants are not designed to treat wastewaters with high salt concentrations or presence of radioactive material or traces of heavy metals). According to Vengosh et al. (2014), among the principal ways that surface water quality may be directly altered by hydraulic fracturing activities are:

- Inappropriate wastewater management practices affecting water quality:
  - Chemical constituents of fracking fluids, flowback, produced waters,
  - Discharge of liquid wastes to surface waters after inappropriate treatment ,
  - Inadequate response to accidental spills and leaks of fracking fluids, flowback and produced waters,
  - Insufficient number of deep disposal wells,
  - Presence of illegal disposals on surface waters.
- Large generation of sediments and improper practices for erosion control:
  - Runoff originated from roads and drilling (Total Suspended Solids),
  - Nutrification from landscape activities,
  - High runoff potential in shale gas developments.
- Undesired alterations of stream flow:
  - Excessive load of water extraction rates,
  - Impact of drought season on water quality.

In addition to these direct impacts on surface water, several indirect impacts may also be experienced, as noted in the introduction.

6.2.1 Well Construction & Use

The development of fracking operations involves: construction of drilling wells, pipelines and roads, forest clearing, quarrying of gravel, construction of access roads in the case of rural areas and increased truck traffic. These activities may lead to increased erosion and sedimentation and increased risk to aquatic ecosystems from chemical wastes, spills or runoff. Activities may affect basic ecological factors such as water quality e.g. changes to water temperature may negatively affect fish habitats (Weltman-Fahs & Taylor 2013) and water quantity.

These operations may increase total suspended solids (TSS) in local aquatic environments and facilitate mobility thereof through precipitation-accelerated sediment transport due to enhanced flow rates during runoff events that can transport more and larger sediments. The accumulation of some metals and higher molecular weight aromatic and saturated hydrocarbons in sediments has been correlated with produced water discharge near shallow estuarine and marine waters possibly harming biota (Lee & Neff 2011). An assessment of hydraulic fracturing activities in central part of Arkansas reported that the deterioration of surface water quality near operation sites were from erosion, illegal disposal and spills (Burton et al. 2014).

Runoff from hydraulic fracturing processes may alter the chemical nature of sediments and rate of deposition, transport and re-suspension. Surface water quality may be affected when chemicals from fracking sites are leached. The ability of a chemical to be leached varies and could depend on parameters such as water solubility, hydrolysis, adsorption, volatility, and stability in the soils. Soils can regulate the transport of contaminant to surface water and underground aquifers. The key soil properties that impact contaminant fate and transport include: texture, permeability and organic matter content. Substances with high affinity for soil will not be readily transported to water source. But, soils with high permeability and low content of organic matter have high tendency to permit the easy transport of pollutants.

Evaporation, leakage of ponds, or storm events can lead to pollution of water or soil. When stormwater runoff comes into contact with contaminated environments, it can transport chemicals from waste containment facilities into aquatic environments, whether surface or subsurface. Runoff from industrial activities, construction and agriculture can alter hydrological settings by making soil more permeable thereby enhancing the movement of runoffs that may be conveying fracking wastes. The rapid movement of runoffs increase soil erosion and consequently reduces water quality and threaten wetland plants.

Hydraulic fracturing operations can pose a risk to aquatic environments. For example, during well construction, land clearing can expose the soil to erosion. Spills, leaks, overflow or any related accident can occur from fracturing. Spills or leaks can release wastewater fluids to surface water. Shale gas exploration continues to be linked to water problems. In Bradford County, PA, a drilling wastewater spill released between 16,000 and 24,000 L of fracking flowback fluid into wetlands and tributary of Webier Creek, which drains into the Tioga River, a cold water fishery. The spill was due to pump failure and sand collection in a valve at Talisman Energy well in Armenia Township (PA DEP, 2010c). In 2009, a damaged joint in a transmission line released about 29,800 L of diluted fracking fluids into unnamed tributary of Brush Run, in Hopewell Township, PA. About a-hundred and sixty eight fish and other aquatic organisms died from the spill. Brush Run is a high-quality warm water fishery receiving special protections for its rich biodiversity (PA DEP, 2010a).

Fracking fluids and wastes are deleterious to aquatic life. As an example, Kathon® biocide active ingredients 5-chloro-2-methyl-2H-isothiazol-3-one and 2-methyl-2H-isothiazol-3-one has been linked to aquatic toxicity (Papoulias & Velasco 2013). The level of toxicity and impact on the ecosystem by chemical substances from fracking to aquatic environment could be influenced by the chemical make-up and relative toxic effect of individual chemical component and its product of degradation, rate of discharge and its fate in the environment. In 2007, deaths of fish species *Lepomis cyanellus* (Green Sunfish) and aquatic invertebrates C*hrosomus cumberlandensis* (Blackside dace) and *Semotilus atromaculatus* (Creek club) in Acorn Fork, KY were associated with fracking chemicals from flowback waters (Riedl et al. 2013).

Some of the chemical substances used in fracking fluids may be transformed in aquatic environments. Transformation processes in the environment may be physical, chemical or biological in nature, including processes such as sorption, biodegradation and metabolization (Swiss Centre for Applied Ecotoxicology 2013). The degradation products may be toxic to aquatic organisms. For instance, octylphenol, the degradation product of the surfactant octylphenol ethoxylates, has been linked to impaired reproduction and endocrine disruption in fish.

6.2.2 Process water recovery, transport and storage

Wastewater produced from fracking activities contains chemical pollutants both from fracking fluids and from natural sources underground. It returns to the surface in large amounts as flowback immediately after fracking and as produced water over a longer period while a well is producing oil or gas.

Produced water is the largest waste product associated with oil and gas exploration. It includes water from the well, water injected into the reservoir, and any chemicals added during the production and treatment processes. The treatment and disposal of produced water is a growing problem for operators of oil and gas industry. Depending on the availability of wastewater treatment facilities, the nature of the waste fluids, and the regulatory environment, wastewater may be treated on-site for re-use in subsequent fracking operations. It may be returned to surface water after appropriate treatment in either a publicly owned treatment facility or in a centralized wastewater treatment plant. Alternatively, it may be disposed of subsurface (depending on regulatory requirements) or potentially applied to land surfaces.

Post-treatment, solid, sludge and liquid wastes remain for discharge and disposal. Solids and sludges are commonly disposed of through municipal landfills while liquid wastes, often characterized by high salinity, are disposed of either by injection into deep underground wells or evaporation ponds. Depending on the final effluent quality post-treatment, treated water can be discharged into surface water, recycled, or taken to wastewater treatment facilities, which may employ additional techniques such as coagulation and precipitation to remove dissolved solids. The challenge with most municipal treatment plants is that they are not designed to adequately manage radioactive materials or exceptionally high total dissolved solids (TDS) concentrations in waste fluids. Following treatment, fluids containing radioactive materials and salts are disposed of into surface water, some of which are sources of drinking water.

Wastewater from hydraulic fracturing is composed of a mixture of inorganic and organic compounds. The physical and chemical properties of wastewaters from fracking are defined heavily by the geology of the formation, geographical location of the shale play, life span of the reservoir, the type of hydrocarbons generated, fracking conditions and the chemical composition of the fracking fluid (Lee & Neff 2011). Organic compounds most commonly present in fracking wastewater include aliphatic and aromatic hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene, xylene (BTEX), and phenols. The major inorganic constituents are TDS, cations such as sodium, calcium, magnesium, strontium, barium, potassium, and iron, and anions such as carbonate, bicarbonate, chloride, bromide, sulfate, nitrate, and neutral species such as silicate, borate. In addition to these, organic compounds used in fracking are also present including biocides (e.g. tetrakis hydroxymethyl-phosphonium sulphate), cross linkers (e.g. triethanolamine zirconate), demulsifiers (e.g. isopropanol), and foaming agents (e.g. 2-butoxyethanol).

Ferrar and colleagues (2011) analyzed effluent contaminants from three facilities discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania. Their results indicated elevated levels in the effluents of benzene, barium, strontium, bromides, chlorides and TDS above acceptable limits. Other toxic substances from fracking were detected at lower levels including toluene, ethylbenzene, xylene and 2-butoxyethanol (2-BE).

Orem and coworkers (Orem et al. 2011) characterized produced water from hydraulic fractured coalbed methane (CBM) in Wyoming. Organic compounds were detected at concentrations between 0.0001 and 0.018 mg/L. The organic compounds detected included PAHs, heterocyclic compounds, other aromatics (e.g. substituted biphenyls and alkyl benzenes), phenols and substituted phenols, long chain fatty acids, higher alkanes up to C25, alkyl benzenes, nonylphenols and substituted biphenyls. A similar study investigated flowback and produced waters from hydraulic fractured shales with several organic compounds identified including naphthalene and alkyl naphthalenes, phenanthrene and alkyl phenanthrenes, anthracene and alkyl anthracenes, acenaphthene and alkyl acenapthenes, pyrene, chrysene, alkyl chrysenes, and benzothiazole. The concentrations of these compounds were between 0.0001 and 0.025 mg/L. Chemical additives in fracking fluids such as biocide, hexahydro-1,3,5-trimethyl-1,3,5-triazine-2-thione, and breaker, ethylene glycol, were also present in the flowback water (Orem et al. 2014). Ozgun et al. (2013) characterized wastewaters from oil and gas field in Trakya, Turkey based on geological and seasonal variations. They observed that the characteristics of wastewater changed with time, place, and geology of the formation. They detected organic and inorganic compounds such as BTEX, phenols, cyanide, chloride, bromide, nitrate, phosphate, sodium, calcium, and metals. In their 1992 study, Filo and colleagues analyzed onshore produced water from oil and gas to note a significant presence of volatile organic compounds, including benzene (< 10,000 μg/L), toluene (< 10,000 μg/L), ethylbenzene (< 2,000 μg/L), and semi-volatile organics - C10 to C30 straight chain hydrocarbons (2000-20,000 μg/L).

Wastewater discharged from fracking may contain high levels of TDS, which can be used to indicate the concentration of inorganic salts found in solution in water. High salinity is mainly from ions such as Ca^{2+}, Mg^{2+}, NO^{3-}, CO_3^{2-}, SO_4^{2-}, Na^+, K^+ and Cl^- (Nero et al. 2006; Ferrar et al. 2011). Salts exist in dissolved phase in fracking fluids. The source of high salinity in flowback fluids is principally from dissolved salts and minerals in the shale formation. This high salt content in flowback water depends on the geology of the shale formation. In the northeastern part of United States, increased and unstable chloride concentrations is a threat to fresh water by increasing the TDS in fresh waters, degrading habitat for aquatic organisms, and impacting source of drinking water that support human population in the region (Kaushal et al. 2005). Chloride may also mobilize heavy metals, phosphates, and other chemicals present in sediment (Nelson et al. 2005). Runoff waters that carry sorbed sediments can promote or cause eutrophication of aquatic systems due to the presence of nutrients, such as nitrogen, phosphorus, and organic acids, which enhance microbial and phytoplankton growth in surface water (Lee & Neff 2011).

Shale gas exploration continues to be linked to water quality challenges. Between 2008 and 2009, significant increases in levels of TDS were reported in the Monongahela River, PA, which is the source of drinking water for about 350,000 residents. Since fracking flowback contains large amounts of TDS, and drilling fluids constitutes one-fifth of the wastewater being treated by some of the local wastewater treatment facilities, the PA Department of Environmental Protection (PA DEP) mandated these facilities place restrictions on the proportional intake of drilling wastewater (PA DEP, 2008). Accumulation and persistence of TDS poses a risk to water quality and plants, aquatic organisms, wildlife, and humans who depend upon it. Haluszczak and coworkers (2013), characterized flowback fluids from the Marcellus shale deposit, PA, noting increasing concentrations of Cl^-, Na, Ca, CO_3, Br, SO_4 over time after initial fracking. The reported maximum concentrations of these ions were 151, 441, 148, 0.095, 1.19, and 0.089 g/L, respectively (Haluszczak et al. 2013). A 2009 report estimated 6,804-11,340 metric tons of salt could be produced daily using 76 million L of shale gas extraction water (SGEW) in the Marcellus shale (McElreath 2011).

In addition to salts and organic compounds, fracking also creates potential routes for heavy metal contamination of the environment. Metals such as lead, arsenic, chromium, uranium, strontium, magnesium, manganese and barium have been detected in flowback water (Paleontological Research Institution 2011). Heavy metals may enter the environment through leaks, spills and the legal discharge to land or water. Drill cuttings in hydraulic fracturing may also increase PAHs and metal availability in fracking fluids constituting a significant threat to surface water quality. These compounds are harmful to many forms of aquatic life and may slow development, disrupt endocrine activities, serve as carcinogens, or even cause fatalities. Metals are not only very toxic, but often bioaccumulate in the food chain depending on speciation. The pH and matrix of chemical additives in fracking fluids can alter the geochemistry of a shale formation, which may in turn affect the presence, toxicity, and bioavailability of metals in waste fluids.

Because of speciation and dissociation, the pH value determines the dominant species in the environment. Low pH can result in the release of toxic compounds, such as metals, into water. Acid additives in fracking fluids and naturally occurring acids in shale formations can contribute to the lowering of the pH of flowback fluids. Shale formations often contain a significant amount of minerals such as pyrites (FeS_2), calcites ($CaCO_3$) and dolomites ($(CaMg)(CO_3)_2$). When pyrites react with oxygen, acid is formed, which could promote the release of metals into the aquatic environment (Sullivan & Yelton 1988). However, the acid generated from pyrite oxidation can be neutralized by calcites and dolomites (Equations 1-3) (Chermak & Schreiber 2014). In the reaction, pyrite, oxygen and water combine to produce acid. The acidity generated is neutralized by the dissolved calcite.

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \quad (1)$$

$$4CaCO_3 + 4H^+ \rightarrow 4Ca^{2+} + 4HCO_3^- \quad (2)$$

$$2FeS_2 + 4CaCO_3 + 17/2O_2 + 5H_2O \rightarrow 2Fe(OH)_3 + 4SO_4^{2-} + 4Ca^{2+} + 4HCO_3^- \quad (3)$$

6.3 INFORMATION GAPS

6.3.1 Direct risks to surface water

6.3.1.1 Contamination from fractures / fluids rising to the surface

During well fracturing, fluids containing a mixture of chemicals are injected under high pressure into shale to release natural gas. Fracturing fluid generally includes a mix of acids, biocides, friction-reducing agents, and other chemicals to facilitate gas retrieval (Vidic et al. 2013). A proportion of this fluid remains underground after its application, the amount of which varies substantially among geologic formations, but can be as high as 90% (Entrekin et al. 2011).

Due to the depth of most hydraulically fractured shale-gas formations (900–2800 m), the contamination of groundwater and surface water by subsurface migration of fracturing fluid is considered unlikely (Engelder 2014; Vidic et al. 2013). Nevertheless, potential geologic pathways for chemical migration have been identified (Warner et al. 2012). Evidence from conventional hydrocarbon fields shows that hydraulic fracturing due to the injection of fluids can, in very exceptional circumstances, lead to fracture propagation to the surface or near-surface, if it takes place at relatively shallow depths (Davies et al. 2014).

Results of modeling scenarios suggest that there is a large degree of uncertainty surrounding the potential transport times of fracking fluid to the surface. A review by Meyers (2012) suggested that advective transport could allow contamination of aquifers in less than 10 years. However, this paper was strongly opposed by several sources (Saiers & Barth 2012; Cohen et al. 2013) and contamination on these timescales is therefore considered very unlikely. One thing that was highlighted from these discussions was the need for the implementation of approaches capable of yielding more reliable estimates of fluid migration and solute transport in subsurface environments surrounding shale-gas reservoirs.

A complementary approach to modeling potential fluid migration is to measure the heights of stimulated and natural hydraulic fractures caused by high fluid pressure, using images created with three-dimensional seismic data (Davis et al. 2012) or Tomographic Fracture Imaging using Seismic Emission Tomography (Geiser et al. 2012). Both approaches identified natural hydraulic fracture systems of >1000 m extent in sedimentary rocks, whereas the tallest upward propagating stimulated hydraulic fractures, generated by fracking operations for gas and oil exploitation were 588 m (Geiser et al. 2012). However, it is believed that confining stresses would cause fractures to close-up when pumping stops and the pressure in the fluid drops (Davis et al. 2013).

6.3.1.2 Contamination from leaks from the well during construction

Rozell & Reaven (2012) reported the use of probability bounds analysis to assess the likelihood of water contamination from natural gas extraction in the Marcellus Shale. Probability bounds analysis is well suited when data are sparse and parameters highly uncertain. The study model identified five pathways of water contamination: transportation spills, well casing leaks, leaks through fractured rock, drilling site discharge, and wastewater disposal.

The Groundwater Protection Council (2011) report evaluates agency groundwater investigation findings in two states, Ohio and Texas. During the 25 year study period (1983-2007), Ohio documented 185 groundwater contamination incidents caused by historic or regulated oilfield activities. Of those, 144 groundwater contamination incidents were caused by regulated activities, and 41 incidents resulted from orphaned well leakage. Seventy-six of the incidents caused by regulated activities (52.7 %) occurred during the first five years of the study (1983-1987). When viewed in five year increments, the number of incidents caused by regulated activities declined significantly (90.1 %) during the study period. Seventy-eight % (113) of all documented regulated activity incidents were caused by drilling or production phase activities. Improper construction or maintenance of reserve pits was the primary source of groundwater contamination, which accounted for 43.8 % of all regulated activity incidents (63) in Ohio. During a 16 year study period (1993-2008), Texas documented 211 groundwater contamination incidents. More than 35 % of these incidents (75) resulted from waste management and disposal activities including 57 legacy incidents caused by produced water disposal pits that were banned in 1969 and closed no later than 1984. Releases that occurred during production phase activities including storage tank or flow line leaks resulted in 26.5 % of all regulated activity incidents (56) in Texas.

6.3.1.3 Contamination from leaks from the well during use

Freshwater contamination may result from well blowouts, casing failures, illegal discharge, and spills. Uncontrolled fluid and gas releases can occur when the pressures encountered during drilling and fracturing exceed the ability of the cement or drilling mud used to contain fluids and gases. These occurrences are often termed blow-outs and the Oil and Gas commission state that these has proven difficult to predict as existing planes of weakness in target formations may result in fracture lengths that exceed initial design expectations (Campbell and Horne 2012).

Davies et al. (2014) assessed 25 worldwide datasets on well barrier and integrity failure in the published literature and online. The datasets varied considerably in terms of the number of wells examined, their age and their designs. Therefore the percentage of wells that have had some form of well barrier or integrity failure in the datasets was highly variable (1.9 - 75 %).

Ingraffea and colleagues (2014) reported that casing and cement impairment in oil and gas wells can lead to methane migration into the atmosphere and/or into underground sources of drinking water. An analysis of 75,505 compliance reports for 41,381 conventional and unconventional oil and gas wells in PA drilled from January 1, 2000-December 31, 2012, was performed with the objective of determining complete and accurate statistics of casing and cement impairment. Statewide data showed a six fold higher incidence of cement and/or casing issues for shale gas wells relative to conventional wells (Ingraffea et al. 2014). The Cox proportional hazards model was used to estimate risk of impairment based on existing data (Ingraffea et al. 2014). The model identified both temporal and geographic differences in risk. For post-2009 drilled wells, risk of a cement/casing impairment is 1.57-fold (95% confidence interval (CI) (1.45, 1.67); $P < 0.0001$) higher in an unconventional gas well relative to a conventional well drilled within the same time period. Temporal differences between well types were also observed and may reflect more thorough inspections and greater emphasis on finding well leaks, more detailed note taking in the available inspection reports, or real changes in rates of structural integrity loss due to rushed development or other unknown factors. Unconventional gas wells in northeastern (NE) PA are at a 2.7-fold higher risk relative to the conventional wells in the same area. The predicted cumulative risk for all wells (unconventional and conventional) in the NE region is 8.5-fold (95% CI (7.16, 10.18); $P < 0.0001$) greater than that of wells drilled in the rest of the state (Ingraffea et al. 2014).

6.3.1.4 Contamination from pipelines and transport

There is the potential for contamination of surface waters during the construction of well sites and from transport associated with both well construction and transport of recovered product. During well construction temporary roads are often constructed to allow vehicles to access the site. These roads can dislodge soil and create large volumes of sediment which have been shown to enter surface waters from stormwater runoff (Michaels et al. 2010). This can form a pathway for contaminants to enter the water and also affect physiochemical parameters in the water such as turbidity which can be detrimental to biota (Kivat 2013). Additional sources of contamination can arise as some states in the U.S. have allowed operators to spread fracking fluids to suppress dust and for de-icing purposes to maintain service roads (Vengosh et al. 2014), however this is no longer permitted for Marcellus waste water (Lutz, 2013). Vegetation on roads and along pipelines are also often controlled through the use of herbicides, which can pose risks to surface waters from leaching and runoff (Kivat, 2013).

The indirect risks to surface waters through the construction of roads are well understood. There is best practice guidance available for provinces/states to limit the risks of sediment transport to surface water features; the same is true for the application of herbicides. However, there is a knowledge gap determining how often these practices are adhered to and what the end result to surface water quality is. Data for the Marcellus shale region in Pennsylvania indicated that between 2008 – 2012, 6% of approximately 1000 complaints related to water being impacted by sediments, turbidity, and/or drill cuttings (Brantley et al. 2014). There is also uncertainty surrounding the impacts to surface waters of using fracking fluids on roads for de-icing and dust suppression. It is likely that the impacts will vary significantly on a site by site basis and throughout the year.

6.3.1.5 Contamination of Drinking Water Supplies by Well Communications

According to Margaret Munro (2014a) rare thermal springs adjacent to active hydraulic fracturing sites in northeastern BC and the southern Yukon are bringing water up to the surface from depths of up to five kilometres. The spring waters spill onto the landscape along with heat, gas and chemicals. This “thermogenic gas” is what is brought to the surface through hydraulic fracturing operations, but is rising naturally to the surface through these springs because “natural cracks and faults extend deep underground” and provide conduits for gas migration. There is growing speculation that with increased fracturing activities in Canada and the U.S. hydraulic fracturing fluids will find their way to the surface through naturally occurring fractures, as well as the "man-made holes, cracks and fractures" deliberately created to release thermogenic gas from shale. However, industry and government spokespersons say that the fluids used in fracturing will stay within the boreholes and fractures deep below the surface.

Munro (2014a) wrote a three part series covering issues related to fracturing operations and the possibility that drinking water supplies will become contaminated with fracturing fluids through cracks, fissures and faults underground. She says that 30% of Canadians rely on groundwater for drinking water. The first article Munro, (2014b) addressed the possibility that "leaking wells" from old abandoned or "orphan wells" are enabling natural gas, especially methane to reach surface water supplies in Ste. Francoise, QC, and near the Calgary airport, AB. Munro reported that "as many as 10 per cent of oil and gas wells leak in British Columbia" and that this is because of "cracked, poorly formed, and decaying plugs and seals."

Munro (2014b) suggests that "tens of thousands of wells are leaking" which poses "a threat to the environment and public safety." Monitoring and repairing leaking wells is of major concern throughout the country, and is recognized in studies conducted for Alberta Energy Regulator (AER) and the federal government. Provincial regulators, like AER require oil and gas operators to regularly test for leaks in the casings of operating wells, and "after old leaking wells started turning up in new subdivisions and developments in AB, the Alberta Energy Regulator issued a directive two years ago that requires energy companies to inspect the hundreds of old wells near existing or planned developments, and reassess them at least once every 10 years." Canadian standards, industry practices, and monitoring and enforcement need to be developed to ensure proper sealing of wellbores and repairs of leaks.

In the second article, Munro (2014c) described the problem of old leaky gas wells when encroached upon by urban development, which happened in Calmar, Alberta. Imperial Oil purchased homes where methane was discovered by and the company spent considerable effort and money over five years unsuccessfully trying to plug the leaking well. Stronger legislation is required to make sure homes and buildings are not developed near old abandoned wellbores in the first place, and industry should be required by regulation to monitor all abandoned wells, especially those within a kilometre of where people live and work on a regular basis to test for emergent leaks. In Alberta, the setback for residential development from old wells is 5 m.

The third article by Munro (2014d) addressed the problem of wellbore "communication," where the fracturing operations in one wellbore are affected by activity in wellbores close by or in the same formation. According to BC and Alberta regulators, new rules are being established to avoid wellbore interactions, called "frack hits." Munro further reported that the "communications" between wells can undermine production and pose a serious safety and environmental hazard by sending fracking fluids into and up other wells" considerable distances away. Decommissioned wells create a "seepage pathway for hydraulic fracturing fluids".

6.3.1.6 Contamination from leaks from the well post decommission

The terms 'abandoned', 'idle' and 'orphaned' are used to describe the state of a well that did not locate economic hydrocarbons or a well at the end of its production life cycle (Davies et al.2014). An abandoned well is a well that is not in use because it has ceased to produce or because it was a dry hole. An idle well refers to a well for which production has been suspended for a minimum time period (usually 5 years), and an orphan is a well, pipeline, facility or site that does not having any legally responsible or financially able party to deal with its abandonment and reclamation. It is good practice for wells no longer in use to be sealed and cut and the land reclaimed. However, for various reasons this is not always performed.

Dusseault et al. (2014) state that the most common long term well integrity issue after abandonment is slow gas seepage around the external casing. The number of wells that display high rate leaks is low, and the overall average leakage rates also appear to be low. Dusseault et al. (2014) identified that rigorous statistics remain elusive although, it seems that the number of significant problems encountered in AB and BC, relatively mature regulatory environments, is not large. When leakage is identified corrective measures can be employed to rectify problems. The risks of leaks occurring will vary in different locations due to various local geological factors including tectonic stresses, rock density, subsurface strata, and the quality of the recovered product. However, these risks can be minimized by following good regulatory practices (guidelines and enforcement), quality control, and monitoring to ensure that the site is geologically understood, that wells are properly installed, and that well abandonment is done according to best practice guidelines Dusseault et al. (2014).

Despite the positive outlook from Dusseault et al. (2014), there is a large uncertainty around the potential risks from decommissioned and orphaned wells as these are not regularly inspected and less visible pollutants such as methane leaks are unlikely to be reported (Davies et al. 2014). Therefore it is difficult to establish the extent of the problem and risks to surface waters and it is possible that well integrity failure may be more widespread than the presently limited data show (Davies et al. 2014).

6.3.1.7 Contamination from process water recovery, transport and storage

After hydraulic fracturing operations have been terminated, a mix of fluids start flowing out of the well. This mix, known as flowback fluids, consists of natural water and hydrocarbons (e.g. natural gas, oil or condensates) that were contained in the formation. As noted previously, flowback fluids may also carry residuals of hydraulic fracturing fluid that had been injected previously in the well and new compounds that may be generated if chemicals (e.g. additives used in hydraulic fracturing fluids) react with natural components in the formation (e.g. salts, metals, radionuclides). Produced water is natural formation water that flows out of the well with hydrocarbons once the well starts producing. Flowback fluids and produced waters generated are considered as hydraulic fracturing liquid wastes.

Different forms of chemicals and natural occurring compounds may be present in these liquid wastes. Flowback fluids and produced waters may represent an important source of environmental risk to surface waters if discharged, intentionally or unintentionally, directly into these water bodies. This is mainly because of the presence of potential contaminants that may be found in these wastes. Produced and flowback waters are normally high in salt concentrations, this condition may affect the quality of surface waters if in contact with these wastewaters due to potential concentrations of salts (Cl, Br), alkaline earth elements (e.g. Ba, Sr), metalloids (e.g. Se, As) and radionuclides (e.g. Ra).

Intentional discharges of liquid wastes, generated from hydraulic fracturing operations, into surface waters are prohibited. However, accidental spills may occur and represent potential environmental risks that need to be considered when developing water management plans.

The magnitude of the environmental impacts on surface waters that were exposed to these liquid wastes may depend on the amount of water released, the duration of the exposition, and the nature and concentrations of the contaminants. Flowback waters recovery rates are normally between 25 and 50% (US EPA 2011). Additionally, it has been reported that flowback water volumes may be in the range of 2,175 and 7,200 m^3 per well (Health Canada 2012).

It is anticipated that shale formations and fracturing fluid composition will vary from site to site; this might result in considerable differences concerning the nature and concentrations of compounds present in flowback waters.

It is important to keep in mind the high potential of direct correlation between the number of spills and leaks and the density of shale gas developments as found by Vengosh et al. (2014). Spills of large volumes of wastewater are a familiar concern in the conventional upstream oil and gas industry and these spills of produced water generally far exceed spills of oil by volume (Campbell & Horne 2012). In AB, oil and gas companies spilled 23.3 million L of produced water compared to 6.8 million L of oil in 2009 (AER 2010).

Estimates as to how much flowback water exists vary widely depending on the shale formation.

For example:

- BC Oil and Gas Commission states that roughly 50 to 90% of fracturing fluids are recovered (BC Oil and Gas Commission 2011),
- US EPA states that 15 to 80% of fracturing fluids are recovered (US EPA 2010) ,
- The Post-Carbon Institute (in Hughes 2011) states that between 30 and 70 % of the injected water is brought back to the surface in addition to any formation water present.

Containment ponds frequently serve as temporary wastewater storage at drilling sites, and these vary substantially in structural integrity (Souther et al. 2014). Inadequately designed ponds can overflow during heavy rain, may leak as liners degrade, and are potential sources of air pollution as chemicals volatilize (Entrekin et al. 2011). While the frequency of containment pond failure has not been quantified in detail, Souther et al. (2014) detected 27 violations in a survey of 279 permitted wells in PA citing “pit and tanks not constructed with sufficient capacity to contain pollutional substances”. This indicates that some containment facilities will fail to prevent escape of contaminants from wastewater storage.

6.3.1.8 Illegal dumping of waste

Vengosh and colleagues (2014) noted that, despite a PA ban in 2011 on the disposal of wastewater from fracking activities, evidence of discharge was discovered. In their study, it was isotopic analyses were used to identify elevated Br levels in the Clarion River due to Marcellus wastewater disposal. These data, collected post-ban, suggest possible illegal discharge and disposal and/or inadequate wastewater treatment. It may also be that implementation of the disposal ban was incomplete across the industry in terms of transfer of brine wastes to appropriate treatment facilities (Vengosh et al. 2014).

Further information about illegal dumping of toxic fracking wastes were noted in Dawson Creek, BC in summer 2014 (Linnitt 2014). Although little scientific data is currently available, the incident made national news.

6.3.2 Indirect risks to surface water

6.3.2.1 Contamination of surface water features where water has been removed

Water abstraction is the permanent or temporary removal of water from rivers, canals, lakes, reservoirs or aquifers for human water management. The restoration and preservation of native stream biota requires the rehabilitation of natural flow regimes, yet it is predicted that by 2025, 40% of the world's population will be facing water poverty. The challenge is how we balance these needs. Water quantity and quality are essential for maintenance of healthy rivers and fisheries. Over-abstraction can be highly destructive to fish and invertebrates.

According to the Salmon & Trout Association (2014) in the United Kingdom, "Over-abstraction of river systems can cause:

- Hydrological and hydraulic changes; modifying in-stream habitat and altering the width, depths, velocity patterns and shear stresses within the system,
- Increase the invasion of non-native species,
- Shifts and reductions in invertebrate assemblages,
- Water quality changes; reducing the rivers ability to dilute pollutants, such as phosphorus,
- Increase sediment deposition, thus reducing available fish spawning habitat,
- Increase water temperature, and thus decrease dissolved oxygen in the water, which can seriously impact salmonids,
- Disruption to migratory fish and invertebrate passages,
- Reduce the growth of aquatic flora such as Ranunculus,
- Reduced connectivity with floodplains and riparian margins."

Furthermore, they note that the impacts of hydrological variability influence distribution and proliferation of aquatic biota, including fish, invertebrates, and plants (Salmon & Trout Association 2014; Brooks et al. 2010).

Moulton & Cuthbert (2000) noted that the lower flows lead to warmer temperatures, increasing turbidity due to re-suspension of sediments, and potentially release and reintroduction of previously sunk contaminants from sediments back into the water column.

6.3.2.2 Contamination from aerial deposition

Contamination of surface water from aerial deposition is a topic that falls under the wider issue of air contamination from fracking operations. This includes releases of greenhouse gases such as carbon dioxide and methane, but also toxic contaminants that are more commonly discussed from an acute and chronic health perspective including particulate matter, volatile organic compounds and sulphur dioxide. These can arise from point sources (from a stack or pipe), mobile sources (from trucks, trains, drill rigs), fugitive sources (from equipment leaks, or external forces such as wind, or natural or man-made faults or fractures in the earth's surface) and area sources (Field et al. 2014). Some residents living close to drill sites have complained of eye irritation, headache, sore throat, and difficulty breathing (Earthworks OGAP 2012). However, there is generally a lack of monitoring data to accurately substantiate many of these claims. The topic remains a highly emotive and widely discussed issue, especially from a human health perspective. There is currently a large data gap involving the quantification of the release of airborne contaminants, and an even larger gap quantifying the rates of wet and dry deposition to surface waters.

6.3.2.3 Contamination from discharges from treatment plants

The treatment of processed waters is covered in detail by Goss et al. (2015), therefore this section only briefly summarises the issue of contamination of surface waters from discharges from treatment plants.

Wastewater generated from fracking includes both flowback and produced water. These fluids are enriched with contaminants originating from the shale formation, such as brines, hydrocarbons, and naturally occurring radioactive materials as well as the chemicals used in the original fracking fluid. In the Marcellus Shale wastewater was predominantly treated through municipal wastewater treatment plants. However, in Pennsylvania this has resulted in; an increase in concentrations of bromides and TDS in surface waters (Ferrar et al. 2013; Michaels 2010), the presence of elevated concentrations of toxic disinfection by-products (dibromochloronitromethane and chloroform) in disinfected effluent (Hladik et al. 2013), benzene concentrations in discharge waters above the EPA human health criteria (Ferrar et al. 2013). Furthermore, when large volumes of flowback and process water are sent to municipal waste water treatment plants they have been shown to disrupt the microbial degradation process by increasing the proportion of halotolerant and anaerobic bacteria species (Allegheny Valley Joint Sanitary Authority 2009; Vengosh et al. 2014). This can result in waste water treatment plants being less effective for removing the contaminants they were originally designed to process.

Traditional wastewater treatment plants are not the most appropriate option for the treatment of waters containing very high concentrations of salts, the salinity of shale gas waste liquids may range between 5,000 and 200,000 mg/L concentrations (Warner et al. 2013). Among the components that may be found in these salts are: bromide, chloride, metals as barium and strontium, and naturally occurring radioactive materials (NORM). Many waste water treatment facilities may discharge their effluents to surface waters including rivers, creeks and ponds; increasing the risk of affecting the water quality of these water bodies as the result of high concentrations of untreated salts. Furthermore, these water sources may serve as a main supply to water plant facilities located nearby which provide drinking water for the community.

A published work by Ferrar et al. (2013) indicates that discharges from water treatment plants located in Pennsylvania presented concentrations of salts above recommended concentrations. The research reports that these water works received liquid wastes originated from shale gas developments at the Marcellus Shale; among the analytes that presented concentrations over recommendations were barium, strontium, bromide, chloride and total dissolved solids. The main conclusion in this investigation involves an increase in salt concentrations, observed in surface water monitoring wells, related to the use of waste water treatment plants in the area for the treatment of Marcellus liquid wastes. Figure 6.1 illustrates the conditions observed by Ferrar et al. (2013) in 2010, the figure clearly depicts a large number of water treatment facilities located along a considerable number of rivers in PA.

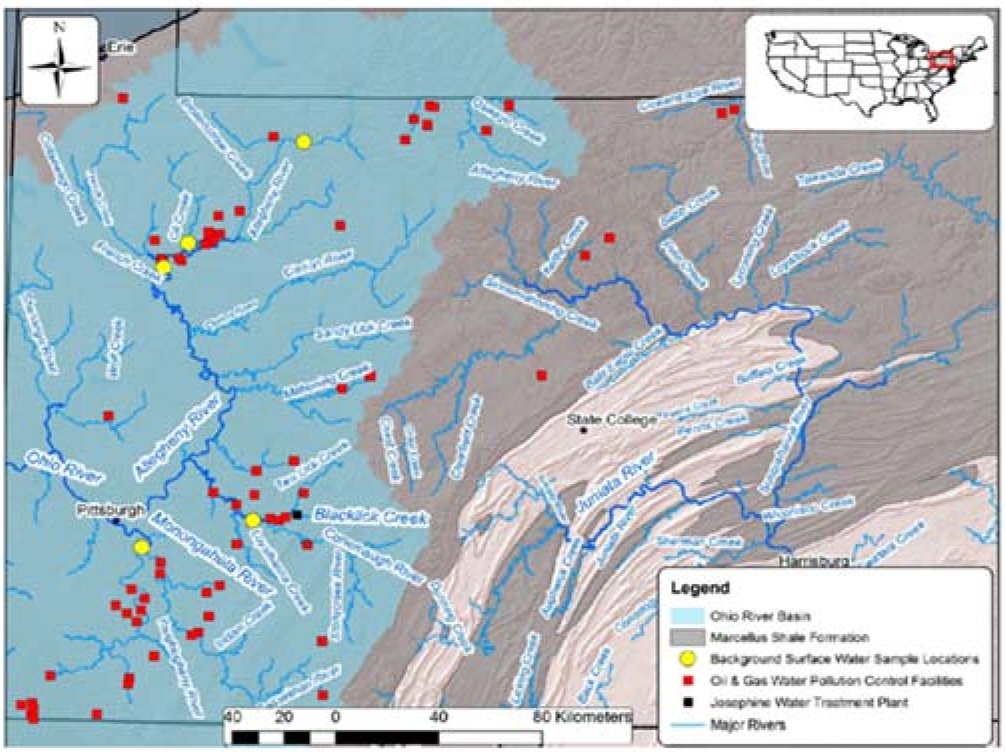

Figure 6.1. **Location of 74 water treatment facilities (red squares) that received produced and flowback in 2010 waters from shale gas developments, located in the Marcellus Shale and Ohio River Watershed. (source: Warner et al. 2013)**

The scenario described here could be repeated in Canadian watersheds if liquid wastes from shale gas developments are disposed to water treatment facilities involving an inadequate design for the treatment of high salt concentrations. Special attention must be paid to general aspects that may strengthen these environmental risks, among these factors are:

- Identification of current and potential shale gas developments in each specific watersheds in Canada,
- Identification of principal surface water bodies that may be potentially impacted by shale gas developments,
- Expected volumes of produced and flowback waters generated from shale gas developments,
- Expected salt concentrations generated from shale gas developments (surface water and sediments), including drought season,
- Location of waste water treatment plants that are or will be accepting liquid wastes from shale gas developments,
- Location of water treatment plants that serve as a potable water supply and use surface waters as their principal source situated near shale gas developments,
- Obtaining reference concentrations (baseline) for the expected contaminants before the start of shale gas development activities,
- Evaluation of whether existing number of deep disposal wells in an specific region are present or will be present in a sufficient amount according to current and expected shale gas developments.

There is a knowledge gap determining the volume of wastewater that is currently produced and how this number will change in the future. The volumes will likely increase as the rate of unconventional drilling increases, except where the practice of recycling increases or viable alternative fracturing methods are developed and adopted (Ferrar et al. 2013). There are attempts to reduce and restrict the amount of fracking wastewater that is sent to wastewater treatment plants, however the extent of this varies in different areas. It took a New York Times investigation to uncover the fact that waste water was being trucked to sewage plants that could not adequately treat it—a situation that regulators were apparently unaware of. In the end it took a year to have the appropriate regulations put in place to manage the waste water (Beaver 2014).

6.3.2.4 Biochemical alterations and potential bioaccumulation of chemicals used in fracking fluids

There is a large uncertainty surrounding the risks from biochemical alteration of chemicals in waste water generated from fracking. However, there have been several documented instances where risks do or could exist. One example is the formation of toxic trihalomethanes (THMs) associated with the presence of stray gas. The formation of THMs were previously recorded in untreated groundwater in the U.S., unrelated to shale gas activities, but associated with agricultural contamination of shallow aquifers (Carter et al. 2008; Carter et al. 2012). Numerous studies have demonstrated that the presence of halogens together with organic matter in source waters can trigger the formation of THMs, specifically in chlorinated drinking water (Vengosh et al. 2014). We are not aware of any studies linking process this to shale gas activity, however the literature indicates that it is a possibility.

Another problem that is specifically related to drinking water extraction is that for bromide concentrations above 0.1 mg/L, chlorination of water can result in the creation of carcinogenic brominated disinfectant byproducts (Bonacquisti 2006). This could therefore pose a risk if potable surface waters were to be contaminated by fracking wastewater. One instance of this nature was reported by Wilson and Van Briesen (2013) who monitored the Monongahela River (PA) and identified elevated bromide concentrations in drinking water that could be linked back to discharges from fossil fuel associated wastewaters.

Over time, metals, salts, and organic contaminants can build up in sediments in freshwater environments. Each respective compound has a fixed solubility and reactivity that varies as a function of pH, Eh, temperature, and the occurrence of other components in the water. As a result, the physicochemical conditions of surface waters and the distribution coefficients of each compound will determine how it interacts with particulate matter. Ultimately, these properties will determine the long-term environmental fate of such reactive contaminants; reactive constituents would be adsorbed onto soil, stream, or pond sediments and potentially pose long-term environmental and health risks (Vengosh et al. 2014). As well as contamination of sediments there is the potential for accumulation of these compounds in biota. Biomagnification of organic and inorganic contaminants along food chains in the freshwater environment may pose risks to top predators. This process is well understood for contaminants such as PCBs and mercury, which are regularly monitored in the freshwater environment by provincial-federal bodies such as Environment Canada and the Ministry of the Environment. However, less is known about the bioaccumulation and biomagnification of the contaminants associated with hydraulic fracking.

6.3.2.5 Contamination via groundwater under direct influence of surface water (GUDI)

Across the Canadian Prairies, in particular, the majority of near-surface to medium-depth ground water systems are directly linked and affected by surface water systems. The interactions can lead to contamination in either direction. The extent of the resulting effects depend on several factors including pumping rates, yields and volumes as well as natural discharge rates (where these exist), physical properties of the aquifer, and both natural and anthropogenic recharge rates. Another potentially important factor is the drilling method used for well formation. Geng et al. (2013) showed that compressed air from a drilling well is capable of creating a high pressure gradient in groundwater at hundreds of meters from the drill hole, even if the air leakage from the drilling well occurs in a confined aquifer, and even if the leakage duration is only 2 h.

Within deeper ground water supplies, threats to water quality include saltwater intrusion (land-based or marine systems), as well as direct contamination of fracking fluids into the geological formations and fracked deposits (Gleick 1996). Under natural conditions the boundary between the freshwater and saltwater tends to be relatively stable, but pumping can cause saltwater to migrate inland and upward, resulting in saltwater contamination of the water supply.

6.3.3 Political and regulatory challenges (see also Chapter 9)

Legislatively in Canada, the federal government plays a collaborative role in water governance with the provinces through provincial-federal agreements. Environment Canada (the Ministry of the Environment) has the lead role for issues related to surface water, while Natural Resources Canada (NRCan) takes the lead on groundwater issues. In addition to these two federal departments, three other ministries have responsibilities for water governance under various conditions and applications, including Agriculture and Agri-Food Canada (AAFC), Fisheries and Ocean Canada (DFO), and Health Canada.

First Nations and Métis roles with respect to water management are increasingly referenced since repatriation of the Constitution in 1982. At that time, a clause was added to recognize aboriginal treaty rights, including use or ownership of lands and waters. Although these rights are not currently well defined within Canadian legislation, future considerations and planning for hydraulic fracturing activities should include potential for not only "duty to consult", but also water management and governance challenges when working on treaty lands, traditional lands, and/or federal lands.

Provincially, ownership of water resources and the authority to legislate water management, allocation, and quality (including treatment requirements) is assigned by the Constitution Act of 1982. The provinces are owners of all groundwater and surface water resources (except those originating on or passing through federal and First Nations land). As with federal government, provinces tend to not have a single water ministry or inter-ministerial agency responsible for water. Rather, there are multiple and diverse ministries in each province, reflective of economic, social, geographic, and historic differences.

According to Centner and O'Connell (2014), the USA does not have federal legislation that directly addresses hydraulic fracturing (or shale gas production). Thus, they argue, baseline data are not collected and the presence of potential contaminants in water resources cannot be properly traced to specific activities or origin. Because there is no direct federal provision, some state governments have responded with regulations and codes designed specifically to address risks associated with fracking, but these are discontiguous and uncoordinated (Centner & O'Connell, 2014; Davis & Hoffer 2012).

In both Canada and the USA, there is significant hydraulic fracking activity and opportunity, including major extraction operations near and across the border in the Bakken Play (SK and ND, primarily), along Canada's east coast (NS & NB and south in the USA), and across the continental USA, in such states as CO, TX, and AR. Several academic papers point to the need for setting strict rules and regulations, policies and best practices. However, the challenge for any of these jurisdictions will include the complexities and uncertainties related to (1) interprovincial and international boundaries, (2) in-field deviations from written expectations, (3) trade secret industrial fracking and produced fluids, and (4) remediation liabilities if/where origin of contamination can be ascertained and reasonably prosecuted.

One particularly interesting approach to the politicking of fracking has been noted more recently in the USA as part of the debate over the construction and operation of the Keystone XL pipeline. There, the debate has centred on making a deliberate choice to promote independent energy production rather than imports, even from Canada's oil sands. From this, there has also been increasing debate over the potential combined impact of Keystone XL pipeline crossing areas of fracking and the potential geological instability that may result.

Further resources on the regulatory environment in Canada are related to the Nova Scotia Environmental Goals and Sustainable Prosperity Act 2007. In New Brunswick, the discussions around fracking have been fraught with both legal and public opinion challenges that include moratoria on operations (with similar stories and experiences in other jurisdictions, including the United Kingdom). To date, both SK and AB have experienced relative calm in terms of legal and public challenges, despite significant activities, including that in the Bakken Play, to fracking operations. One particular incident of opposition that engendered some support was a case involving the Kerr family in southern SK in which they expressed concerns about water quality, livestock health, and human health impacts due to both fracking and enhanced oil recovery areas near their property. The same concerns have also been echoed by residents in AB who have produced several short films under albertavoices.ca. In instances where problems occur there is a lot of anecdotal evidence to suggest that many affected residents have opted to sign a nondisclosure agreement and receive compensation. This can make it very difficult to establish the actual extent of any problems, and can increase resentment towards the oil and gas industry from opposition groups.

6.3.3.1 Disclosure of chemicals used in fracking fluid

The actual composition of fracking fluids can vary considerably. The fluid generally contains approximately 98% water with the remaining 2% (by volume) a mixture of sand and chemicals (Campbell & Horne 2012). The water used can vary from fresh water, saline water and recycled water. Water-based fluids may also be energized with nitrogen or carbon dioxide which results in much lower water volumes being required. It is important to recognize that non-water carrier fluids are also in use. These include hydrocarbon fluids such as diesel or oil and high-vapour pressure fluids (e.g. propane).

Democratic members of three U.S. House of Representatives committees recently published a list of 750 substances used in hydraulic fracturing of oil and gas wells in the U.S. between 2005 and 2009 based on information voluntarily provided by producers. Of these substances, 29 are known to be possible human carcinogens and/or regulated toxic chemicals (U.S House of Representatives Committee on Energy and Commerce 2011). A recent analysis of independent on-line data submitted by fracking operators to FracFocus.org showed that 34 % of the fracking operation used at least one carcinogenic substance (Manthos 2013).

As noted by Vengosh et al. (2014): "Few studies have analyzed the major chemical constituents in injected hydraulic fracturing fluids" (although considerable information is available on the Web site www.fracfocus.org). The chemicals used in hydraulic fracking fluids include; friction reducers to reduce the resistance to the movement of the fluid through the well casing, 'biocides' to prevent bacterial colonization and growth that can lead to formation of hydrogen sulphide, and scale inhibitors to prevent material build up on casings. Although the chemicals are a small proportion of fracking fluid component, the total volumes of the chemicals used can be large. Based on the available information, hydraulic fracturing fluids include water (either fresh water or reused hydraulic fracturing water), proppants (sand, metabasalt, or synthetic chemicals added to "prop" incipient fractures open), acids (e.g., hydrochloric acid), additives to adjust fracturing fluid viscosity (guar gum, borate compounds), viscosity reducers (ammonium persulfate), corrosion inhibitors (isopropanol, acetaldehyde), iron precipitation control (citric acid), biocides (glutaraldehyde), oxygen scavengers (ammonium bisulfite), scale inhibitors (e.g., acrylic and carboxylic polymers), and friction reducers (surfactants, ethylene glycol, polyacrylamide). Based on different hazardous components of hydraulic fracturing fluid additives used in wells from the Marcellus Shale, it was suggested that sodium hydroxide, 4,4-dimethyl,oxazolidine, and hydrochloric acid would be good indicators to monitor water contamination upon a leak or a spill of hydraulic fracturing fluids."

6.3.3.2 Contaminant monitoring, identification and analysis

Several federal, regional, state, and municipal government agencies monitor surface water quality. However, shrinking budgets in regulatory agencies, combined with the difficulty of keeping pace with the rapidly developing shale gas boom, have created challenges to creating and maintaining robust regulatory infrastructures for surface water monitoring (Jalbert et al. 2014). Firm conclusions from the risks of fracking to surface waters can be hampered by i) the lack of information about location and timing of incidents; ii) the tendency to not release water quality data related to specific incidents due to liability or confidentiality agreements; iii) the sparseness of sample and sensor data for the analytes of interest; iv) the presence of pre-existing water impairments that make it difficult to determine potential impacts from shale-gas activity; and v) the fact that sensors can malfunction or drift. Although the monitoring data available to assess contamination events are limited, in Pennsylvania the state manages an online database of violations. Overall, one fifth of gas wells drilled were given at least one non-administrative notice of violation (NOV) from the PA regulator (Brantley et al. 2014).

Prior to the construction of a drill site a pre-construction soils assessment investigation is conducted by a consultant. This report includes a checklist to identify any environmentally sensitive areas and recommends control measures to mitigate any potential risks. Chemical monitoring of soil is also required along with sampling from local water wells both pre and post drilling. However, the required monitoring parameters are based upon routine standard water tests for aesthetic quality and health concerns. The suite of chemicals analysed are not specific to the oil and gas operations and only contain contaminants such as; TDS, chloride, fluoride, hardness, nitrate and nitrite, sulfate, several metals, turbidity pH, conductivity, alkalinity and coliforms. Whilst chloride and fluoride can be used as good indicators of flowback water, there are still large gaps in the testing schedule with respect to contaminants that could originate from fracking activities. Contaminants not considered include; naturally occurring radioactive materials (NORMS), organic compounds that could be present in drill fluids such as friction reducers and biocides, along with hydrocarbons from recovered product and gases such as methane. Analysis for many of these additional compounds can be undertaken relatively cheaply by commercial laboratories. However, a full characterization of every potential chemical that could be present as a result of fracking would be expensive and time consuming.

The existing monitoring is only normally undertaken on the end receptor (e.g. a potable water well) at a defined period before and after drilling. A spilled contaminant will not immediately arrive at a potable drinking well and it may take many years to reach a receptor, therefore the current program is not protective for future users. In many other sectors that deal with water contamination (such as remediation of contaminated land and landfill construction), there is a requirement to install groundwater monitoring boreholes on the boundary of site and to monitor them regularly over a period of several years. This is an effective system as it is able to identify a potential problem before there is contamination of a sensitive water resource.

6.4 SUMMARY OF INFORMATION GAPS

Information gaps related to the impacts of fracking fluids, shale gas exploration and development, and operation and decommissioning phases of operation exist across the regulatory and disclosure (access to information), technological, and fluids characterization spectrum. As noted in section 6.3.3, challenges persist in fully elucidating and confirming these as the primary risks for surface water contamination due to general lack of information about the fluid characteristics, spill incidents – and the NDAs that may be enforced following such incidents, remediation plans and efforts, and location and timing of incidents that may impact surface water resources. Brantley et al (2014) support these perspectives in terms of imprecise conclusions and challenges associated with obtaining timely and comprehensive information from industry, governments, and/or land owners. In addition, they add challenges due to the complexity of the monitoring and analytical regimes that would be required both pre-development and in-operation. That is, there is a sparseness of collected and archived samples lack of background, baseline data, and insufficient monitoring equipment, access, and communication (Brantley et al 2014). The same co-authors go on to state that, "Although the monitoring data available to assess contamination events in PA are limited, the state manages an online database of violations. Overall, one fifth of gas wells drilled were given at least one non-administrative notice of violation (NOV) from the PA regulator."

The information gaps identified in this study have been summarised below. The gaps have been split into three main areas to include; direct risks to surface waters, indirect risks to surface waters and political and regulatory challenges. Within each of these areas we discuss a variety of different types of gaps such as; knowledge gaps, information sharing gaps, understanding and trust gaps, implementation gaps and institutional or framework gaps.

6.4.1 Direct risks

The direct risks to surface water from fracking are discussed in Section 6.3.1. The most pertinent risks identified were establishing the risks from fracking in the long term. This included identifying leaks from wells post decommission and also identifying the potential for fractures and fluids to rise to the surface. There are risks from spills, leaks and illegal dumping however the effects from these instances are more localised and can be tackled through better regulation and by following best practice guidance.

There is a significant knowledge gap associated with the potential for the vertical migration of fracking fluids to impact surface waters. Davis et al. (2013) state that after thousands of fracking operations, there are no proven examples of contamination of drinking water aquifers due to hydraulic fracturing. However, based on the timescales associated with migration of subsurface fluid, fracking is a very recent process and little is understood about the potential risks from vertical fluid migration over longer timescales. More research should be undertaken using the techniques discussed by Davis et al. (2012) and Geiser et al. (2012) to generate the data needed to model and estimate the potential travel times of fluids associated with fracking. Then it can be better established if there are significant risks to surface waters or if these risks will be mitigated by natural attenuation processes like adsorption, adsorption and biodegradation. There is also a large data gap associated with the risks from leaks from wells post decommission. Currently these wells are not regularly inspected and therefore less visible pollutants such as underground leaks are unlikely to be reported until it is too late and they have had a significant visual or olfactory impact on a surface water resource.

6.4.2 Indirect risks

The indirect risks to surface water from fracking are discussed in Section 6.3.2. The most pertinent risks identified were associated with waste water management. These included indirect risks from transport (including transport of water) and discharges from waste water treatment plants that receive water from the fracking industry. Another significant area of concern is the potential for the bioaccumulation of contaminants and their transformation into more toxic compounds. Nutrification is a wider issue that is well understood and is not just limited to fracking. The changes to the chemistry of surface waters where abstraction has occurred are likely to be dwarfed by physical and biological changes and aerial deposition is likely to be more of a localised concern with respect to human health. However, estimations of emission inventories of contaminants released from fracking would be useful to help establish the potential risks to the wider environment and to surface waters. Despite the large amount of research on emissions from a global warming perspective as there is little data on contamination. We have not discussed the relationship between fracking and climate change as it was deemed outside of the scope of this report, however we believe it is an important area for future research.

There is a significant knowledge gap associated with determining the volume of wastewater that is currently produced and how this number will change in the future. Many waste water treatment plants were not designed to deal with waste from fracking and so there is an uncertainty surrounding their effectiveness at removing contamination. Recent research has identified some of these risks which has led to changes in regulation in the Marcellus Shale regions however further research is required to generate more data which could be used to study the impacts on surface waters receiving effluent containing fracking waste water. This should include a study on the effectiveness of different types of treatment plants to remove different types of contaminants unique to fracking waste water (such as NORMS, metals and hydrocarbons), as well as the effects that fracking waste water can have on the normal operating efficiency. There is a large data gap and knowledge gap surrounding the risks in surface waters from the transport, accumulation and remobilisation of contaminants originating from fracking waste water. Both inorganic and organic contaminants originating from mine waste water and waste water treatment plant effluent have long been linked to elevated concentrations of contaminants in sensitive ecological receptors through bioaccumulation and biomagnification along food chains. The main contaminants of concern need to be identified and monitored to establish the risks from waste water generated by fracking.

There is a knowledge gap associated with alternative drilling techniques, for example fluids energized with nitrogen or carbon dioxide that use less water. The potential applicability and affordability of these types of alternatives, on a broad scale, is not well understood and currently their use is not widespread. Further research in this area could help reduce the potential impacts to surface waters.

6.4.3 Political and regulatory challenges

The political and regulatory challenges posing a risk to surface waters are discussed in Section 6.3.3. The main risks have developed as a result of the rapid emergence of fracking over the last two decades. This has been most prominent in the U.S. where many environmental groups point towards a lack of strong regulation including the exemption of the oil and gas industry from major pieces of environmental legislation such as; The Safe Drinking Water Act, The Clean Water Act, Comprehensive Environmental Response, Compensation, and Liability Act and The Toxic Release Inventory of EPCRA. Many regulatory agencies are ill-prepared for the pace of drilling, and the environmental impacts that accompanied the shale gas boom. Not only were regulations inadequate to protect the environment and public health from shale gas development, but state agencies tasked with overseeing drilling, production and waste disposal were and in many cases remain underfunded and understaffed (Sumi, 2013).

There are several key information gaps associated with political and regulatory challenges. These include understanding the uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under the existing legislation. There are also gaps associated with how the current framework relates to the First Nations and groups that may not covered by the current legislation.

6.5 POTENTIAL APPROACHES TO FILL INFORMATION GAPS

There are several different approaches that could be used to fill the information gaps identified in section 6.4. There is some overlap between the information gaps identified and so these have been grouped into five key issues of relevance:

- Understanding fractures and leaks from direct well use
- Chemical disclosure and characterization of chemicals of concern
- Efficiency and effectiveness of current legislation relevant to surface water
- Understanding indirect releases
- Understanding the effects on surface water features where water has been removed

These key issues and their associated priority knowledge gaps are presented below and in the summary tables at the end of this chapter. The following section discusses several research approaches that could be used to fill the knowledge gaps and includes advantages and disadvantages for each approach.

6.5.1 Understanding fractures and leaks from direct well use

There is currently a degree of uncertainty surrounding the possibility of fractures reaching the surface and contaminating surface water features. Although the literature suggests that fractures are unlikely to result in surface water contamination, further monitoring of different geological strata in different locations would help to confirm this and also help to establish a “safe drill zone” which could be used as a minimum permissible depth to target shale gas. Advantages of this approach are that there is great potential to address this knowledge gap as existing techniques including groundwater modeling and tomographic fracture imaging techniques have already been used to monitor fractures in several locations. With monitoring in further locations it would reduce the scientific complexity and uncertainty. As the techniques have already been tested this would assist undertaking tests in different locations. Disadvantages of this approach are that it would not provide information on leaks associated with the well itself, which are likely to be a greater potential source of spills. It is also worth noting that fractures pose a greater risk to ground water resources than surface waters and therefore initial efforts should be focused on the risks to ground water rather than surface waters.

A second approach would be to develop and improve existing standards for monitoring leaks during use. There is a large degree of uncertainty surrounding the rate of well barrier or integrity failure with rates ranging from 1.9 to 75% (Davies et al. 2014). Development of a more thorough inspection and monitoring procedure would help to identify any leaks before they could impact surface waters. There is great potential to address this gap as the scientific knowledge already exists. However, one disadvantage is that there is currently a lack of legislation to enforce a more stringent monitoring program. This would likely need to be addressed to produce successful results.

A third approach would be to develop and improve existing standards for monitoring leaks from abandoned wells. It is good practice for these wells to be sealed and cut and the land reclaimed, however for various reasons this is not always performed. An advantage is that initial investigations could be undertaken relatively cheaply by performing a desk study of historic maps and well records to identify the extent of this problem and fill a large portion of this knowledge gap. A disadvantage with this approach is that once the wells have been identified monitoring the status of every single abandoned well would be an expensive and time consuming process. There are also likely to be many wells that will not be identified and so there is likely to be a degree of uncertainty remaining.

A fourth approach would be to continue to improve existing well design and materials. Leaks from wells are a main source of potential contamination and so the development of better wells would reduce the likelihood for contamination. Much of this research is already being conducted and funded by the oil and gas industry, however complimentary research could also be undertaken.

6.5.2 Chemical disclosure and characterization of chemicals of concern

The actual composition of fracking fluids can vary considerably. Over the past several years great progress has been made in understanding this knowledge gap, largely through the development of the ‘fracfocus.org’ website. However, there is still a long way to go as not all U.S. states are required to disclose information using FracFocus and Canada is not included in the website. One approach to fill this knowledge gap would be to introduce a similar initiative to the FracFocus.org website in Canada. This would require oil and gas operators to disclose details of their hydraulic fracturing fluids and for this information to be available to the general public. There is a good potential to address this gap, the project has been largely successful in the U.S.. The advantage of this approach is that it would be relatively easy to implement and could be used to quickly gain information on what chemicals are used.

This approach would also help the public have more faith in the industry as they would be able to search for information by location and so see what was happening near them. Disadvantages are that this approach only covers additives to drilling fluids and does little to understand the major chemical constituents of hydraulic fracturing fluids, the process, flowback and waste water produced and how the chemicals behave once released into the environment. It may be easier to set up a voluntary program rather than making it a legal requirement to disclose details, however this would likely result in less data being obtained.

A second approach would be to develop complimentary monitoring programs to analyze; a) the fracking fluids themselves, b) the flowback and produced water, and c) surface water features receiving waste water treatment effluent plus those that have been impacted by illegal dumping of fracking fluids. Few studies have analyzed the major chemical constituents in injected hydraulic fracturing fluids and so there is still a large degree of uncertainty associated with characterizing fluids and identifying the chemicals of concern. Each monitoring program would have its advantages and disadvantages, however there is a good potential to address this gap as the research capacity largely exists but would require further analytical method development.

The advantage of analyzing a large number of different fracking fluids is that it would allow for a better characterization of the chemicals present. However, much of this information may be obtained easier and cheaper by requiring companies to disclose details of their hydraulic fracturing fluids. Sample collection may also be an issue as it would require full cooperation with oil and gas operators who may not wish to disclose the exact information of their fluids to potential competitors.

An advantage of analyzing the flowback and produced water is that it would allow for characterization of not just the additives and fracking fluid but also of other potential contaminants that may be released from the fracturing process and from the recovery of the oil and gas. This would fill a large knowledge gap and help to identify the contaminants of concern. However, sample collection may again be an issue as it would require full cooperation with oil and gas operators.

There are several advantages to collecting samples from surface water features receiving waste water treatment effluent plus those that have been impacted by illegal dumping of fracking fluids. The analysis of these samples could be compared with results from the other monitoring studies to identify the fate and transport of contaminants produced by hydraulic fracturing. There is currently a knowledge gap understanding not only what the chemicals of concern are, but how they behave in the environment. Certain chemicals may be accumulated in biota on transformed into more toxic daughter products once undergoing treatment or being released to surface waters. Understanding this would allow for more informed decision making and better risk assessment which could be used to protect surface waters more cost effectively. One disadvantage of this technique is that it would be more scientifically complex to understand the key processes compared to the other two monitoring programs that only involve characterization of the samples. There may also be issues obtaining samples from waste water treatment companies and land owners bordering surface waters.

6.5.3 Efficiency and effectiveness of current legislation relevant to surface water

Across Canada, hydraulic fracturing practices are regulated differently by the various provincial agencies, which in large part reflect the historical depth and breadth of oil and gas activity in that jurisdiction. In addition, there are overriding federal jurisdiction that may impact aspects of hydraulic fracturing operations. These are discussed more thoroughly in Chapter 9 and this section focuses on legislation in relation to surface water contamination.

One approach would be to conduct a peer review of regulatory activity. There is already a large amount of information in the literature however this is quite disjointed and reflects cases for individual states or provinces. A study could be undertaken to review the different current regulatory practices to determine the appropriateness of the legislation in place for ensuring an adequate level of protection to surface water from a Canada wide perspective. It could also draw conclusions with regard to the key risks to surface waters of such operations in other areas of the world and learn lessons from the U.S. and EU. The advantages of this approach are that the basis of this work as already been done and is presented in Chapter 9 of this report. Disadvantages are that it does little to identify the actual effects of hydraulic fracturing in the environment.

A second approach would be to develop database of baseline water quality and quantity, and geologic information across a shale gas formation. Surveys of water quality and levels could be carried out before, during and after all stages of hydraulic fracturing operations. The first step would likely involve compiling existing data, identify gaps and complete field investigations to complete data, the end product could be to develop infrastructure to host an interactive data base where users could view information on regional water quality. The advantages of this approach are that it would provide useful baseline data which is currently lacking. There are currently governmental and regulatory bodies that regularly monitor surface water quality (e.g. Environment Canada and the Ministry of the Environment) so this assessment could potentially be incorporated into these existing programs. Disadvantages could include finding an appropriate body to manage these databases and providing constancy across the different provinces.

A third approach would be to develop appropriate industry practices and Canadian standards for monitoring for surface water impacts. There are several existing standards and best practice guidance including those produced by the American Petroleum Institute (API, 2011) and United States Environmental Protection Agency (EPA, 2014). The Canadian Association of Petroleum Producers (CAPP) has developed a limited set of guiding principles for hydraulic fracturing (CAPP, 2012); there appears to be a lack of similar guidelines set by the Program of Energy Research and Development (PERD) (Natural Resources Canada, 2013). However, within this there is little focus on surface waters and the guidance is quite vague and recommends proactively working with state and local regulators to assess the baseline characteristics of surface water bodies (API, 2011). There is currently a large difference in the requirements of each province as was identified by Precht and Dempster (2012). More focus could be placed on establishing a universal approach particularly confirming when it is necessary to undertake monitoring and what contaminants to include in the assessment. The advantages of this approach are that the findings could supplement the existing guidance. Disadvantages are that there may be issues with regional and national applicability and would result in extra costs to industry who would likely have to pay for any extra assessment.

6.5.4 Understanding indirect releases

The challenges related to identifying, measuring and monitoring, and determining impacts due to indirect releases create significant challenges by their very nature of being indirect. Here, there are aerial contamination challenges, treatment plant impacts, biochemical alteration and bioaccumulation outcomes, and groundwater-under-direct-influence (GUDI) transportation and interactions to be assessed, quantified, and minimized or eliminated, as possible.

Approaches for each of these challenges are provided in the data gaps table that follows. Each is further discussed and described here.

One approach includes a multi-season year-round monitoring program that includes several field locations in (a) well-known deposition zones relative to key sources; (b) particularly sensitive environments situated along aerial deposition pathways; and (c) regionally and nationally vital watersheds and resources upon which large populations and industrial/agricultural activities rely. A coordinated national effort will be required to effectively and appropriately develop strong data sets and comparative analyses in support of identifying solutions to reduce impacts on surface water due to aerial deposition. The advantages of this approach include a strategic opportunity to focus on sensitive regions and make use of well-documented and mapped global air flow patterns. The disadvantage related to scale is of concern since monitoring stations do not exist in all regions. However, some existing stations (both government and research) could be multi-purposed to collect additional samples for monitoring aerial deposition. Leveraging existing monitoring regimes, equipment, and locations is possible within this approach.

A second approach for assessing indirect releases and impacts on surface water quality focuses on quantifying the contributions of contamination to surface water originating from treatment plant discharges. It is recommended that at least 3 treatment plants be chosen as representative of the regional, national, and industrial differences in fracking activities and, thus, differences in the discharge quality and quantity under investigation. A pan-Canadian research team is expected to be a requirement in completing this approach. By highlighting at least 3 regions of concern, the majority of research questions can be answered in a relatively straight forward and consistent approach. This is particularly advantageous for interpreting data and making recommendations for environmental and surface water protection. The disadvantages are related to the complexity of and design and operational differences of the various treatment plants and inflow quality that each receives. Some data may not be easily normalized through this approach. However, the local and regional advantages for surface water would remain.

A third approach to understanding indirect releases and where they transform and accumulate in the environment depends on the success of and must be initiated in sequence to rather than simultaneously with, research and data compilation related to “chemical disclosure and characterization of chemicals of concern”. As the data and knowledge gap is filled with respect to chemical characterization of fracking fluids, a literature review of peer-reviewed documents, industrial factsheets and chemical descriptions, and treatment process design, operation and performance can be completed. Following that paper-based compilation and analysis, laboratory-based experiments can be initiated to assess the behavior, degradation characteristics and pathways, transformation mechanisms, and bioaccumulation properties and impacts. The disadvantages related to this approach are that they are so dependent and interdependent on the successful completion of other research activities and industrial disclosure of information. The advantages abound for quantifying contamination transport, as well as environmental sources and sinks of fracking fluid contaminants in surface water. Without this information, environmental monitoring, treatment plant design and operation, and remediation processes cannot be as beneficial or effective. Advantages extend into the realm of human and other animal health, as bioaccumulation data are produced and assessed.

The final approach focuses on assessment of GUDI contamination, with a requirement to adequately address and assess movement of chemicals in aqueous form. Outcomes from the laboratory experiments outlined in the third approach described above will help to inform the sorption and dissociation behaviours of the various fracking fluid chemicals expected and documented to be present in industrial fracking activities. To adequately quantify potential transportation and surface-ground water mixing zones, volumes, and extent, in-field tracer studies and environmental monitoring programs will be required. Where high quality groundwater maps exist and information about potential GUDI locations is available, research approaches and methods can be field tested prior to application to fracking regions with lesser or unknown groundwater aquifers and GUDI. As with the previous approach, there are advantages in understanding sources and sinks of fracking fluid contaminants in order to develop and implement effective and efficient monitoring and remediation plans. Further advantages include reductions in surface water contamination and treatment requirements for other consumers and industries. The key disadvantages are the significant complexity and lack of baseline information available nationally regarding groundwater resources, formations and yields, and interactions with surface water. There is little data or proven analysis surrounding the presence GUDI systems.

6.5.5 Understanding the effects on surface water features where water has been removed

Both surface water quality and quantity assessments and monitoring programs are required to fully address the challenges related to understanding the effects of water abstraction on surface water resources.

One proposed approach to this research includes both mathematical and theoretical calculations based on literature review and industrial documentation, as well as in-field quantification at an active hydraulic fracturing site making use of a surface water resource for its extraction or related activities. Ideally, research may begin prior to industrial activity permit at least one full year of baseline data collection and analysis. Impacts on water quantity, as they relate to water quality, support for aquatic life and ecosystem function, as well as impacts on water quality as they relate to the needs of other consumers and the changes to treatment requirements to sufficiently remove contaminants for those consumers' uses and concentration of contaminants due to reduced dilution and diminished natural self-cleansing capacity are all recommended for in depth analysis. The advantage to this approach is that is can solely rely on mathematical and theoretical calculations to provide adequate advice and information to both industry and regulators. The disadvantage is that it's possible that those calculations may be insufficient and the field-testing to confirm adequacy and statistical relevance may not be completed. This approach requires the addition of a supplementary or complementary field monitoring program that can produce confirmatory data for the mathematical approach.

A second approach involves establishment of an interdisciplinary field research program to observe and identify, then monitor and assess in-field impacts and effects of water abstraction on surface water features. Without field-proving the calculations, the full extent of impacts on surface water features where water has been removed cannot be assessed. Some of these impacts may not be catalogued, inventoried, or assessed without in-field analysis, monitoring, and articulation. The advantages include confirmation (or calibration) or calculated outcomes from the first approach and also the development of an incremental, progressive program of research that includes both sophisticated mathematical modeling and statistically relevant in-field monitoring, but also data collection and information gathering that can have multiple benefits for this and other programs of research related to environmental management, surface water protection, and cumulative impacts assessment for situations in which multiple consumers and industrial extraction processes rely on a single, or closely linked, surface water resource.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

8. Understanding fractures and leaks from direct well use

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES:

- Are fractures caused by hydraulic fracturing likely to contaminate surface waters?
- Do leaks from wells during use pose a significant risk to surface waters?
- Do leaks from abandoned wells pose a significant risk to surface waters?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Modeling fractures	Least difficult	Moderately difficulty	Least difficult	Least difficult	$1 million for program	1-3 years	Regional differences in geology will lead to a large amount of uncertainty and so modeling and monitoring should be undertaken to encompass different geological areas
2) Develop/ improve existing standards for monitoring leaks during use	Least difficult	Least difficult	Moderately difficulty	Least difficult	$1 million for program	2-5 years	Most of this knowledge already exists and is employed by other disciplines. The results of research could be used to inform future best practice guidance and regulations. (findings may result in extra costs to industry)
3) Develop/ improve existing standards for monitoring leaks from abandoned wells	Moderately difficulty	Least difficult	Moderately difficulty	Least difficult	$500 k for initial desk study	2-5 years	Research could start by considering the best approach to tackle this problem. There are thousands of abandoned wells across Canada and it may be a contentious issue deciding who is responsible for identifying them and monitoring their status.
4) Develop/ improve well design	Moderately difficulty	Moderately difficulty	Least difficult	Least difficult	>$1 million	Ongoing	Much of this work is currently being undertaken by the oil and gas industry anyway

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

9. Chemical disclosure and characterization of chemicals of concern

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES:

- Disclosure by companies of which chemicals they use for hydraulic fracturing
- Which contaminants are present in hydraulic fracturing fluids and waste water
- How do these contaminants behave in the environment
- Do these contaminants pose a significant risk to surface water features

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Develop an initiative for disclosure of chemicals in hydraulic fracturing fluids	Least difficult	Least difficult	Moderately difficulty	Least difficult	$1 million for program	2 years	To be most effective it would require coordination between different provinces to ensure the same requirements are enforced across Canada.
2) Identify contaminants of concern in hydraulic fracturing fluids	Moderately difficulty	Moderately difficulty	Most difficult	Moderately difficulty	$3 million for program	2-5 years	Would require co-operation from industry partners and different land owners to allow collection of samples.
3) Identify contaminants of concern in flowback and produced water	Moderately difficulty	Moderately difficulty	Moderately difficulty	Moderately difficulty	$3 million for program	2-5 years	
4) Identify contaminants of concern in treated waste water, receiving water bodies and biota	Moderately difficulty	Most difficult	Moderately difficulty	Moderately difficulty	$5 million for program	2-5 years	

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:							
10. Efficiency and effectiveness of current legislation relevant to surface water							
PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES • uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation • Sparseness of baseline surface water quality data • creating and maintaining robust regulatory infrastructures for surface water monitoring							
Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
1) Peer review of regulatory activity	Least difficult	Least difficult	Least difficult	Least difficult	$300,000 for program	1 years	The results of research could be used to inform future best practice guidance and regulations.
2) Develop database of baseline water quality and quantity, and geologic information	Moderately difficulty	Moderately difficulty	Moderately difficulty	Least difficult	$2 million for program	2-5 years	Would require co-operation from industry partners to allow access and monitoring
3) Developing appropriate industry practices and Canadian standards for monitoring for surface water impacts	Moderately difficulty	Least difficult	Moderately difficulty	Moderately difficulty	$2 million for program	2-5 years	There may be some issues with regional and national applicability, however if this could be agreed the results could just supplement the existing guidance. Findings may result in extra costs to industry) and it may be difficult and costly to examine the consistency of transposition and implementation of legislation

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

11. Understanding Indirect Releases

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES

• uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation
• Sparseness of baseline surface water quality data
• creating and maintaining robust regulatory infrastructures for surface water monitoring

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Collecting data and monitoring contributions and extent of impact due to aerial deposition	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$500,000 for program	2-3 years	Regional and national activities are required to monitor aerial deposition from source to deposition zone over a few seasons and climatic conditions
2) Quantifying contamination from discharges from treatment plants	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$750,000 for program	2-3 years	A series of monitoring programs across fracking-active regions for development of a comparison and compilation of data is required.
3) Understanding, through both peer reviewed literature review and laboratory-based experimentation, the biochemical alteration and potential bioaccumulation of chemicals used in fracking fluids	Least difficult	Moderately difficult	Moderately difficult	Least difficult	$1 million for program	3-5 years	While it is possible that some of the information and data may be obtained through examination of peer reviewed literature, it will be necessary to respond fully to this data gap through experimentation and analysis, using authentic industrial fracking fluids or simulated fluids based on access to chemical formulae obtained in the gap entitled, "*Chemical disclosure and characterisation of chemicals of concern*"

4) Assessing, through groundwater maps where available and direct monitoring and environmental tracer research, the interactions of groundwater with surface water and potential contamination due to fracking fluids migration of those GUDI systems	Moderately difficult	Most difficult	Most difficult	Moderately difficult	$2 million for program	3-5 years	Groundwater maps are lacking in most regions of Canada; where they exist, they do not necessarily include information about the presence of GUDI. Transportation of fracking fluids between groundwater injection locations and directly linked surface water resources will be very challenging to assess and even more challenging to address or implement solutions for.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

12. Understanding the effects on surface water features where water has been removed

PRIORITY KNOWLEDGE GAPS TO ADDRESS THE ISSUES

• uncertainties regarding the extent to which risk to surface waters from hydraulic fracturing activities are covered under current legislation
• Sparseness of baseline surface water quality data
• creating and maintaining robust regulatory infrastructures for surface water monitoring

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1) Quantifying water abstraction and the degree of contaminant concentration due to the presence of fracking fluid contamination	Least difficult	Least difficult	Moderately difficult	Least difficult	$300,000 for program	1 year	This research represents a "quick win" in the demonstrated protection of surface water resources in terms of both quality and quantity in relation to hydraulic fracturing activities.

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7 LIFE CYCLE ASSESSMENT OF HYDRAULIC FRACTURING ACTIVITY

7.1 INTRODUCTION

The approach we have taken in this report considers the full range of landscape impacts of hydraulic fracturing development and operations on surface water and watersheds. Understanding the scope of activities that are required before, during and after the actual fracking operation is aided by employing a lifecycle assessment (LCA) methodology. In the context of the current report, LCA is both a way to provide a review of unconventional oil and gas development stages and an approach that could be further developed to assess hydraulic fracturing impacts. An LCA approach provides valuable input into identifying cumulative effects (see Chapter 8).

LCA is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and environmental releases, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to effect environmental improvements.

It is a robust tool because it provides opportunities to identify sources of problems and consequently facilitates the possibility of intervening before the problem occurs (Dunmade, 2012). Historically, lifecycle assessment focused primarily on environmental impacts. Recent efforts at addressing the need to incorporate economic and social factors into lifecycle assessment has resulted in the development of an enlarged LCA tool called Lifecycle Sustainability Assessment (Assefa and Frostell, 2007; Graedel and van der Voet, 2010; Guinee, et al, 2011; Klopffer, 2003; Klopffer, 2008; Koroneos and Rokos, 2012; Lee and Kirkpatrik, 2001; Parkin et al., 2000; Weidema, 2006).

The application of lifecycle sustainability methods to unconventional oil and gas development provides a platform for comprehensive evaluation of potential environmental, social and economic implications of decisions taken at each stage of the lifecycle. A comprehensive analysis is beyond the scope of the current project, but the following provides an initial attempt to identify the primary phases and associated impacts.

We have divided the lifecycle of hydraulic fracturing development into four stages, namely, exploration, development, production, and end-of-life stage. Figure 7.1 below is an illustration of a typical fracking process lifecycle stages including activities at each stage and their potential impacts. What follows are short explanations on the potential relationships between the fracking process stages, individual activities within each stage, and the environmental, economic and social impacts. *This is provided for illustrative purposes and would require significant refinement through collaborative efforts with industry experts involved in the respective stages.*

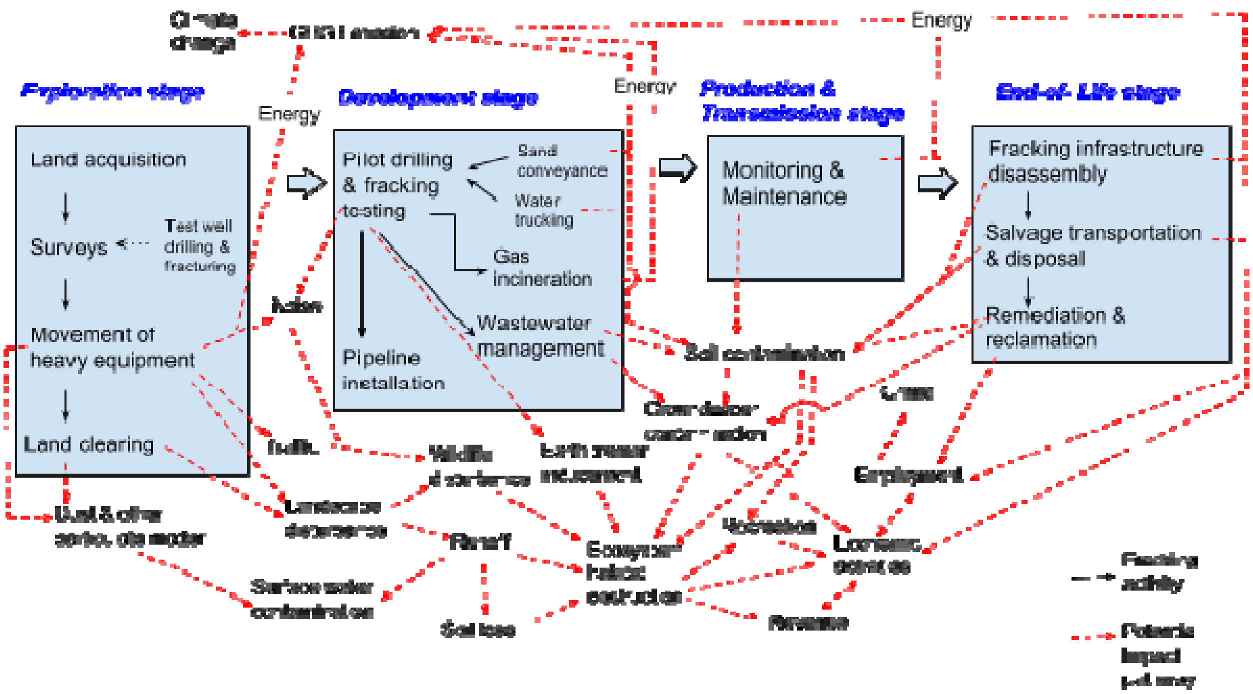

Fig. 7.1 Fracking Process (Linear) Lifecycle

7.2 Stages of Unconventional Oil and Gas Development and Associated Impacts

7.2.1 Exploration stage

The details of the exploration stage vary significantly depending on the region, geologic formation, land ownership, etc. In addition, the overall process will vary with size of the play and the overall stake that an individual company has in the region. This stage, essentially, involves land acquisition, securing seismic and drilling location permits, and land use agreements. It also includes initial geophysical and geochemical surveys in some regions. The goal at this stage is identification of the petroleum resource and determination of shale oil/gas presence and whether it can be extracted or not. Beyond initial exploration activities, several test or preliminary wells will need to be drilled and fracked to fully assess the potential of the field. These activities will involve movement of equipment and land clearing. Such movement of equipment and land clearing activities may cause air pollution with particulate matter, noise pollution and some land disturbance. The intensity of the impacts depend on the number and size of the equipment used for seismic activity and land clearing, the extent of induced vibrations, the pitch and duration of noise, and the nature of the ecosystems at the affected location(s). Furthermore, the movement of heavy equipment could lead to soil compaction, thereby reducing soil porosity. This could lead to erosion and consequently result in surface water contamination from the runoff. Soil compaction, erosion, and dust settlement on crops as well as surface water contamination could negatively affect farming and other land-used by reducing yields. Economic trade-offs with other existing and potential land-uses should be included in this phase of the process. Socially, this initial phase establishes the relationships between other land-use interests (see Chapter 3 for more on social license).

7.2.2 Development stage

7.2.2.1 Early field development phase

This is the pilot project drilling and pilot production testing stage. It involves the drilling of initial horizontal well(s) to determine reservoir properties and optimize completion techniques (includes some level of multi-stage fracturing). It may also include additional drilling of vertical wells in additional regions of shale gas potential as well as initial production tests. This stage is aimed at characterising the source formation and its economic viability. It also includes planning and acquisition of pipeline rights of way for field development. For large, complex plays, the planning of other infrastructure such as water treatment facilities, etc. might also be considered (although final decisions about such activities will be made after a more complete understanding of the field productivity is established).

Similar but more intense environmental impacts of equipment movement, noise, land clearing, vibrations from drilling and testing, and other land disturbances are expected at this stage. As it was mentioned earlier, more studies would be necessary to determine the types and intensity of the environmental impacts at this stage. There would also be some socioeconomic impacts on the surrounding communities. Gas incinerators are usually installed at this stage to burn off initially recovered gas. This could result in air pollution with particulate matter, CO_2 and unburned methane gas. Potential consequences of these emissions could result in health problems, and climate change impact. This could affect the productivity of those affected, increase health care costs, and many other side effects. Socio-economic impacts at this stage is similar to but more intense than that of the exploration stage.

7.2.2.2 Peak development phase

This is the commercial development stage. It involves commercial decision to proceed. It also involves government approvals for construction of gas plants, pipelines and additional drilling. This is the stage when the site development is completed. Pipelines are laid and connected to the mains for gas conveyance to the market. The pipelines and other linear infrastructure may affect ecological connectivity. The use of water (or alternative fracking fluids), energy, sand, and fracking chemicals need to fully assessed at this stage. Produced water and flowback are the most significant elements to be considered with respect to potential impact on surface water and watersheds (see Chapter 6). Fracking sand or other proppant materials are generally sourced from remote locations. This is extends the physical footprint of hydraulic fracturing beyond the geography of the play and must also be considered as part of the overall LCA. Likewise, the effects of transporting materials and equipment to the well sites must be considered.

7.2.3 Production stage

7.2.3.1 Facility operation phase

This is the point at which the facility development has been completed and kept running for gas production at full scale. Some monitoring and maintenance would be required during this period. These activities may have significant environmental releases which may affect human health and the ecosystems.

7.2.4 End-of-Life Stage

This is the stage when decisions are made to dismantle the facility and recover what can be techno-economically salvaged. Decisions regarding the best course of actions to take in satisfying the regulatory requirements of restoring the site to recommended state are taken at this stage.

7.2.4.1 Remediating sites and restoring the full field landscape

There are few reported remediation and reclamation reports of decommissioned horizontal drilling and hydraulic fracturing operations because of the relative youth of the activity. However, conditions and techniques are expected to approximate those of conventional petroleum development sites.

7.2.4.2 Associated infrastructure (seismic lines, roads, energy transmission, pipeline)

Careful identification and quantification of impacts of this infrastructure on the environment is needed. Available feasible alternative options would have to be identified. Comparative analysis of the options as well as possible areas of improvement would need to be identified, analyzed and implemented. Figure 7.2 shows identified potential areas of intervention for lower ecological, health and socio-economic impacts. Planners, designers and developers have enormous opportunities to examine the outcomes of lifecycle sustainability analysis in order to identify where and how sustainable design and eco-industrial design principles can be incorporated in the system. This would be with the intent of minimizing the impacts, reducing the costs, and reducing the resource use. The material and energy use can be reduced by designing the fracking infrastructure for reuse, remanufacture and recycling. Such endeavor will reduce the environmental impacts from resource use and result in the overall economic benefits to various stakeholders.

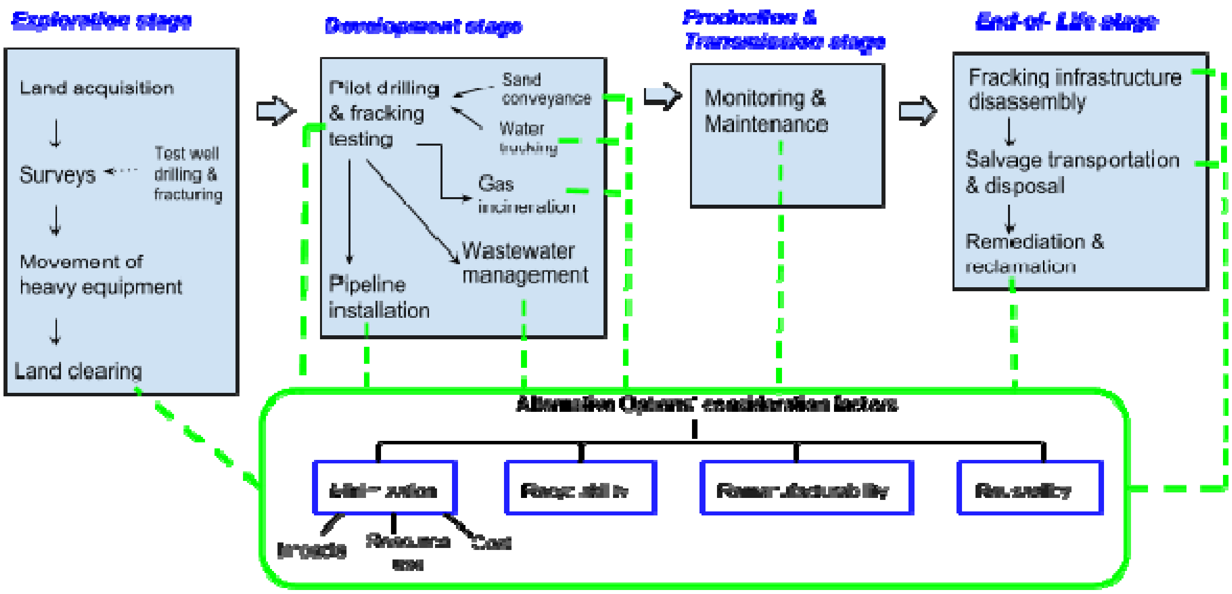

Fig 7.2 Possible Closed Cycle Fracking Process Lifecycle

7.3 Information gaps and LCSA methods to address them

Lifecycle sustainability assessment (LCSA) provides a platform for viewing issues of interest to multiple stakeholders. However, there are many information gaps that need to be filled in order to reap the benefits of this robust analytical tool. Figure 7.3 is an illustration of primary data gap areas. This has to be done right from the exploration stage through the various stages of the fracking process lifecycle to the point of closure, including remediation and restoration of the landscape to its preferred state. Furthermore, the gaps include articulating improvement opportunities, analysing potential midpoint and final consequences of possible improvement steps that could be taken, and determining the "best" pathway(s) that would yield maximum benefits while minimizing negative impacts.

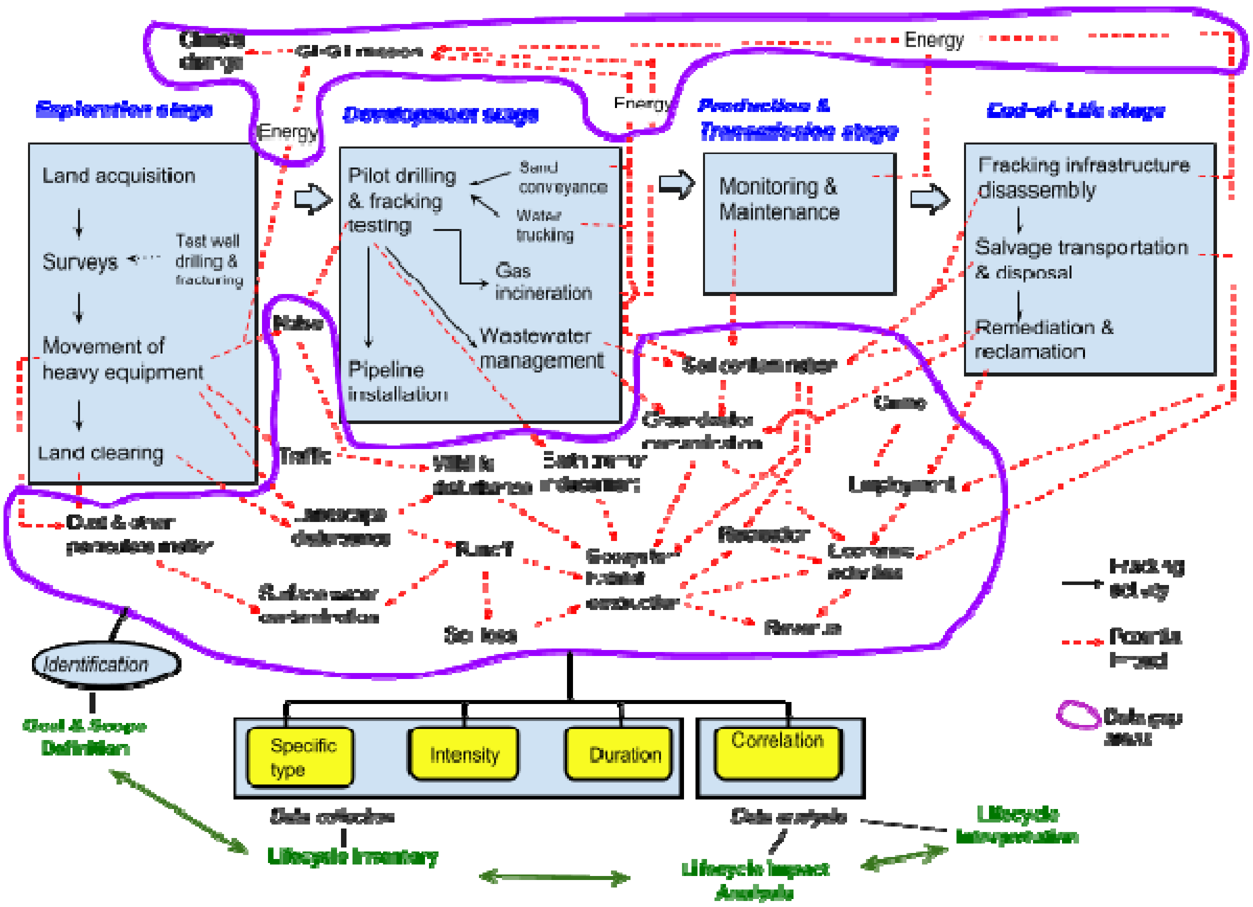

Fig. 7.3 Data Gap Areas in the Fracking Process Lifecycle

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

13. Lifecycle of fracking processes

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES :

1. Determination of the goals and scope of the process lifecycle analysis.
2. Collation and harmonization of new and already identified environmental, economic and social burdens associated with each stage of the fracking process
3. Quantification of the burdens associated with each stage of the fracking process lifecycle
4. Characterization and quantification of the linkage between the fracking process and the attributed impacts.
5. Interpretation of data and analysis of fracking process lifecycle burdens and impacts
6. Identification and experimentation of the "best" sustainable remediation and reclamation process for fracking well site

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
1. Goal and Scope definition	Low	Low	Low	Capacity in Canada	Low	Implementable within a very short period	
2. Lifecycle Inventory (Data collection)	Low	Low	Low	Capacity in Canada	Moderate	1-3 years. Progressive updating would also be necessary	The risk involved is in not fully (or completely) identifying all the burdens associated with fracking. The risk may also be in misplacing some identified burdens in the wrong category or overstretching the burdens..
3. Quantitative study: Lifecycle Inventory	Moderate	Moderate- Some of the environmental, and economic burdens are measurable but a number of enviro-economic and social burdens are difficult to quantify.	Moderate-Some level of expertise may be required to quantify some of the identified burdens	Capacity in Canada	Moderate	1-3 years	Could create some rancour and/or stifle economic activities if some burdens are inappropriately quantified.
4. Quantitative study. Lifecycle Impact Analysis	Moderate	High - The characterization process is	Moderate	Capacity in Canada- but greater commitment is	High- significant research infrastructure	Several years	The myriad of incomplete knowledge of correlations of the factors and their potential impacts poses significant risk of making incorrect claims and judgements.

		scientifically complex as there are many unknowns.		required	and expertise are required		In addition, overstretching or underestimating the impacts, double counting or mismatch could cause socio-political backlash.
5. Lifecycle interpretation	Low	Low	Low	Capacity in Canada	Low	short time period	The previous stages of the Lifecycle Sustainability Assessment (LCSA) are needed to be done correctly to avoid risk and uncertainty. In addition, social upheaval could occur if any of the previous steps in the LCSA is incorrectly done.
6. There are many potential mixes of sustainable remediation options that could be experimented. These include oxidation, bioremediation, thermal or a combination of these and other remediation processes.	High	High - depending on the mix of chemicals found in the fracking well site.	Moderate to Low - depending on remediation process.	Capacity in Alberta	High – Remediation and reclamation are expensive	moderate to long	If remediation is difficult, it may confirm the misgivings regarding the impacts of fracking on humans and the ecosystems. This may consequently have socio-political backlash.

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8 Cumulative Landscape and Watershed Effects of Hydraulic Fracturing Activity

8.1 Introduction

Cumulative Effects Assessment (CEA) and Regional-Scale Strategic Environmental Assessment (R-SEA) (Gunn and Noble, 2009) are the selected frameworks this report uses to review landscape and watershed impacts associated with hydraulic fracturing. CEA emerged in a Canadian federal context in the mid-1980s with the creation of the Canadian Environmental Research Council (Duinker and Grieg, 2006). R-SEA was recognized as one of the tools for Federal Environmental Assessment in the Canadian Environmental Assessment Agency's Sustainable Development Strategy 2007-2009 and its core principles and protocols were adopted by the Canadian Council of Ministers of the Environment in 2008 and 2009 respectively (CCME, 2009). CEA and RSEA frameworks have value in so far as they focus on alternative future scenarios involving multiple stressors on valued ecosystem components and can provide strategic and situational decision-support related to changes over time in terrestrial and aquatic systems involving human land use and extractive resource activities. However, the practice of CEA and R-SEA is generally reported in case study or pilot project format which is location specific. One of the practice issues related to CEA and R-SEA is that results are case and region specific and not universal or transferable to different watersheds/landscape biogeoclimatic conditions and social land use histories. The uncertainty and complexity involved in understanding multiple stressors and valued ecological component thresholds in highly variable and distinct social ecological systems over time and at different spatial scales is highly contextual and cannot be easily measured or 'summed up'. As a result, there are a number of knowledge gaps involved in what both practitioners and decision-makers need to know about the cumulative effects of hydraulic fracturing on regional landscapes and watersheds in a Canadian context.

The final section of this chapter identifies important knowledge gaps and suggests research approaches for addressing these gaps. Section 8.2 provides a summary of literature on landscape and watershed impacts and potential cumulative effects related to hydraulic fracturing including brief summaries of two relevant Canadian case studies. Finally, Appendix A of this report, provides a demonstration of a regional cumulative effects assessment approach to hydraulic fracturing development in an area of Southwestern Alberta and its potential decision-support functions.

8.2 Research/Literature Review Results

8.2.1 Cumulative Effects Assessment (CEA)

CEA requires a strong relationship with regional spatial land use planning in order to be effective. However, the play-based scale of unconventional oil and gas development does not conform to any singular existing regional or municipal unit and there is a lack of institutional mechanisms to address this scale of trans-boundary inter-jurisdictional spatial planning. Large scale unconventional oil and gas development represents the start of what may be several decades of drilling and production involving tens of thousands of wells. As such, environmental impact assessments (EIA) cannot focus on just a single well or well pad, but must also consider the context of local and regional landscape Impacts over time. However, CEA of landscape and watershed Impacts “requires significant amounts of data spanning over a large time period” (Dubé et al, 2012:389) and this is generally lacking.

The Canadian Council of Ministers of Environment (CCME) provides an inter-governmental forum for the discussion of environmental issues and establishing priorities for collective action. The CCME (2014) defines “cumulative effect” as “a change in the environment caused by multiple interactions among human activities and natural processes that accumulate across space and time” and CEA as “a systematic process of identifying, analyzing, and evaluating cumulative effects.”

This definition is consistent with the general understanding of cumulative effects in a Canadian context going back to Hegmann et al. (1999) and restated by Dubé (2003: 723) as: “an effect on the environment that results from the incremental, accumulating and interacting impacts of an action when added to other past, present, and reasonably foreseeable future actions.”

The CCME (2014) has identified seven CEA “principles”:

1. **Knowledge-based**: Knowledge is needed to assess the cumulative effects of activities on air, water, land and biodiversity. Effective science and monitoring systems and networks provide the information needed to measure performance and support the development of outcomes and objectives.

2. **Outcomes and environmental objectives-based**: Cumulative effects management is driven by defined outcomes or objectives for the desired quality or state of air, water, land and biodiversity now and in the future. Cumulative effects approaches recognize the economic, environmental and social (may include cultural and spiritual) implications of meeting those objectives.

3. **Future-focused**: Cumulative effects denote the combined impacts of past, present and reasonably foreseeable future human activities on the region’s environmental objectives. It requires a broader, forward-looking approach to planning and management that balances environmental factors with economic and social (may include cultural and spiritual) considerations.

4. **Place-based**: Cumulative effects management is place-based or site-specific and intended to bring people and their activities together and build relationships among stakeholders to support shared stewardship within an area. Any outcomes must support and reflect the interests of the area being considered and its people.

5. **Collaborative**: Collaboration is a significant and challenging component of a cumulative effects management approach.

6. **Adaptive**: Cumulative effects management includes a shared responsibility to adapt and take corrective actions if outcomes or objectives are not being achieved.

7. **Comprehensive**: Uses both regulatory and non-regulatory approaches.

Similarly, Alberta's "cumulative effects management system" (CEMS) as described in the *South Saskatchewan Regional Plan* (AESRD, 2014:2) describes these principles as the "elements" of the regional land use planning and management. While these principles may represent contemporary cumulative assessment thinking, they have also proven difficult to put into practice. The Canadian regional implementation experience identifies a number of implementation limitations, such as a lack of effectiveness, which have been documented in the literature since 1999 (Noble, 2010:3):

> *The effects of human development on the landscape, when assessed, generally continue to be assessed and managed on a site-by-site, project-by-project basis with little consideration for desirable futures, outcomes, assimilative capacity, or the effects that might result from proposed initiatives in combination with other past, present, and future anthropogenic-induced disturbances in the same spatial area As a result, CEA remains limited in spatial and temporal scale, and disconnected from the broader planning and decision-making context*.

8.2.2 CEA Knowledge Gaps

Based on a review of relevant CEA practice literature, a number of gaps emerge that affect practice (Dubé, 2003; Noble, 2008; Noble, 2010; Harriman and Noble, 2008; Sheelanere et al., 2013; Seitz et al., 2011; Rahm and Riha, 2012):

- region-specific and historical gaps in baseline data and monitoring related to human activities in landscape and watershed systems;
- lack of collaborative and systematic approaches and methods for establishing thresholds for valued ecosystem components at large scales &cross-scale;
- lack of integrative approaches to regional land use and watershed planning and decision-making;

Given the scale of hydraulic fracturing in the provinces of British Columbia and Alberta, it is important to consider the long term cumulative effects of large scale hydraulic fracturing development in the context of regional landscapes and watersheds. However, CEA requires large amounts of data, collaboration and time. Therefore, in order to practice CEA effectively in assessing hydraulic fracturing effects decision-makers need to know:

How are cumulative effects different from Environmental Impact Assessment and why is current EIA at the project level not enough?

Why isn't current government policy and regulations enough to deal with the landscape and watershed impacts of hydraulic fracturing?

What are the highest risk landscape and watershed cumulative effects associated with hydraulic fracturing?

How much time is involved in doing R-SEA and CEA assessment for hydraulic fracturing?

Given the future-orientation of CEA, what is the 'scientific' reliability of R-SEA and CEA methods?

What are the 3 top priority actions necessary to move R-SEA and CEA approaches forward in addressing landscape and watershed impacts?

In order to answer these questions, the 'Gaps and Approaches' tables, as well as the following results of the literature and practice review need to be considered.

8.2.3 Play-Based Development and Spatial Landscape Planning

The Alberta Energy Resources Conservation Board (ERCB) now the Alberta Energy Regulator (AER), defines the term *"play"* as a "three-dimensional entity that is the target of oil or gas development." Generically, a play is characterized by factors such as: "geological formation, areal extent, geographic location, types of fluids in the rock, and other geological and reservoir characteristics." A "resource play" is a specific type of play with a "known or estimated amount of oil or gas with similar geologic, geographic, and temporal properties, such as the source rock, migration pathway, trapping mechanism, and hydrocarbon type." Unconventional oil and gas resource plays often target large subsurface areas. For example, the areal extent of the Horn River (shale basin) formation in Northern British Columbia (B.C.) is approximately 18,400 km^2 and the Duvernay East and West Shale Basin in Alberta is estimated to be 131,000 km^2 (Advanced Resources International, 2013).

Historically, environment and energy are areas of shared constitutional jurisdiction in Canada. Because of the predominant legal separation between surface and subsurface rights in Canada, governance frameworks for subsurface resources such as hydraulic fracturing are independent and separate from frameworks for planning and regulation of surface activities. As such, the areal extent of subsurface resource plays do not compare to the areal extent of the corresponding area of overlying surface landscape and its multiple land use activities which includes the infrastructure that supports hydraulic fracturing. The spatial surface footprint and potential density of wells and well pads required for resource play extraction do not exist in an otherwise empty landscape. Depending upon the geographic location of a play, its overlying landscape surface supports complex social-ecological systems represented by multiple economic and cultural land uses, population settlement patterns, ecological habitat, and drainage systems. The potential for and risk from economic land use conflicts and cultural landscape conflicts associated with intense surface infrastructure development and its spatial pattern is a very real issue for both the public and decision-makers, as evidenced in other chapters of this report (see for example, Chapters 3, 4 and 10).

Because of the separation between surface and subsurface activities and the respective independent institutional frameworks that have developed around each, hydraulic fracturing is not within the mandate or jurisdiction of regional or municipal land use decision-makers. Local and regional land use plans, land use regulation and development approval processes occur independently from energy development approvals and under different legislation and institutional frameworks. As such, municipal land use and oil and gas development regulation operate in parallel, with little opportunity to consider their respective cumulative spatial footprints on the landscape.

The concept of spatial planning, as distinct from land use planning, is not well known in Canada relative to Europe where it is used in coordinating trans-boundary economic and infrastructure development.

Spatial planning is concerned with minimizing multiple land use conflicts and finding landscape interconnections through spatial analysis and spatial pattern connectivity. Traditionally, North American municipal land use planning has been more focused on facilitating land development to generate a municipal tax base to provide municipal services. The dichotomy between conventional municipal land use planning and oil and gas development processes creates an opportunity for spatial conflicts between landscape occupants and land users. For example, such conflicts can occur in the following types of areas:

- areas experiencing rapid population growth or where population density is widely distributed;
- or in areas with little history of surface energy infrastructure development;
- areas with extensive landscape amenity driven recreational and tourism activities, critical habitats; and,
- areas incorporating First Nations lands and communities.

Linking land use and spatial planning with the cumulative surface infrastructure requires oil and gas development activities to be coordinated at larger spatial and temporal scales. This offers an opportunity to coordinate multiple land uses and related infrastructure systems as well as minimize spatial and user conflicts. But it is not enough just to ensure that oil and gas operators coordinate their activities in a play. Municipalities, major landowners and other sectors operating on the same landscape also need to be involved in long-term play based planning and management.

8.2.4 Concerns About Hydraulic Fracturing

Conventional impact assessment has historically focused on specific measurable concerns such as potential contaminants or specific species in the context of project-specific temporal and spatial boundaries (Squires et al., 2012). This individual project "footprint" bounds the assessment process consistent with conventional regulatory processes which have been conducted on a one project at a time basis. In contrast, a CEA framework focuses on multiple projects in the context of larger watershed or landscape spatial areas and project assessment is bounded spatially. All projects within a particular political or geographic region, population area, landscape, or watershed boundary are included in assessment. This shift in scale is significant because it increases the number of possible variables (indicators) to be considered and the complexity of all possible interactions in a place-based rather than project-based framework (Noble et al, 2014; Gunn and Noble, 2009; Harriman and Noble, 2008) This doesn't negate or eliminate concerns related to specific contaminants or species, rather it puts them in a systems context where they are considered in the context of related social- ecological interactions over space and time.

The final shale gas review report of the Canadian Council of Academies (CCA) supports the CEA view that regional context matters. Ecological systems, geography and geology and cultural landscape patterns all vary dramatically across the country. As such, these regional differences need to be considered by decision-makers in determining shale gas and other types of landscape and watershed related development approval and regulation. However, rapid expansion of shale gas development in the

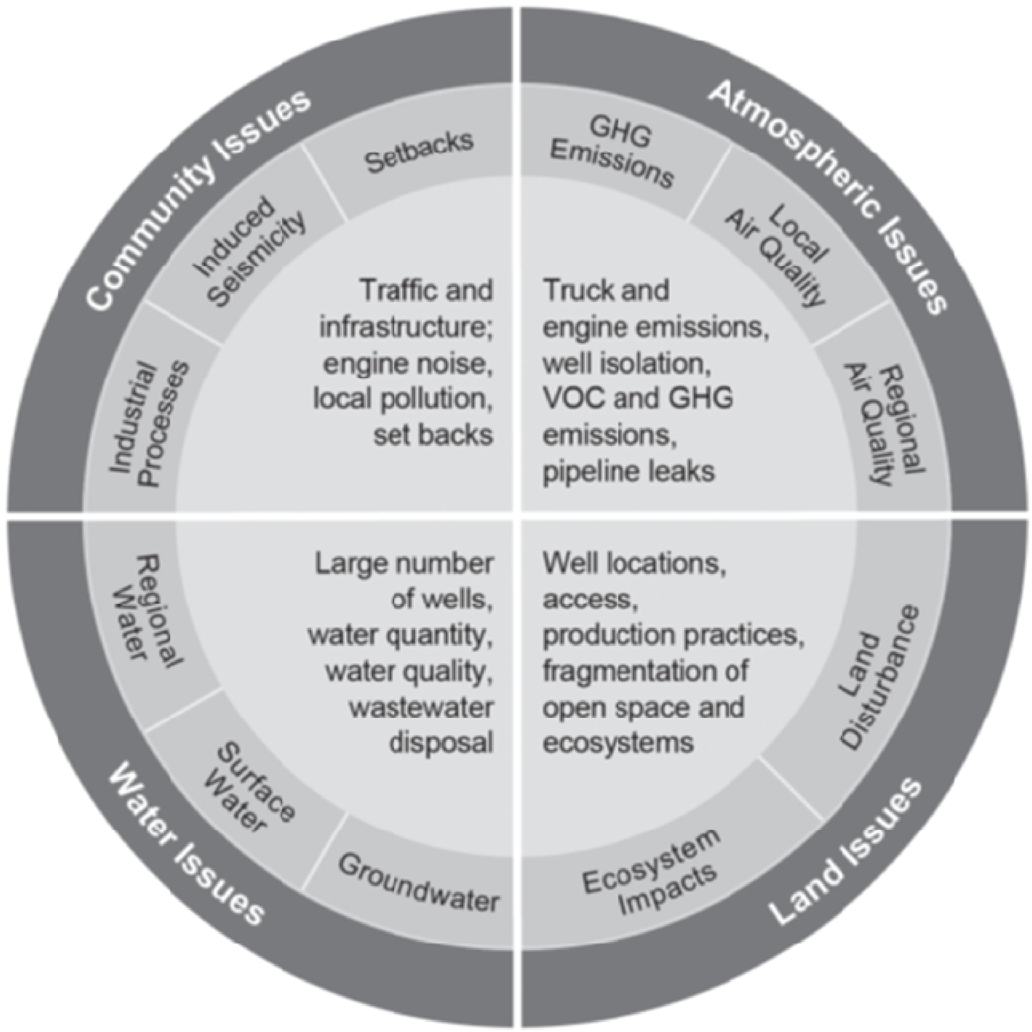
United States and Canada over the past decade has generally occurred without a corresponding investment in research and monitoring to understand these distinct regional operational characteristics. As a result, “the land impacts from shale gas production in Canada are not well-defined though many can be inferred from United States experience” (Canadian Council of Academies 2014, 128).

The types of land and water concerns/risks associated with hydraulic fracturing have been identified in both Canadian and US comprehensive reviews and publications (for example: CCA, 2014; Christopherson, 2011; Kargbo et al., 2010; NYSDEC, 2011) and include:

- degradation of surface and groundwater quality, including safe disposal of large volumes of wastewater;
- water use extraction, demand, and contamination of aquifers, surface water and wells
- fugitive methane emissions during and after production;
- disruptive community effects and cultural landscape disturbances;
- adverse effects on human health, including the local release of water and air contaminants;
- potential for triggering small to moderate earthquakes in active seismic areas;
- increased and intensive truck and vehicle traffic;
- land clearing and landscape fragmentation from well pad development density and new road construction;
- leaks and air quality impacts associated diesel fuel use in compressors and equipment;
- seasonal and permanent disruption of wildlife movement, lifecycle habitat requirements, and stream flow regimes;
- Impacts on rural and communities associated with both intensive development and landscape change.

Zoback and Arent (2014:19) provide a useful summary of shale gas concerns in the United States experience in Figure 8.1 below.

Figure 8.1 Summary of American Shale Gas Impact Issues



Source: Zoback and Arent, 2014:19

It is necessary to go beyond site-specific project impacts to understand regional scale cumulative effects (Dubé, 2003; Duinker and Greig, 2006; Harriman and Noble, 2008). The following section reviews regional scale cumulative approaches to understanding landscape and watershed impacts.

8.2.5 Cumulative Effects and Regional Strategic Environmental Assessment

Understanding the dynamics and drivers of change involves consideration of past, present and future conditions. The behavior of complex landscape, watershed, and social systems interacting in space and over time is highly uncertain. Therefore, understanding landscape and watershed change needs to be considered and assessed under different future scenarios which incorporate different rates of development. As Harriman and Noble, (2008:26) point out, CEA is inherently "one concept-multiple form" and there is no single regional CEA approach or method that fits all situations. There are generally two different approaches recognized in regional scale CEA: 1) environmental impact assessment driven (EIA-driven); and, 2) strategic environmental assessment driven (SEA-driven). Harriman and Noble (2008: 43) further suggest: "EIA-driven approaches to regional CEA are largely defined by the spatial scale of the stressors, and stressor sources (individual and multiple projects); whereas in SEA-driven approaches, regional CEA reflects the spatial scale of the processes (i.e. land uses, industry, regulatory and administrative systems) that control the resources of concern." EIA-driven CEA approaches can be either single or individual project-based or multiple project-based where the combined effects of multiple projects are the focus. Most CEA knowledge in Canada has been built in an EIA-driven context based on the nature of existing legislative requirements. In a conventional EIA process, the type of project concerns and the need for project assessment are established as the initial basis for the EIA. In contrast, the purpose of CEA is to identify potential impacts that are not initially identified. EIA-driven CEA in Canada has been done under the federal government's EA framework (or joint provincial-federal frameworks) for large projects or multiple project proposals.

SEA-driven approaches are appropriate at a regional scale where multiple projects and/or multiple sector development plans are involved and decision-makers need to consider a range of impacts and partnerships among multiple proponents and regional authorities. The primary purpose of this regional scale (R-SEA) process is to identify alternatives and actions that best support preferred outcomes. Harriman and Noble (2008:39) identify three types of SEA-driven approaches

1. *single-sector SEA, which refers to sector-based initiatives and impacts (e.g. transportation corridors, oil and gas fields);*
2. *multi-sector SEA, which applies multiple sector-based initiatives and broader planning and management initiatives (e.g. land use planning); and,*
3. *SEA which has no explicit "on the ground" dimension (e.g. fiscal policies).*

Four types of SEA-driven cumulative effects assessment and their comparative and key characteristics are illustrated as follows in Table 8.1.

Table 8.1 Characteristics of regional strategic environmental assessment

	Project-specific environmental assessment	Programmatic environmental assessment	Sector-based strategic environmental assessment	Regional strategic environmental assessment
Typical proponent	Single development proponent.	Single proponent or multiple proponents involved in related undertakings.	Single industry sector, or government agency responsible for the sector.	Regional planning or administrative authority; public-private partnership; group of industry partners.
Trigger	Effects of project actions in the local project environment.	Combined effects of multiple projects in the local projects' environment.	Effects of proposed or existing sector-based plans or development initiatives.	Cumulative change or need for regional PPP development or review.
Alternatives considered	Proceed or not proceed; project technical design.	Alternative spatial or temporal project configurations.	Sector development vision or plans.	Region-based alternatives or scenarios driven by broader regional, sustainability, or policy-oriented goals and objectives.
Scope	Individual project stressors and impacts.	Combined project stressors and impacts.	Stressors and effects of the sector.	Outward-focused, taking into account the combined effects of PPPs, projects, and exogenous factors.
Temporal bounds	Project life-cycle, including effects of past stressors.	Past, present, and planned project developments.	Past, present, and planned sector activities.	Past, present, and longer-term futures of regional environments and economies.
Spatial bounds	Site specific, defined by the single project or project proponent.	Defined by multiple projects within an administrative or physical region.	Boundaries of sector initiatives (e.g. forest harvest area) or by sector-claims (e.g. oil and gas licensing block).	Planning region as defined by natural features such as watersheds or other eco-regions.
Sources and pathways of effects	Individual, predicted project actions.	Multiple projects or activities, individually contributing and interacting.	Activities of a single sector, often of a similar type and interacting with other similar sectoral activities or initiatives.	Activities of multiple sectors, often diverse and interacting with other regional activities, PPPs or developments.
Typical CEA questions	What are the likely additive or incremental impacts of the proposed project activity? What are the key stressors?	Are residual effects of many single projects significant? What is the effects-based contribution of multiple projects?	What are the potential cumulative impacts of each sector alternative? What are the opportunities and constraints on development?	What are the potential cumulative effects of alternative future scenarios? What are the opportunities and constraints to current and future developments?
Planning orientation	Individual project planning.	Incremental, multi-project planning.	Industry planning and initiative prioritization.	Regional development or environmental management.
Management focus	Mitigation and monitoring of significant project based impacts.	Mitigation and monitoring of significant individual, project based impacts. Multiple proponent responsibility.	Select preferred sector-based development strategy; risk reduction; regulate future project development.	Select preferred land use alternatives; enhance sustainability; risk reduction to regional environment; PPP development to manage future land uses.

Source: Gunn and Noble, 2009:261 (based on Harriman and Noble, 2008)

While an understanding of the types of CEA approaches is important, the larger issue is whether or not the practice of CEA is effective. Noble (2010:10) makes a distinction between "*status quo*" CEA and "efficient" CEA which is identified below in Table 8.2.

Table 8.2 Requirements for Effective CEA

	Status Quo CEA	**Effective CEA Requirements**
Assumptions	**abundance**	**limits**
Receptors	**single media**	**environmental systems**
Spatial context	**project**	**multiple scales**
Temporal context	**past, present**	**past, present, future**
Scope	**regulated activities**	**all disturbances**
Assessment	**stressor effects**	**stressors and effects**
Futures	**predict impacts**	**possible outcomes**
Management	**mitigation**	**avoidance**
Monitoring	**regulatory compliance**	**thresholds and capacity**
Responsibility	**individual proponents**	**multi stakeholder**
Performance	**increased efficiency**	**increased efficacy**

Source: Noble (2010:10)

Noble (ibid) identifies "three silos" in CEA practice that limit the effectiveness of CEA in practice: "stressor-based" project focus; "effects-based" science; and, "land-use" planning. Each of these is characteristic of a different community of participants. Specifically, project proponents and regulators are primarily stressor-based focused, the scientists and academics are primarily effects-based, and land use planners and managers are primarily environmental planning (social-ecological-economic) focused. But, what is considered important from a scientific perspective is not what a project proponent or regional land use planner is likely to consider most important from their perspectives. As such, Noble (2010:11) argues "These silos need to be better integrated if cumulative effects are to be identified, assessed, and effectively manage"; but there is a gap with respect to the mechanisms available to enable integration.

The CCME (2009:13) identifies a list of circumstances in which regional scale strategic environmental assessment (R-SEA) should be undertaken. Four of these eight circumstances would seem to apply directly to regional energy development, watershed management, and integrated land use planning and include:

- "A strategic decision is to be made that will establish a framework and conditions for future development, land and resource use, or management actions in a region".

- “There is a need to coordinate disparate regional resources, programs, data, management objectives, strategic initiatives in relation to a common regional issue”.
- “Regional decisions are to be made concerning resource use, development, or land access that is multi-jurisdictional or multi-sector in nature”.
- “The public demands that an R-SEA be carried out”.

An R-SEA approach is inherently futures oriented and requires a systematic approach to generating and analyzing “what if” questions about future development possibilities. Typical R-SEA questions such as “What are the potential cumulative effects of alternative future scenarios? and, “What are the opportunities and constraints to current and future developments?” may not be sufficient in the context of play-based hydraulic fracturing.

Strategic questions need to focus on the spatial and temporal evolution of play-based development and resource extraction. For example, there may be more interest in knowing how long surface operations will continue and how the government and oil and gas industry intend to decommission surface sites when fracturing is completed. Although there has been general agreement in the CEA literature over the past fifteen years about the need for R-SEA, there is a corresponding lack of specific tools and methods for doing it. Specifically, there is a lack of specific tools and methods for systematically generating and analyzing multi-objective ‘futures’ and integrating information across scales in light of the potential for emergent properties to appear at different levels of organization in complex environmental systems over time. If R-SEA is to be applied in the context of hydraulic fracturing, there are a number of gaps that will need to be filled. For example, a “typical proponent” (Table 8.4.1) for R-SEA is currently a “regional planning or administrative authority: public-private partnership; or group of industry partners.” In contrast, at the scale of play-based hydraulic fracturing, it is unclear who a ‘typical’ proponent would or should be. Play-based R-SEA are likely to require new frameworks for connecting multi-jurisdictional surface conditions and interests of stakeholders currently not connected.

The literature also identifies a need for systematic methods to establish targets and thresholds at different scales. For example, Bell (2011) found that valued ecosystems components (VECs) identified for individual projects within the South Saskatchewan River watershed could not be just “summed up” to represent the watershed as a whole. Therefore, to be effective R-SEA practice needs to develop integrative, cross-scalar, cross-sector, multi-objective techniques for decision-making support. It is also important to recognize that the development of hydraulic fracturing infrastructure on the landscape surface follows a play far beneath the Earth’s surface. The development of alternative future landscape and watershed scenarios cannot simply being forced on hydraulic fracturing operators because surface operations must necessarily follow the play at the best locations for maximum extraction in a relatively short period of time.

8.2.6 Cumulative Watershed Effects

Potential water impacts arising from hydraulic fracturing have generally had more attention in popular media because of public health concerns with drinking water quality. There is an acknowledged lack of specific Canadian regional information about chemical concentration, mobility, persistence in ground and surface water, bio-accumulation properties, and potential chemical interactions (see Chapter 6 of this report). Concerns with the withdrawal of water for fracturing (see Chapter 5), the amount of water required per well over an average well life cycle, the volume of flowback and produced water, and the treatment of waste water are all important factors for which there is a shortage of accurate regional data across Canada. The sources and amount of water extraction at a regional level over time and at different rates of well development is important information for decision-makers. However, this information is usually viewed and analyzed quantitatively and qualitatively on the basis of totals and averages and quite independent of a spatial and functional watershed context. For example, few studies have investigated the potential effects of water extraction from small unregulated streams and despite progress in understanding how flow variability sustains river ecosystems; "there is a temptation to ignore natural system complexity in favor of simplistic, static, flow rules" (McKay and King, 2006; Arthington et al, 2006:1311).

Watershed-based cumulative effects assessment (WCEA) will need a standard set of ecosystem components and indicators for assessment across the watershed, but there is no consensus as to how valued ecosystem components (VECs) and related measurable parameters should be identified. VEC driven R-SEA begins with a scoping phase involving both scientific and social input to identify the components that will be the focus of assessment. The importance of watershed scale and regional scale VECs in CEA has been identified in the Transboundary Crown of the Continent Manager's Partnership regional cumulative effects assessment along with the use of VECs as regional ecosystem health indicators (Quinn et al. 2002).

Cumulative watershed effects (CWEs) refer to changes involving watershed processes directly and indirectly related to landscape change and multiple land-use activities. The term "Cumulative hydrological effects" has also been used to represent CWE in British Columbia's Forest and Range Practices Act (2004). This term applies to specific management objectives such as fisheries-sensitive and community watersheds. Overall watershed processes are rarely affected exclusively by a change in a single process unless it occurs over a large area of the watershed. The effect of individual land use actions or specific natural disturbances may seem localized and relatively minor but can become significant at an overall watershed scale when combined over time. Four types of changes can affect a wide range of human services including drinking water supply and quality, reservoir storage, irrigation and flood damage, recreational fisheries and cultural use and values (Scherer, 2011:14):

- "physical hydrology- changes in the generation, transport, and delivery of water affecting water quantity and timing of flows;
- riparian function - altered nutrient dynamics, bank stability, sedimentation, and floodplain function;
- water quality - turbidity, stream temperature, nutrient inputs, chemical reactions;
- channel morphology – change in flow capacity and seasonal flow regime, loss of aquatic habitat, change of substrate and aerobic and anaerobic function".

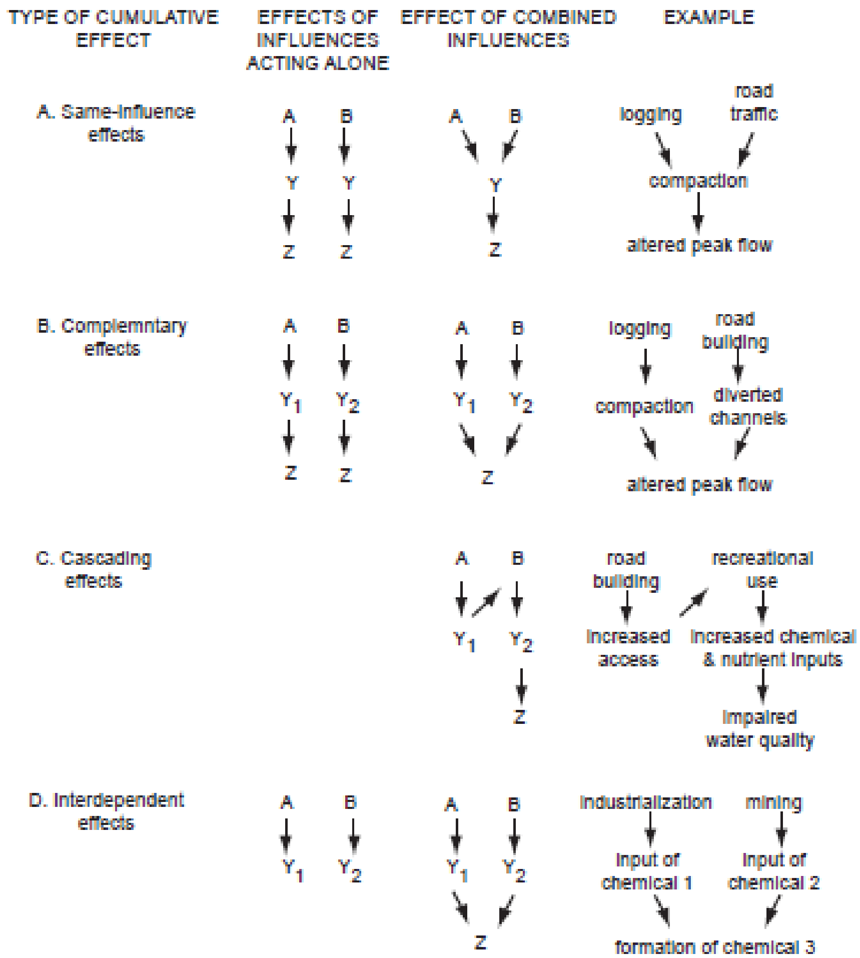
Similarly, examples of cumulative effects within a watershed management context include:

- agricultural, industrial and municipal land use related water withdrawals on seasonal low flows, downstream flow targets, stream temperature and biological system requirements.

- expansion of road networks and road construction on surface drainage and wetlands, increase in erosion and sedimentation, increased run-off and chemical contaminants from road surfaces and disconnection of flow though road culverts.
- riparian function loss from agricultural, industrial, and municipal land use practices and development resulting in removal of vegetation and restriction of floodplain area.

Watersheds are topographical landscape forms shaped over time through hydrologic, geologic and climate processes involving living organisms, chemical interactions and temperature gradients. Because watersheds can be topographically bounded they can be viewed as physical 'objects' in the landscape rather than areas of specialized processes within the landscape. The notion of 'drainage basin' encompasses topographic and gravity driven flow connections across the landscape at multiple scales. Reid (1993:19) was critical of previous CWE interpretations of a watershed which included only "changes within the bounds of a drainage basin" and treats the definition of watershed as simply the location or receiver of impacts. Instead, Reid (ibid) viewed watersheds as dynamic systems in which "… changes are influenced directly or indirectly by watershed processes such as water and sediment transport" and combinations of activities and interactions among land, water, biotic and abiotic processes actively generate changes of different types and at different scales (Figure 8.2).

Figure 8.2 A Watershed Process-Driven Approach to CWE Assessment



Source: Reid (1993:20)

Changes in watershed processes seldom exhibit a simple distinct threshold of change. Most processes respond incrementally and are manifested at various temporal and spatial scales (Reid, 1998). Therefore, CWE assessment requires consideration of a wide range of temporal scales and relevant time scales associated with a specific process or effect (Ziemer 1992). The number of possible watershed process interactions is spatially and temporally significant.

Further complexity arises from natural variability within the system. Some watershed systems may have a high level of variability due to their biological, geological, climatic, spatial and human activity history. However, long term baseline data are necessary to understand patterns of variability and this can be complicated as some processes may be sensitive to change at the microhabitat or habitat scale but more resilient to change at a watershed scale. Further complexity is associated with the spatial and areal distribution of watershed disturbances. For example, Scherer (2011:18) suggests the spatial pattern of disturbance can “desynchronize or synchronize various watershed processes (e.g., synchronization of spring freshet peak flows generated from two sub-basins within a watershed).” The larger the areal extent of a watershed, the more difficult it becomes to monitor the overall effects. As Rahm and Riha (2012:14) suggest: "… the potential for rapid increase in well density within newly discovered plays, necessitate a need for strategic planning and management of development at the regional (state) scale … it is important to examine water resource consequences of shale gas development over time and space in addition to project-level impacts".

8.2.7 Cumulative Landscape Effects

As discussed in previous sections, watersheds are topographic landforms and part of the regional landscape. Watershed processes and landscape processes involve interconnected spatial and temporal biological, geological, climate systems and social systems. The impacts of linear disturbances on landscape connectivity required for wildlife movement has previously been well researched in relation to forestry, conventional oil and gas exploration on public lands and agriculture. In these land use contexts this linear disturbance is associated with increasing human access into remote areas, landscape fragmentation, increased erosion, and invasive species. Installation of new bridges and road culverts also affect aquatic habitats through changes in drainage patterns, channelization and increased sedimentation. For example, in contrast to the media exposure water quality concerns have received, roads and increased vehicle and truck traffic related to hydraulic fracking operations have received relatively little attention. The number of trucks and trips necessary to service the scale of fracking development over its full life cycle are not known in any detail and there is an overall lack of monitoring and reporting about road impacts related to hydraulic fracturing in a Canadian regional context. Some estimates of cumulative truck loads associated with phase and type of operation do exist for specific US locations have been identified (Efstathiou, 2012) but no thresholds related to these numbers in the context of CEA are available in a Canadian context.

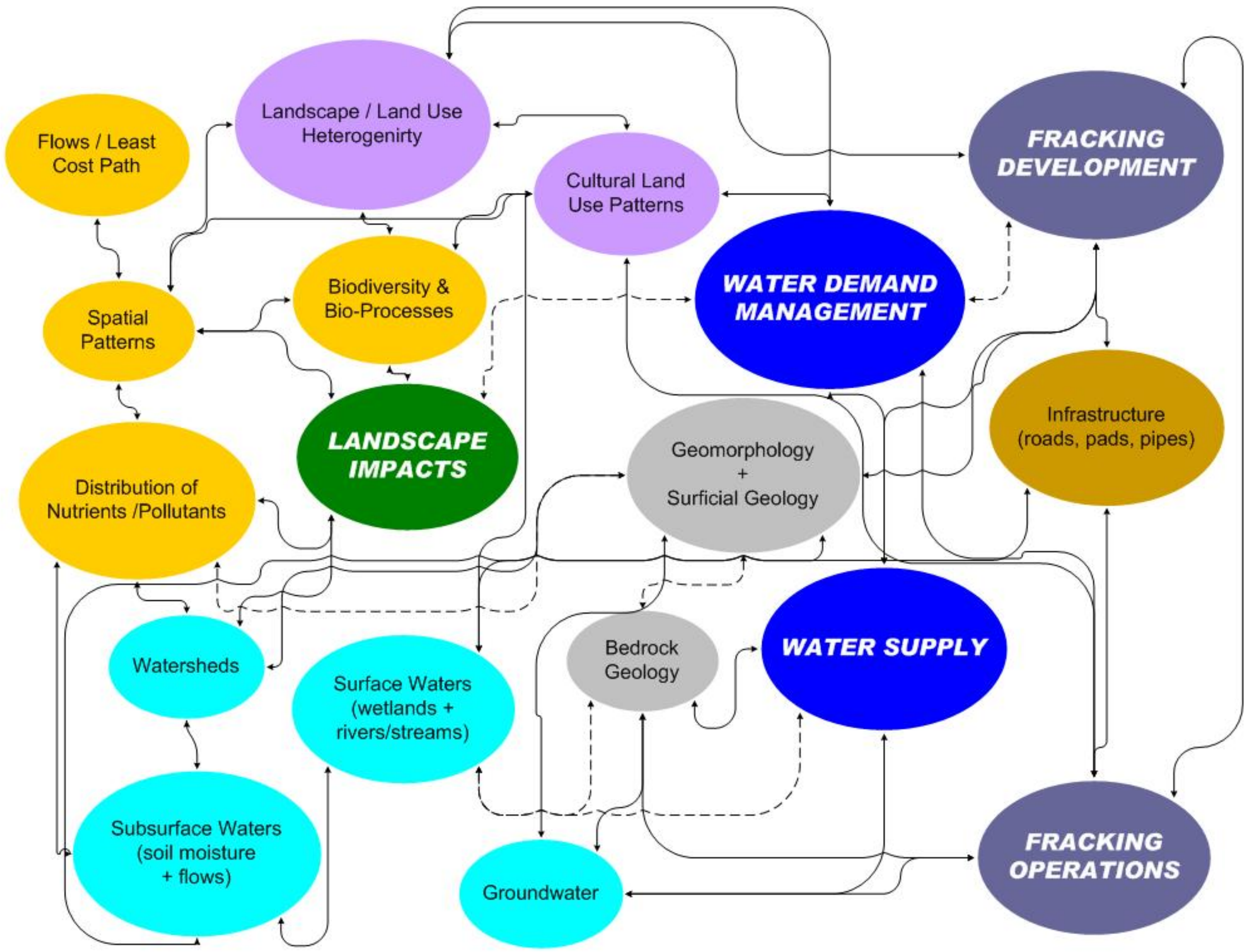
In addition to roads, shale gas development requires other types of extensive surface infrastructure that includes well pads, compressor stations, pipeline rights-of-way, and staging areas; all of which are regional geology and operator specific. Although the use of multi-well pads and extensive subsurface horizontal lateral piping does reduce surface footprint - the scale of shale gas development and density of wells impose a substantial spatial footprint on the landscape and affect landscape connectivity and ecology over time. Infrastructure performance, possible fluid migration and eventually well closure procedures also need to be considered and require monitoring over time.

Region specific landscape impacts from shale gas development include: deforestation; loss and fragmentation of ecological habitat; and a range of conflicts with existing land uses, including agriculture, tourism and First Nations cultural lands. But it is difficult to estimate and evaluate these effects without specific information on the location, pace, and scale of future shale gas development. The need for and extent of future land reclamation efforts related to shale gas development is unknown and uncertain in most Canadian regional landscapes. . Consideration needs to be given to the long term and cumulative risks, costs and liability issues that may arise given that thousands of regional wells could remain in different stages of production for upwards of seventy years.

'Landscape' is a complex and dynamic system of ecological, geological, and human influences. Landscapes are carriers of ecological systems at specific locations and times and cultural landscapes represent place-based human-environment interactions over time. As discussed in Chapter 3, potential landscape and watershed effects of hydraulic fracturing and related strategies to mitigate or manage these effects must be considered in light of local community concerns and social values. Very little research literature exists on social impacts of shale gas development in a Canadian regional context (CCA, 2014, Rahm et al, 2012). However, from a landscape and watershed perspective, social concerns include public health and safety related to air, quality, water quality, intensive truck traffic, and potential loss of cultural and traditional land use values and rights. For example, residents in both relatively unpopulated areas of northern British Columbia and relatively populated rural areas of eastern Canada depend primarily on private water wells. Therefore, it should not be surprising that concerns about water quality and well contamination arise in these areas. Similarly, new road development, increased truck traffic, loss of access to or degradation of high quality recreational or amenity landscapes in rural or peri-urban areas, and the loss of culturally valued activities and spiritually significant places are also reasons for social concerns about hydraulic fracturing. Therefore, public acceptance or so-called social license for large scale and long term shale gas development involves assurances that important cultural landscape values will not be lost. VECs can play an important role in representing regional social values in shale gas development CEA. Earning public trust in the broadest sense involves understanding the risks, uncertainties, and trade-offs of development as well as who benefits and who pays. Having credible information from multiple stakeholder and multidisciplinary research, monitoring and consultation processes is a necessary part of creating and maintaining social license.

The challenges in assessing landscape cumulative effects are multiple because of the complexity of regional landscape systems, not the least of which is the social system component. For example, are R-SEA concerns such as VECs, risk, and thresholds 'real' biophysical quantitatively measurable entities or more intangible science social constructs? As conceptually illustrated in Figure 8.3, landscape cumulative effects assessment (LCEA) in the context of subsurface hydraulic fracturing involves an integrated and complex system of spatial and functional surface and subsurface functional interrelationships. Landscape has in the past been viewed as just a set of biophysical conditions in a specific area over a specific period of time. But that view is neither a useful nor accurate representation for the purpose of understanding cumulative effects of unconventional oil and gas development at a regional scale. A role for R-SEA in this context is to act as 'bridging' mechanism to integrate site specific activities with larger regional spatial patterns and values.

Figure 8.3 A Landscape Cumulative Assessment Framework for Hydraulic Fracturing



8.2.8 CEA and R-SEA Practice Precedents

There is no shortage of access to current state-of-the-art environmental assessment methods, as evidenced by New York State's (NYSDEC, 2011) "Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: (GEIS). But, CEA approaches and methods are not independent form institutional frameworks and associated policies, laws, and regulations; nor, do they proceed without region specific information and reliable baseline data. Therefore, a better understanding of why CEA and CEAM approaches have not been effective in practice can be helpful in documenting where implementation gaps have occurred and what lessons have been learned from practice. To this end two regional Canadian CEA experiences are reviewed in the following sections: 1)

BC Oil and Gas Commissions experience with CEA in Northeastern BC (AXYS, 2003); and, 2) Saskatchewan's Great Sand Hills (Noble, 2008).

8.2.8.1 Cumulative Effects Assessment in Northeastern BC

The CEAMF has been used to address shale gas development related to the Horn River play in northeastern British Columbia (BC). The initial development of this framework was driven by a number of principles, performance criteria, and assumptions (AXYS, 2003: iii-iv) including:

- Need to assess and manage cumulative effects within a regulatory review process meant for individual project applications;
- Need to identify and implement cumulative effects thresholds;
- With or without thresholds, new regional initiatives should provide necessary information and data to support land and resource decision-making; and,
- A 'dual-track' approach is needed to address cumulative effects a project level while simultaneously addressing cumulative effects at a regional level.

The CEAMF was implemented under the oversight of the BC government's "Sustainable Resource Management Strategy (SRMS)"; a dual track process with a Steering Committee to assist in the review of project applications (AXYS, 2003:iv). It was implemented as a pilot project with thresholds prepared for two selected areas as case studies. The pilot approach was to demonstrate the thresholds within a provincial regulatory review and planning context with the understanding that if successful, thresholds would be incorporated into the Oil and Gas Commission's other northeast review processes. However, in the seven years that followed an information gap emerged as to what had actually been implemented and what had not been done; prompting Koop (2010) to ask what happened?

The three factors subsequently identified as contributing to this apparent lack of effectiveness were: the nature of the dual-track approach; the pilot project status of the framework; and, the unpredictable political nature of the SRMS. Specifically, pilot project status implies less commitment to long term implementation and smaller scale pilot demonstration projects do not usually capture important regional scale information. Similarly, in a dual-track approach, if there is a lack of regional baseline information, it is easier to trade-off regional VECs and thresholds for project specific and measurable indicators (such as a specific contaminant). Finally, how government will act if thresholds are exceeded is not entirely predictable. Similarly, the performance of Steering Committees is also unpredictable.

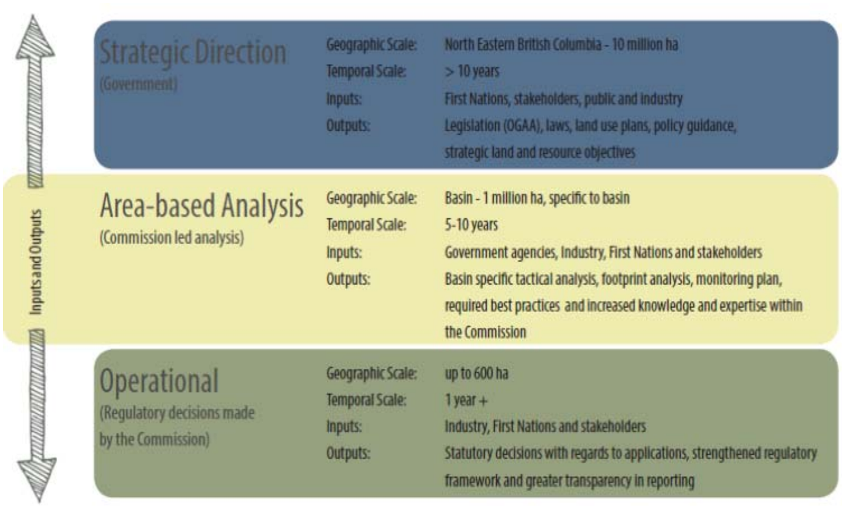
The CEAMF experience was very instructive and the BC Oil and Gas Commission (BCOGC) has led the country in developing innovative water modeling for hydraulic fracturing and comprehensive freshwater use monitoring programs. Therefore, issues and gaps the BCOGC has experienced – such as challenges with existing laws and regulations, lack of information and unpredictable institutional decision-making – are also likely to be experienced in other regions with less CEA and energy development history.

In 2013, and based on lessons learned from the experience in northeast BC, the BCOGC moved to an area-based analysis approach for oil and gas development (BCOGC, 2013). This approach was s intended to better inform regulatory decisions. It evaluates the overall landscape to facilitate management of surface and subsurface impact for the purposes of improving transparency and enabling clearer communication about what is happening at the landscape and watershed level and complements site specific values at the individual permit level. The purpose of this approach is to (ibid: 5):

- "provide a consistent process for identifying social and environmental values;
- clarify objectives set out in relevant government policy and legislation;
- analyze existing development together with opportunities for future oil and gas activities;
- provide a simplified and transparent framework to assess and manage oil and gas development impacts incorporating social and environmental values".

Of particular interest is the institutional placement for area-based analysis approach (envisioned in Figure 8.4) which positions area-based analysis between the strategic function of government policy and regulation and operational function of industry. As such, its purpose is to bridge these two functions through information exchange. The process is also intended to engage local and regional residents of the area under analysis, including First Nations. As promising as this area-based analysis approach may be, especially coupled with the BCOGC's advanced water modeling and monitoring systems, it is still in its early stages. Like the previous CEAMF experience in northeast BC, it will take time to see whether or not it can be successful in addressing existing challenges such as effectively deal with thresholds and VECs.

Figure 8.4 Area-Based Analysis as a Strategic Link



Source: BC Oil and Gas Commission, 2013:12

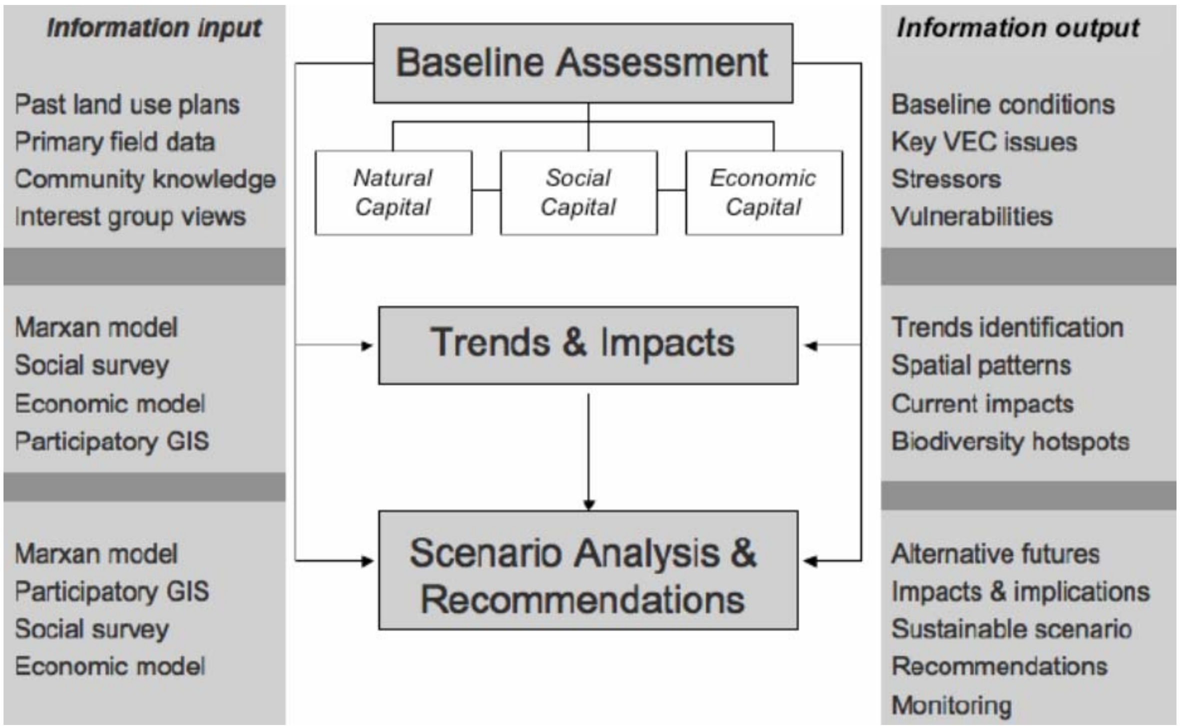
8.2.8.2 The Great Sand Hills

The Great Sand Hills is a sand dune covered landscape of ecological importance covering approximately 1,942 square kilometres in south western Saskatchewan. In 2004, a regional environmental study (RES) was initiated by the province to: “provide a strategic assessment of human activities that cumulatively affect the long-term ecological integrity and sustainability of the region” (Noble 2008:79). The results were intended to inform a regional land use management plan. As such, the Great Sand Hills RES is an important practice precedent for hydraulic fracturing in a Canadian regional context and illustrates the following (ibid):

- an R-SEA approach was used but was not legally required;
- it demonstrated an R-SEA approach in practice;
- First Nations cultural landscape interests were involved; and,
- Natural gas development and land use conflicts were involved.

The Great Sand Hills represent a large area of unconsolidated sands and native prairie. Roughly 78% is occupied by major dune complexes. Landscape topography and surface conditions have created a diverse and patchy mix of soils, vegetation and moisture conditions that support a regional ecological community that includes threatened, endangered and sensitive species as well as game species such as deer, antelope, upland game and waterfowl. There are large areas within the Sand Hills without Saskatchewan’s historical grid road pattern which makes access difficult. As a result of these conditions the area is relatively unpopulated and livestock grazing and natural gas development have been the major activities in the area since the 1950s. An estimated 70% of the Sand Hills region involves gas Leases and land leased for exploration. Specifically, Noble (2008:80) has identified “more than 23 gas companies currently operating in the region and approximately 1, 500 gas wells” with “production estimated at over 180 billion cubic feet, with reserves estimated at nearly 670 billion cubic feet”. However, only five of these 1,500 gas wells were subject to an EA under the Province’s Environmental Assessment Act (ibid). In addition to natural gas operations, ranching historically shaped the social and physical landscape of the area. The Sand Hills also are a significant cultural landscape for First Nations peoples from Alberta and Saskatchewan as well as the United States. As Noble (2008:81) states: “There are over 299 known sites of archaeological significance within the region, most of which have been discovered through surface disturbances associated with natural gas development.” The three phases used in the R-SEA framework implemented in the Great Sand Hills are illustrated in Figure 8.5 below.

Figure 8.5 Great Sand Hills R-SEA Approach



Source: Noble, 2008:82

Key R-SEA practice lessons learned from the Great Sand Hills experience include (ibid).

- A multi-scale approach is necessary;
- A "tiered" system of policy-planning-program assessment is required to move between strategic and project scales;
- A spatial analytical model for integrating and interpolating data across space and time is required.

The following section describes a type of spatial modeling software tool that can be used in an R-SEA process as identified above.

8.2.9 Regional Cumulative Effects Simulation Demonstration

Implementation of cumulative effects assessment is made difficult by the requisite future perspective and comprehensive scope. Assessment of the diverse consequences of multiple land uses and ecological processes operating over space and time is complex due to the number of interacting variables and large spatial and temporal scales involved. Computer simulation models are well suited to the task due to their ability to track numerous interacting stressors and indicators in order to project the outcomes of land-use options. Although incapable of predicting the future state of an ecosystem due to uncertainty and contingency, simulation modeling can consider a range of scenario to provide insight into key drivers and tradeoffs (Peterson et al. 2003). Computer simulation models can also play a role in overcoming the fragmentation that limits the utility of knowledge and decision-making processes to cumulative effects assessment. A computer model provides a structured approach for integrating diverse sources of information to facilitate cohesive assessment, and helps identify key knowledge gaps that should be addressed by research. If used collaboratively, a simulation model can foster improved and shared understanding among stakeholders of trade-offs associated with land use. This function is invaluable to the pursuit of broadly supported land-use decisions that balance benefits and liabilities.

To meaningfully contribute to cumulative effects assessment, a simulation model should be comprehensive in its scope. It should simulate past, present, and future impacts over long time frames and across multiple spatial scales, including large regions. The impacts of a broad suite of land use sectors (e.g., hydrocarbon development, agriculture, forestry, settlements, mining, transportation, and recreation) and strategies (e.g., best management practices, access management, development pace, and spatial zoning strategies such as protection) should be incorporated, and numerous environmental and socioeconomic indicators should be tracked to provide a holistic account of the benefits and liabilities of land-use options. As well, to integrate knowledge and foster learning across groups, a simulation model must be transparent and accessible. An example of such a model is the ALCES toolkit, which has been used extensively to inform R-SEA (e.g., Carlson and Stelfox 2014, Carlson and Chetkiewicz 2013) and WCEA (e.g., ALCES Group 2014), and is available as a web-application to promote accessibility (Carlson et al. 2014).

There is a lack of operational precedents in Canada for applying a cumulative effects approach to assessment of regional gas extraction from low permeability unconventional geological formations using horizontal wells with multi-stage hydraulic fracturing. Therefore, a demonstration case study was developed for this report and fully presented in Appendix A. ALCES was applied to simulate historical and future cumulative effects of hydraulic fracturing in an area known as Petroleum Services Association of Canada Region 2 or AB2 (ERCB, 2012). It incorporates parts of both the Duvernay and Montney shale gas formations along the eastern slopes of the Rocky Mountains in Alberta and covers 72,000 square kilometers. This area includes one third of the provincial population (including the Calgary metropolitan area) and almost two-thirds of new gas wells, the majority of which are horizontal drilled.

The purpose of the case study is to demonstrate how a simulation model, in conjunction with an R-SEA approach, could inform regional management of hydraulic fracturing through the identification of risks and mitigation opportunities, and identify key uncertainties that require further attention. Past and future consequences of hydraulic fracturing and other land uses to water use, landscape composition, wildlife (grizzly bear), and the economy (GDP and employment) were simulated. Maps and regional summaries of simulated indicator performance highlight strategic issues that require attention, including: a) oil and gas plays are susceptible to cumulative effects due to the sector's dispersed footprint and spatial overlap with other stressors; b) water use by fracturing is likely to be substantial but below that of other major water consumers including municipalities and agriculture; c) development of previously uneconomic reserves may cause industrial footprint to expand into previously intact regions, with negative implications for sensitive wildlife; and, d) land-use zoning is a promising strategy for balancing the economic benefits and environmental risks of oil and gas development.

The simulation outcomes were sensitive to uncertainties, emphasizing the importance of improved understanding of hydraulic fracturing's impacts. A sensitivity analysis completed using ALCES reinforces the importance of research priorities identified elsewhere in this report, such as: water requirements for fracturing, and the extent to which it can be reduced through energized treatments and use of saline water (Chapter 4); and quantitative study of economic and environmental impacts such as landscape disturbance (Chapter 7). Addressing other research priorities identified in the report would permit additional indicators to be simulated, most importantly variables related to water availability (as discussed in Chapter 4) and water contamination (as discussed in Chapter 6).

Cumulative effects assessment is contextual and 'place-based'. This means assessment is specific to a geographic area or geologic formation and not universal in all situations. As such, conclusions from the case study cannot be assumed to apply elsewhere. Rather, completion of similar simulation modeling exercises in other jurisdictions would provide the futures-orientated and holistic perspective needed to address the cumulative effects of hydraulic fracturing. In such studies, the suite of indicators should be selected to inform key planning issues. For example, the use of the Grizzly Bear Exposure Index illustrates how the cumulative effects of unconventional petroleum development might affect a particular VEC. The model is very flexible in allowing the users to select VECs of most value to a particular purpose. Careful selection of indicators will ensure that simulation outcomes are relevant to stakeholders and decision makers, as will the use of simulation models that are accessible to planning participants. The importance of relevance and accessibility cannot be over-emphasized, as it determines the extent to which simulation modeling can engage and inform participants in the planning process.

8.3 Key Knowledge Gaps Tables

The following tables identify priority knowledge gaps about CEA for Landscape and Watershed Impacts that could, if addressed, advance knowledge for decision-making. However, it should be noted that effective CEA requires more than just improved data collection. Specifically, "[f]or an assessment to be useful, it must feed back into the regulatory process, providing managers (and decision-makers) with a guide for future assessments and mitigation measures" (Squires et al., 2012:389). While CEA is a system for *detecting* and *assessing* Landscape Impacts, it also is a process for creating future scenarios and monitoring change to help decision makers manage landscape scale change for desired outcomes (Pike et al., 2010). CEA includes "watershed assessment" which is a relatively new science involving emergent modeling programs based on a range of theoretical approaches (values based, stressor based, effects based) and 'pilot' or demonstration projects such as "model rivers" (Squires et al., 2012).

The range of approaches identified in the table below are both qualitative and quantitative, and reflect current knowledge about CEA processes including regional scale value-setting by diverse stakeholder groups coupled with science-based indicators that can be measured over time and modeled as performance objectives . For each identified knowledge gap, at least two approaches are provided as first steps for developing agreed upon methods to assess multiple types of cross-scalar effects (Squires et al., 2009).

There are four priority CEA knowledge gaps:

- historical and region specific data gaps, including baseline data about Landscape Impacts and results of monitoring over long periods of time;
- collaboratively sanctioned systemic approaches and methods for establishing valued ecological components (VECs) needed to set performance objectives and assess Landscape Impacts;

- inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts; and,
- integrative and collaborative institutional CEA decision-making frameworks for managing Landscape Impacts.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

14. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Region-specific valued ecological components (VECs) for Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: 5-10 pilot studies in different regions of Canada that are experiencing rapid growth in hydraulic fracturing at the watershed or landscape-scale. Bring together sufficient numbers of region-specific stakeholders to determine valued ecological or ecosystem components of the landscape that could help determine indicators of landscape health and could be monitored over time to detect trends or changes.	High	Needs a qualified coordinator of the 5 -10 pilot projects and qualified facilitators with knowledge of VECs and fracking	High	High Could be done by provincial regulatory bodies	$25,000 for each project and $50,000 for project coordination and reporting	1-2 years	Overall strongest approach for achieving the desired outcome. The results from each region could be analyzed and correlated across the country to find national VECs. Creates places for knowledge sharing and creation through face to face interaction among diverse stakeholders in 5-10 regions in Canada. Weaknesses: it takes time to develop the parameters of the study and to identify the key stakeholders who should be at the table. Costs can escalate if many meetings of stakeholders are required to finalize region-specific reports.
Qualitative research: national online survey targeting 5-10 regions where fracking is a growing industry	Moderate	Low – moderate Needs qualified survey design and analysis	High	High University programs or professional consultants could work with provincial regulatory agencies to design, administer and analyze results	$100,000.00	6 months-1 year	Strengths: Easy to administer and no need for meetings. Tools exist for achieving desired outcome and just need to be applied. Professionally designed and conducted survey with analysis and report comparing region-specific VECs across the country.

Qualitative research: regional scale facilitated workshops in 5-10 locations in Canada to develop region-specific VECs for fracking impacts on the landscape.	Moderate May not have enough time	Low	High	Workshops could be conducted by provincial department or by governance networks or consultants.	$15,000 per workshop and $50,000 for project coordination and final reports.	6 months-1 year	Strengths: relationship building and knowledge sharing at the regional scale. Less costly than pilot projects. Less time needed to organize and develop the program to achieve outcome. Weaknesses: identifying workshop participants may take time. Not enough time in one workshop to fully develop concepts of VECs or cumulative effects of fracking on landscape. Would require some time before and after the workshops by professional workshop facilitators.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

15. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Region-specific indicators of landscape health based on VECs for managing Landscape Impacts

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Quantitative research: 5-10 pilot studies in watersheds/landscapes in different regions of Canada: based on region-specific data and using best available science and software modeling programs like BASINS, set baseline “reference condition” of landscape/ Watershed.	High	High	Low	High	$250,000 Depends on who does the work and how many pilots are conducted to achieve outcomes	2-3 years to establish pilots, develop conceptual framework and principles and 2-3 years to develop set of indicators for use across Canada. Given the variety of landscapes, watersheds in	Strongest research approach using science to establish reference condition of landscape/watershed in 5 regions of the country to establish similarities and differences in national “indicators” of landscape or watershed health. Weaknesses are that there are few agreed upon conceptual frameworks or principles and processes to develop indicators of landscape health and the indicators of watershed health are usually related to surface flowing water bodies. Also, costs would be extensive to establish

						Canada, this may not be possible, but may need to be region specific.	
Quantitative research: 5-10 pilot studies in different regions of Canada using VECs and baseline of landscape or watershed, set indicators of landscape health that can be monitored over long periods of time. Use modeling programs such as ALCES (see appendices) or watershed health assessment tool like THREATS. (see Squires et al.., 2012.)	HIGH	High	Low	High	$200,000	2 years	Strength is that indicators would be developed by experts and put in place in different river basins and landscapes and monitoring could begin right away. Weakness is that indicators would be based on current knowledge from pilot projects and might not be transferrable from one model river system to another. Also, there is very knowledge about indicators of landscape health and how to detect and make predictions, except possibly ALCES model.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

16. CEA: Historical and region specific data gaps including baseline data about Landscape Impacts, and results of monitoring over long periods of time

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing and testing region-specific monitoring and modeling programs of indicators for performance objectives of managing Landscape Impacts

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Quantitative research: 5-10 pilot studies in different regions of Canada. Test existing monitoring and modeling programs for a set of landscape health indicators relevant to all the 5 regions that could be used as predictive models, scenario description and selecting management objectives	High	High Would need to be national study with scientific coordinator of the pilot projects	Low	High	Unknown- depends on who does the research	4-5 years	Strong approach to developing scientific tools. Would be expensive and take a long time to develop and test monitoring and modeling programs and processes for reliability and robustness as predictive tools for managing Landscape Impacts over time. Would move toward R-SEA approach.

to achieved preferred future states. Need to move from project to project (stressor) studies to (effects-based) R-SEA approaches.							
Quantitative research: 5-10 regions in Canada on a "paired-watershed" basis (Squires et al., 2012). Develop region-specific monitoring and modeling programs to determine if the models can be rolled up to be used in other regions. Would require R-SEA approach to CEA.	High	High Requires experts in landscape dynamics and complex system dynamics	Low	High Models already exist as prototypes	$250,000	2-3 years	Strong approach based on existing research literature, models and methodologies for watershed assessment of model rivers in Canada. Weakness is that current models etc, are all based on flowing surface waters and are not landscape based. Would need to develop indicators of landscape health based on reference conditions before hydraulic fracturing and then compile large amounts of data over large time scales to create models and predict scenarios. See ALCES model and Human Footprint models that do not consider flowing surface water, but other land use impacts.
PhD research: literature and on-line, conference attendance and interview research with experts to compile a compendium of best known monitoring and modeling programs for detecting and predicting Landscape Impacts. Would explain purpose, application and strengths and weaknesses of each model or program.	Moderate Based on what is known and no new knowledge created	Moderate Student would need to understand monitoring and modeling programs and how they are developed and for what purpose.	High	High	$45,000 - $80.000	2-5 years	Strength is that the PHD student would compile all existing models and programs for decision-makers and explain the design strengths and weaknesses for each model. Major weakness is that this is compiling what is known and no new knowledge would emerge. Could design the project to propose a "best" model for certain regions and Landscape Impacts.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

17. CEA: Collaboratively sanctioned systematic approaches and methods for establishing valued ecological components (VECs) for setting performance objectives and assessing Landscape Impacts

Developing collaboratively sanctioned systematic approaches and methods for establishing valued ecological components (VECs) and setting performance objectives for managing Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: Literature and online research with interview input from government departments across Canada to develop summary of systematic approaches and methods for establishing valued ecological components (VECs) and setting performance objectives for managing Landscape Impacts. Summary would need to be tested with experts in a collaborative process –see approach below	High	High	High	High	$50,000-80,000 Depends who does the research	2-3 years	Strong research to create a compilation of methodologies used across Canada and potential for peer review and testing. VEC development requires knowledge of communities at a regional scale, and when working on a national project to design the "best" approach for developing VECs to inform selection of indicators and performance outcomes could be expensive and time consuming. Requires a dedicated person to develop a compilation to then be tested by experts. Weakness: this is an emerging field of knowledge and requires expert knowledge of system dynamics and collaborative processes during crisis or change scenarios. Not much is known about Landscape Impacts, but new knowledge is emerging.
Qualitative research informed by experts. Expert panel or workshop to review the summary of VEC setting processes and collaborate to design a sanctioned process that may work in different regions of Canada.	High	High	High	High Could be done through gov't depart.	$100,000 - 200,000	1 year	Strength would be to create a collaborative process for experts to design a system for establishing VECs that would be sanctioned by scientists at a national scale as a "best practice."

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

18. CEA: Inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing inter-jurisdictional and trans-boundary regulatory frameworks, and non-regulatory approaches to CEA of Landscape Impacts (see Chapter 9)

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative research: Graduate student using this report as a baseline of current literature on inter-jurisdictional and trans-boundary regulatory frameworks and non-regulatory approaches to CEA of Landscape Impacts compile and analyze a "state of report" to inform decision-makers of what is currently being done.	Moderate	Low	High	High	$45,000-85,000 Depends on who does the study.	1-5 years	Strong approach for creating baseline of information. Would be least expensive and fastest option for informing decision-makers about regulatory and non-regulatory systems that are already being used in Canada. Comparative analysis of provincial systems would be of benefit to understand regional disparities and needs for resources, data, etc. Weakness: There is very little literature or knowledge specific to CEA in Canada because this is an emergent field of study.
Qualitative research informed by experts: An expert panel could be assembled to collaborate and sanction a "best" approach for regulating or implementing CEA through R-SEA or other similar approaches	High Based on existing or baseline knowledge	High	High	High	$100,000 Should be federal gov't Program to learn more about CEA and R-SEA and how to regulate processes or support non-regulated processes	2 years	Would be integrative, collaborative and would create public space for co-creation of new knowledge or advancing knowledge about regulations for CEA or R-SEA approaches. Research and expert review would flow from this report ensuring benefit from investment.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

19. CEA: Integrative and collaborative institutional CEA decision-making frameworks for managing Landscape Impacts

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Developing integrative and collaborative institutional CEA decision-making frameworks for managing Landscape Impacts

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research: using this report as a baseline of current literature for decision-making frameworks in Canada, Graduate level study to compile and analyze how CEA of Landscape Impacts is currently being used by decision-makers to regulate hydraulic fracturing. Study could propose a "best" CEA decision-making framework based on the literature to be tested by experts.	Moderate	Low	High	High	$45,000-85,000 Depends on who does the study.	1-5 years	Strong approach for creating baseline of information about CEA decision-making frameworks to be tested with experts. Would be least expensive and fastest option for informing decision-makers about processes that are already being used in Canada. Weakness: There is very little literature or knowledge specific to CEA decision-making frameworks in Canada because this is an emergent field of study.
Qualitative research informed by experts: An expert panel could be assembled to collaborate and sanction a "best" CEA decision-making framework for Canadian decision-makers when regulating hydraulic fracturing.	High Based on existing or baseline knowledge of CEA decision-making frameworks in Canada	High	High	High	$100,000 Should be federal gov't Initiative	2 years	Would develop some systematic decision-making frameworks for use by decision-makers. Would be integrative, collaborative and would create public space for co-creation of new knowledge or advancing knowledge for decision-makers.

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9 POLICY LEGAL, AND REGULATORY KNOWLEDGE GAPS ABOUT LANDSCAPE IMPACTS OF HYDRAULIC FRACTURING DEVELOPMENTS/OPERATIONS ON SURFACE WATER/WATERSHEDS

9.1 INTRODUCTION

Leading research approaches from relevant disciplines to fill key knowledge gaps for decision-makers about policies, laws and regulations to manage landscape impacts of hydraulic fracturing on surface water/watersheds (Landscape Impacts) have been summarized and integrated in the **Research/Literature Review** section below, followed by **Key Knowledge Gap Tables** and **Reference Materials.**

9.2 RESEARCH/LITERATURE REVIEW

9.2.1 Context Matters

Legal, regulatory and policy frameworks for hydraulic fracturing reflect the complex, dynamic social-ecological systems in which they occur. In the Canadian context, the provinces own oil and gas resources and determine when, where, and how energy resources will be developed in the "public interest." Each province regulates hydraulic fracturing according to complex policy and regulatory schemes that reflect their citizens' shared values and desired outcomes for resource extraction. Policies, laws and regulations need to be flexible to address regional variation. For example, surface water availability varies significantly within provinces and requires context-specific approaches to regulating Landscape Impacts.

9.2.2 Policy Precedes Regulation

On Canadian landscapes where hydraulic fracturing is occurring, politics often trumps policy for regulating resource extraction. Politicians can no longer easily convince stakeholders and industry that government regulations are the best way to manage potential Landscape Impacts.

Policy development precedes legislation that guides industry's behaviour and upholds the public interest in resource extraction. A techno-economic revolution is occurring in unconventional oil and gas production that the public perceives could negatively impact surface waters and watersheds. Public policy to address these perceptions is emerging across the country. Policy is a choice informed by evidence, and there is increasing public pressure to identify and fill knowledge gaps about what is crucial in regulating and managing hydraulic fracturing at the landscape or watershed scale.

Identifying knowledge gaps associated with these issues highlights how legal institutions, governance structures and decision-making processes can either promote or constrain patterns of communication, policy learning, networking, citizen engagement, and knowledge brokering about Landscape Impacts. How hydraulic fracturing is currently being regulated on Canadian landscapes reflects emergent technical-policy decision making processes that are being reviewed and reconsidered. Five processes guided and informed the identification of key knowledge gaps noted in this chapter, as follows:

- new public management practices;
- hyper-partisanship;
- the decline in the status of experts and networks that historically played a role in knowledge construction processes;
- declining policy capacity (political/financial) resources; and
- a pattern of intergovernmental relations that is bilateral and more informal (outside the public view).

The key knowledge gaps to addressing Landscape Impacts are largely institutional. Both Canada and the United States (US) are advancing knowledge about institutions. For example, it is no accident that in Alberta, play-based regulation and the “one window approach” to regulation have recently emerged after years of hydraulic fracturing on Alberta landscapes. In Canada, the debate over potential Landscape Impacts is driving some provinces to find ways to resurrect and defend old ideas about the role of the state, and the need for regulation. Since the 1980’s, the assumptions of individualism and rational self-interest have dominated, and old ideas about the need for centrally prescribed rules and processes have been replaced. As a result, financial and personnel resources are directed from program delivery to measuring outcomes, providing more information, and managing processes for industry. The dominant neo-liberal paradigm needs to be contested and the case made that regulations do matter for constraining individual behaviours within complex social-ecological systems. Notions of regulation; links between individual-collective behaviour; and how legal institutions might be designed to achieve “best practices” to manage Landscape Impacts are important knowledge gaps for decision-makers.

9.2.2.1 New Public Management Practices

The rise of a New Public Management (NPM) paradigm decentralized information sharing, challenged and demonized traditional legal institutions/values, and reinforced competitive, individualistic, citizen-centred, silo-based approaches to implementation. NPM is connected to current decision-making knowledge gaps about managing Landscape Impacts in the public interest.

Savoie (2013) says there is a search to rethink NPM, re-integrate knowledge, and regain trust and legitimacy (social license) through new “formal rules and institutions” and investment in policy capacity. Winning back public support and faith in science, experts, and formal institutions is a contest between old Weber-inspired institutional models and the new economic-based theories connected with NPM.

New approaches to knowledge creation and agenda setting (problem definition) tend to emerge when conditions are changing. A crisis that cannot be defined or resolved by the old NPM regime will require adjustment, flexibility, innovation, or replacement, because regime survival depends on identifying gaps, and reconstructing ideas, institutions, and interests. NPM itself emerged in a period of fiscal crisis, and promoters of a knowledge approach took advantage to push change in that direction. Whether defenders of the historical Weber-inspired institutional framework and regulations can successfully contest embedded NPM practices that are not well suited for managing Landscape Impacts will depend on strategy and power, and on creating public spaces essential for dialogue in healthy, democratic social-ecological systems.

The literature offers different strategies for effecting policy change. Structural theories such as incrementalism, culturalism, and institutionalism suggest policy outcomes depend on structural factors. One approach to policy transformation involves gradually reforming the system from within, and integrating new forms of knowledge, ideas, and processes, incrementally. For example, NPM evolved over decades. At the opposite end of the continuum, pluralists (dynamic theorists) assume that policy and regulatory change can happen quickly, as long as there is public and transparent competition. Pluralists see knowledge gaps being filled quickly in the process of interest group competition, and are less concerned with environmental and structural conditions.

9.2.2.2 Hyper-partisanship

Governing is a difficult balancing act where governments must not only pay attention to the opinions of their citizens and conditions abroad, but also science. For political decision-makers the risks of entering into a debate about Landscape Impacts are very high due to polarized interests.

Knowledge construction and brokering is influenced by those in power, and the processes that exist for promoting patterns of competition or collaboration in managing Landscape Impacts. A crucial question is how mechanisms for knowledge construction about those issues are designed. Water scarcity and supply questions set rival stakeholder interests against one another, and regulation involves the power to control those behaviours. Ranchers, farmers, urban communities compete over scarce resources: they have different ideas on appropriate allocation. When formal rules change, so do patterns of discourse and knowledge construction.

Power is reflected in formal organizations and regulations. Regulations and the rise of scientific discourses naturally complicate political decision-making, making it more technical. This can work against efforts to engage citizens while taking into account their competing values about what needs to be regulated. Embedded decision-making structures and processes do not just happen by chance, but reflect power relationships within society and governments. Formal rules are set by government actors who must constantly balance different interests (both internal and external) and perspectives on energy requirements and water usage. But government institutions are also complex: different departments perform different functions in silos, shaped by dissimilar patterns of knowledge construction and brokering. While organized non-government groups are important to policy-political discussions, government is not a monolith, and those in power have their own interests (for example foreign versus domestic policy). Governments also compete for power and influence both domestically and externally.

From a historical perspective, the US has been more integrated than Canada, whether from a cultural or institutional perspective: generally, it has been easier to identify knowledge gaps about regulating Landscape Impacts and address them from a national perspective (Gibbins 1982). Within the context of an integrated party system and an intrastate form of federalism, there was much more opportunity to collaborate on a national basis (Bakvis and Skogstad 2008). In the US hydraulic fracturing represents an opportunity to address challenges of energy self-reliance, improve the environment, and promote national security issues abroad. It is seen as a “game changer” and opportunity to use energy to promote US interests, ideas, and institutions both domestically and around the globe (Kalicki 2013).

In the US hydraulic fracturing policy and restructuring have become important priorities in the field of foreign relations. While the industry remains controversial, it is of strategic importance in the areas of both foreign and domestic policy (Tomblin and Colgan; forthcoming), and closely connected to American power and dominance both within the continent and abroad. In the new world order, when the Russians, OPEC and other competitors have been forced to recognize and acknowledge the increasing competition posed by US-inspired hydraulic fracturing technology and global restructuring, there is incentive within America to actively rethink the role of the state, build capacity and create a more legitimate approach to knowledge construction. At a time when the Russians appear to be trying to mobilize protest movements against the new US driven energy revolution that poses a threat to their sphere of influence (New York Times, 2014), and the ruble is rapidly losing value, it is important to acknowledge that knowledge gaps about Landscape Impacts are not strictly technical.

9.2.2.3 The decline in the status of experts and networks

In Canada a new form of intergovernmental governance has emerged and legislatures, citizens, courts, and interest groups have become more outliers or spectators instead of participants. It has become difficult to build knowledge networks, communicate, or mobilize support. The idea of regulating energy production is openly condemned by the national government, and criticized at the provincial level. For example, one of the three key objectives of Alberta’s new play-based regulatory framework is to “avoid imposing unnecessary regulatory burdens on industry” (ERCB, 2013:2). On the other hand, there is a growing recognition of a democratic deficit problem and the need to create stronger institutions, better regulation, and new patterns of interfacing about Landscape Impacts that affect everyone. Even industry sees the need for social license to operate, and is finding ways to win back public trust while improving environmental outcomes. There is growing interest in finding new ways to share community, expert, and decision-makers’ knowledge in a way that is more integrated and less competitive. Much depends on rethinking the role of institutions in managing government-society relations.

9.2.2.4 Declining policy capacity

There is growing interest in strengthening trust in institutions and building policy capacity that is less focused on economic-centred ideas (Savoie, 2013). Policy literature identifies why knowledge gaps and declining policy capacity have emerged in recent decades as problems for decision-makers. Savoie (2013) argues that beginning in the 1970’s, economic-centred frames (example: public choice, rational choice, and principal agent theories) provided justification for slashing and contesting old patterns of decision-making, knowledge networks, and institutions.

Whether in Canada, the US or Europe, knowledge construction is a carefully managed technical-political balancing act in context. Policy capacity determines whether policy objectives can be achieved and policy gaps resolved. Critical factors in building policy capacity include: knowledge resources, well trained workforce, strong organizations, and capacity development both within and outside of government. These are essential for developing sound policies, effective implementation strategies, and constant monitoring and evaluation of data required for policy/political success.

Not all jurisdictions have experience or the same knowledge about hydraulic fracturing. It will naturally be more difficult for jurisdictions, like New Brunswick, to find the essential financial and material resources for start-up costs to policy development. As a result, provinces must learn from each other to fill knowledge gaps about policy, laws and regulations to manage Landscape Impacts.

Recognition and acknowledgement of asymmetry in levels of policy capacity in provinces, and municipalities, is an important first step to address knowledge gaps for decision-makers. Knowledge gaps with respect to lack of personnel, technical expertise, and infrastructure impact the ability to develop and implement policy, assess risks, or monitor outcomes for managing Landscape Impacts in the public interest.

Even if there are formal rules and regulations, policy objectives cannot be realized unless there are sufficient resources (financial, human knowledge, organization) to support monitoring and enforcement. People responsible for implementation must be trained, and have technical/administrative skills required to effect change. Decision-makers need to know which resources are essential for policy and regulatory design and implementation when managing Landscape Impacts, and consider the budgetary implications of providing those resources in the public interest.

9.2.2.5 Pattern of bilateral and informal intergovernmental relations

Good public policy requires knowing how to construct and promote a common vision that is designed to define and solve a problem. Knowledge gaps exist regarding how to bring different interests together, construct a common vision, and then promote action to manage Landscape Impacts. Policy capacity does not just exist within a black box of government. It also depends on civil society. Academic networks, think tanks, non-profit organizations, and the market sector are all very important to building overall policy capacity required for managing Landscape Impacts.

Practical matters of policy and regulatory implementation are also yawning knowledge gaps. How to build strong organizations, work across silos, maintain, recruit, and train staff, decide how to organize and interpret knowledge resources (qualitative/empirical data) are all major concerns identified in the literature about policy, law and regulations to manage Landscape Impacts.

While there have been efforts through the Canada-US Free Trade Agreement (mid-1980’s) and North American Free Trade Agreement (1994) (NAFTA) to promote more effective integration, facilitate policy learning and manage energy-environmental interdependence better, these efforts have not been effective due to limited resources and political will. The ongoing reliance on a system of transgovernmental relations that has never been very visible has not helped the integration cause (Tomblin and Colgan: forthcoming; Healey 2014). In order to move from “government” or political decision-making to “good governance” or more functional decision-making, there needs to be more investment in new cross-jurisdictional forms of knowledge construction and capacity building that are more open to the public.

There have been attempts to find ways to work together, share knowledge, respect differences, bring in civil society, and learn from one another. For example, under the environmental side agreements for NAFTA, in particular, the Commission for Environmental Cooperation (CEC) initiative, emphasis was placed on improving environmental governance (Healey 2014). These structures were carefully designed to facilitate new forms of integration, bring together government decision-makers, experts, and the nongovernmental community together in a way that would make it easier to share knowledge and develop a common mental map. While these processes have offered potential when it came to filling knowledge gaps about the energy/environment interface, the biggest problem has been the lack of political support and resources.

With the recent collapse of the New England Governors and Eastern Premiers Conference (located in Boston) and move to the more informal Coalition of Eastern Governors in DC, there are clear signs that the sub-national forums relied upon in the past to promote integration and address knowledge gaps are losing momentum (Tomblin and Colgan 2004, forthcoming). Policy coordination has gotten worse, not better with the abandonment of these sub-national regional forums that provided a public place where environmental and energy interests could gather in public, discuss and debate common policy challenges. The move towards a model of intergovernmental relations that is more informal, behind closed doors, and is dominated by regulators and politics has worked against the goal of improving energy/environmental governance and public policy in the northeast region of the continent (Graefe 2013).

Issues of energy production, environmental sustainability, and human health tend to be discussed in separate, competitive silos, and this has complicated the process of knowledge exchange and policy learning. It has been difficult to facilitate knowledge brokering and policy learning across both policy fields and jurisdictions that are silo-based, insular, and highly competitive. But the US has incentive and power to build new national ideas, networks, and institutions essential to reorganize and rethink energy, economic, environmental, and national security interests about hydraulic fracturing. Given cross-border relationships and free trade agreements, the American quest for a new dominant vision for energy empowerment will influence patterns of power and decision-making in both Canada and Mexico.

In Canada, none of the current contextual approaches to regulating or managing Landscape Impacts will be easy to change. In the past, provincial autonomy often trumped expert economic analysis, and this was reinforced by an executive system that made it possible to hide the real costs associated with building competing north-south transportation and energy institutions, governance structures and decision-making processes. While patterns of bilateral and informal intergovernmental relations flourished, citizens were treated as spectators, and community knowledge never received much attention. Hydraulic fracturing issues like Landscape Impacts are still approached in inherently competitive government departmental silos that impede stakeholder agreement on how new knowledge, policy, laws and regulations should be constructed.   Canadian federal and provincial governments still see government institutions as capable of resolving complex, dynamic social-ecological system problems with scientific tools in a market-driven system with public consultation an add-on process to be addressed (see AER, 2014).

9.2.3 Identifying Knowledge Gaps

Discussions with provincial, state, federal, and a diverse range of civil society actors in both Canada and the US (Tromblin et al., forthcoming) highlighted some knowledge gaps about policy, laws, and regulations to manage Landscape Impacts. Several critical themes emerged from those discussions that informed the **Key Knowledge Gap Tables**:

1. **Relatively weak federal presence**. The Government of Canada was perceived to have a limited role in the era of energy-environment discourse. Respondents noted a reluctance to engage or create public spaces essential for bringing different interests and encouraging information/knowledge sharing essential for good governance. In the US, there was more federal action on defining problems, but a weak federal presence when it came to policy implementation and enforcement of regulations.
2. **Relatively weak municipal/state/regional/continental policy capacity**. Many states, regions (both within and across states) municipalities, and continental structures lack personnel, training, technical expertise, political will, and resources required to implement, monitor regulations, share knowledge, and promote social learning.
3. **Issue of legitimacy and democratic deficit.** Disconnect with the general public is leading to growing cynicism, and lack of trust in government, experts, and long-term planning. Knowledge gaps exist regarding the need to convince the public that both anticipated and unanticipated Landscape Impacts can be addressed in a balanced way.
4. **Decline of regional cross-border institutional capacity and knowledge**, rise of a more bilateral, informal system of intergovernmental relations that is disconnected from the legislature, interest groups, and citizens. There are knowledge gaps about how to work across competing, insular, complex institutions and structures.
5. **Declining role of knowledge networks** to sustain legitimate discourse about Landscape Impacts.
6. **Market volatility and risks associated with public investment in physical infrastructure** and expensive regulatory frameworks that require constructing knowledge, constantly evaluating prices, and building policy capacity.
7. **Impacts on other energy projects and priorities:** hydro, wind, solar.
8. **Challenge of multi-level governance and silo-based traditions of knowledge sharing** that are not well designed for addressing "interdependent issues" or complex system dynamics that fall across jurisdictions and policy fields. Informal structures built in the past to address such problems (and facilitate knowledge sharing) have lost momentum.

Public policy decisions can be explained differently (depending on the policy field and the framework employed) and comparative analysis is needed. Policy decisions are not inevitable: they are the products of socio-political knowledge construction in context. The 21st century is an era of post-modern/post-positivist/New Public Management approaches, public cynicism, and increased social media capacity, making the empirical task of separating facts from values more difficult and open to challenge (Howlett 2009). Canadian values about Landscape Impacts remain unknown.

9.2.4 Searching for Approaches to Fill Knowledge Gaps

Water management and human health and safety are critical policy themes for regulating hydraulic fracturing. But, other knowledge gaps about managing Landscape Impacts require policy development about stakeholder engagement (social license) (see Chapter 3). The International Energy Agency (2012) produced "golden rules" or standards intended as a model for build and sustain an effective regulatory regime for managing Landscape Impacts. The "golden rules" emphasize the importance of "measuring, disclosing, and engaging," which are recommended research approaches to resolving policy and regulatory knowledge gaps.

The need to engage communities in each phase of shale gas development; establish baselines for essential environmental indicators (such as water quality); measure and disclose data on water use and water quality over relevant periods of time; disclose fracturing materials; and so on, has been repeated by the Alberta Energy Regulator (AER, 2014), the American Petroleum Institute, Enform, the Canadian Association of Petroleum Producers, state departments, and others. Knowledge gaps about how to resolve each of these policy issues cannot be addressed without agreed upon values, and best practices to sustain those values, that can be monitored across regions and provincial regulatory systems.

Given the historical importance of energy restructuring for major powers such as the US, attention is being focused on identifying knowledge gaps about Landscape Impacts and finding ways to bring about changes to defend American power and influence on the continent and around the globe (Kalicki 2013). In the US, energy restructuring, hydraulic fracturing, and foreign domination are part of the push to find new ways to identify and fill knowledge gaps about policy, laws, and regulations to manage Landscape Impacts, mobilize coalition support (both domestically and abroad) and facilitate a regime change (new dominant ideas, interests, and institutions).

Energy and environment discourses have played out differently in the Canadian context. There are no policies or visions of energy-environmental restructuring at a pan-Canadian level (Tomblin 1995, Bradford 1998). Particularly since the collapse of the National Energy Program (NEP) in the 1980's, energy/environmental issues have been avoided by the national government, accompanied by reluctance to construct a national discourse or even participate in an international one. The hard lifting about policy development to manage Landscape Impacts has been left to the provinces.

Canadian federalism is well known for internal divisions and rivalries about energy sources and energy regulation. As a result, hydraulic fracturing is perceived differently among provinces with individual interests, audiences, and institutions. Province-building and hydro-electric power (hydro) as an instrument for defending boundaries and jurisdictional power has a long history in Canada, whether in Quebec, Manitoba, British Columbia (BC), Newfoundland and Labrador (NL), or Ontario (Tomblin 1995, Bradford, 1998). Energy comes in different forms and balancing technical and political decision-making across policy fields or jurisdictions is not easy.

In Canada, agreeing on policy and regulatory knowledge gaps about Landscape Impacts or how they might be filled is difficult. For example, while hydro is considered green, it not considered that way in many US states. Rather, hydraulic fracturing that is replacing coal-generated electricity (that has been a popular US federal policy) competes with hydro (Tomblin and Colgan, forthcoming). This might explain why hydro producing provinces like Quebec and NL chose to impose moratoria on hydraulic fracturing.

9.2.5 The Provincial Context

A central concern for using surface water for hydraulic fracturing relates to how water should be allocated, permitted and managed in the context of existing land uses, while maintaining ecological function and performance. While some provinces have promoted hydraulic fracturing using surface water and have put in place formal rules to regulate behaviour and build capacity/knowledge for effective management and policy learning, others have made a non-decision by imposing moratoria until more is known about potential impacts on human health, water and ecosystems.

Differences in provincial policy, legal, and regulatory frameworks for hydraulic fracturing create a ragged patchwork across Canada. In some provinces like BC and Alberta, complex policies and regulatory frameworks have emerged along with rapid exploration and industrial expansion made possible by new hydraulic fracturing technologies. Both BC and Alberta learned early that policy and laws appropriate for regulating production of conventional oil and gas were not appropriate for regulating hydraulic fracturing (BCOGC, 2012; ERCB 2011; AER, 2014). In other provinces, like Manitoba and Saskatchewan, policy and regulatory innovation has failed to keep pace with increased interest and exploration for unconventional resources. Provincial governments in Eastern Canadian provinces, like Quebec, Nova Scotia and recently, NL have enacted moratoria.

In the US, hydraulic fracturing has also been perceived differently in dissimilar states, regions, and communities. While Texas, Pennsylvania, Montana, among other states have enthusiastically embraced the industry and put in rules to encourage its growth, states like California and New York have put moratoria in place. In New York, Governor Cuomo was originally supportive, but this changed quickly when public opinion changed, and strong opposition mobilized. New York is now in a holding position.

Table 9.1 How the Canadian provinces and territories are regulating hydraulic fracturing (2014)

Province or Territory	Unconventional policy	Unconventional regulation	Unconventional "good engineering practices"	Moratorium vs. rapid expansion
Alberta	Play-based pilot	*Responsible Energy Development Act*-New play-based regulation pilot supported by AER and AEMERA: see text below for entire regulatory scheme.	No but these are being developed as "Directives"	Rapid expansion
British Columbia	Area-based policy	Area-based regulations supported by NEWT; BC Oil and Gas Commission	Good engineering practices developed and implemented	Rapid expansion
Manitoba	No	No	No	Neither
New Brunswick	No	No	No	Neither-some talk of a moratorium/others rapid expansion
NL	No	No	No	Moratorium
Northwest Territories	Yes	The regulations will follow the *N.W.T. Oil and Gas Operations Act*, which came into force on April 1, 2014.	No	Neither – 2013 and 2014 issued approvals to Conoco Phillips with Husky lined up for approvals
Nova Scotia	No	No	No	Moratorium
Nunavut	No	No	No	Neither

Ontario	No	No	No	Neither
Prince Edward Island	No	No	No	Neither
Quebec	No	No	No	Moratorium
Saskatchewan	No	No	No	Neither
Yukon	No	2014: Yukon Government is in consultations for developing policies.	No	Neither

In 2013, the Alberta Legislature changed the regulatory system for regulating and controlling the development of all energy resources. With the enactment of the *Responsible Energy Development Act* (REDA), the Alberta Energy Regulator (AER) was created to replace the Energy Resources Conservation Board to regulate the development of energy resources in Alberta, including oil, natural gas, oil sands, coal and pipelines. To receive an approval for proposed hydraulic fracturing projects, proponents must apply to the AER through a one-window application process. "Today, the AER is the single regulator of energy development in Alberta—from application and exploration, to construction and development, to abandonment, reclamation, and remediation" (AER, 2014: website). Large hydraulic fracturing projects may require an environmental impact assessment by AER under the *Environmental Protection and Enhancement Act* provisions to enable the AER "to consider the environmental impact assessment when evaluating the overall public benefits of a proposed project." REDA sets out the "mandate, structure, powers, duties and functions" of the AER.

Alberta is exploring regulating hydraulic fracturing from a "play-based" perspective. Complexity increases when developing play-based policy and regulations for regional-scale strategic environmental assessments and management systems. "Play-based regions" do not necessarily follow surface watershed boundaries, or cultural, historical or social-political boundaries, or any surface system traditionally associated with the "regional scale."

Alberta's Play-Based Regulation Pilot flows from research and discussion among stakeholders over a number of years while hydraulic fracturing was occurring province-wide on an exploratory basis. In 2011, ERCB conducted a jurisdictional review of unconventional gas regulatory frameworks in Canada and the United States (ERCB, 2011). Based on the results of that research, in 2013, ERBC began discussing how regulating hydraulic fracturing should unfold (ERCB, 2013). ERCB introduced a framework to "address the unique issues, risks opportunities, and challenges posed by unconventional resource development" (ERCB, 2013:2). The framework's objectives were threefold, to:

- clearly identify and mitigate potential risks to public safety, the environment, and the resource;
- ensure orderly development; and
- avoid imposing unnecessary regulatory burden on industry (ERCB, 2013:2).

To meet regulatory challenges, such as greater concentrations of infrastructure over broad landscape areas; protecting water; and minimizing regional Landscape Impacts, the ERCB proposed a "risk-based and play-focused" framework, where risk management would be proportional to the level of risk posed by development, and play-focused regulatory solutions tailored to an entire play to achieve strategic environmental, economic, and social outcomes (ERCB, 2013:2).

In November 2014, the Alberta Energy Regulator (AER) issued a "Play-Based Regulation Pilot Application Guide" for proponents. The concept of "play development plan" was articulated, requiring a proponent to address key challenges of hydraulic fracturing: "water management; surface infrastructure development; subsurface reservoir management; stakeholder engagement; and life-cycle wellbore integrity that addresses Alberta's critical outcomes." The pilot demonstrates that multi-well pads are a central component of the play-based regulation. Additionally, compliance and outcome assurance are necessary to ensure that the Province and industry retain their social license to develop unconventional resources. Meaningful stakeholder engagement and full-life cycle development plans are intended to ensure collaboration among operators and to ensure that the landowners and those adversely and directly affected are engaged in play development plans throughout the entire life cycle of resource development. The pilot, which initially was to end in March 2015, was recently extended to June 2015 in the Duvernay Play, the Province's first declared play. See Appendix 9-A for a full discussion of Alberta's legal, policy and regulatory system for hydraulic fracturing.

Alberta's play-based regulation is occurring as a parallel process to regional land use planning that provides systems and processes to reconcile competing demands for water on a regional basis. For example, it is too early to tell if the recently adopted South Saskatchewan Regional Plan (2014) will have major impact on hydraulic fracturing at a regional scale. The Lower Athabasca Regional Plan (2012) is more established and more focused on environmentally sustainable oil and gas production, and that regional plan is driving policy development to manage Landscape Impacts in that region.

Comparable policy, legislation and institutional systems exist in BC. The BC Oil and Gas Commission was created as a Crown Corporation through the enactment of the *Oil and Gas Commission Act*. In October 2010, the Commission transitioned to the *Oil and Gas Activities Act*. This regulatory model is designed to provide a streamlined one-stop regulatory agency. Regulatory responsibility is delegated to the Commission through the *Oil and Gas Activities Act* and includes specified enactments under the *Forest Act, Heritage Conservation Act*, *Land Act*, *Environmental Management Act*, and *Water Act*. The cost of operating the Commission is funded through the application of industrial fees and levies on a cost recovery basis" (BC Oil and Gas Commission, 2014: website).

BC uses an area-based analysis approach to minimizing the impacts of hydraulic fracturing that was adopted in October, 2014. The BCOGC (2014: 2) explains the area-based approach piloted in the Laird Basin, as follows:

> The Area-based Analysis (ABA) approach was developed by the BC Oil and Gas Commission Commission) as a framework for managing the environmental and cultural impacts of oil and gas development. The approach integrates strategic direction from statutes, regulations and existing land-use plans with identified environmental and cultural values into a framework for assessing oil and gas activity to:
>
> - Clarify objectives as set out in government policy and statutes.
> - Provide a consistent rationale and process for identifying environmental and cultural values.
> - Provide a simplified and transparent framework to assess and manage oil and gas development impacts on environmental and cultural values.

- Provide an analysis of existing development and the opportunity for future oil and gas activity.

BC established a results-based legislative and regulatory framework, and the province has the largest shale gas resources in the country. BC was the first to require public disclosure of chemicals employed in hydraulic fracturing. BC's regulatory system launched a number of instruments to engage both industry and the public. For example, the government has produced materials dealing with how to communicate with stakeholders; a system to publicly report on water use (August 2010); and a Well Permit Application Guideline (April 2013), all available on its website.

There is a sense of urgency in Canada to develop new policies and laws for hydraulic fracturing because there are obvious gaps in the current government and governance systems. Governments work slowly and regulatory change may take years. However, alongside government regional-scale governance networks, new organizations/networks are springing up in different Canadian jurisdictions to fill policy gaps and create new forms of democratic government-stakeholder collaborative decision-making.

According to Bulkeley (2005:877) "hybrid forms of environmental governance" where government and non-government actors collaborate to resolve environmental problems create a "new sphere of authority" organized in "network terms." The term "governance network" explains the "boundaries" and "conditions" within which actors involved in regional scale environmental governance contribute to production of a "public purpose" (Newig et al., 2010:2). Stakeholders and champions operating within these networks help to bridge connections between government resource management systems and provide new knowledge, resources and processes for improving the system from within existing legislative regimes. Governance networks for hydraulic fracturing are slow to emerge, but when they do, they need government to support their work and legitimize their activities that influence industry to improve Landscape Impact assessment and management processes. From these networked governance systems, new government policies and codes of practice emerge that can be applied by both small and large operators on a regional scale, or even at a provincial, national or global scale where similar context and social patterns exist.

In Canada, Alberta, BC, Saskatchewan, and to a certain extent New Brunswick, have been the provinces most open to the idea of regulation of hydraulic fracturing. They have been the most active in investments for building formal institutional structures, mobilizing political support, and finding ways to resolve conflicts over economic priorities and Landscape Impacts.

In September 2013, the National Energy Board announced its filing requirements for any application that involves hydraulic fracturing in the Northwest Territories and Nunavut. The goals-oriented rules clearly lay out the kind of information that must be provided in any application (impacts on environment, evidence of consultation with First-nations and public, mitigation measures to be employed, and so on).

Even though Quebec instituted a moratorium on hydraulic fracturing, in June 2013, Quebec did approve exploratory drilling on Anticosti Island and behind the scenes, study and discussion is taking place. A report, released in December 2014 by the Quebec Bureau d'audiences publiques sur l'environnement (BAPE) reinforces the moratorium. Along with questioning the economics, the report states: "Other concerns also remain, including plans of social acceptability, legislation and a lack of knowledge, particularly with respect to water resources."

With the recent New Brunswick election, and defeat of a government that ran on the hydraulic fracturing issue, only time will tell what will happen in that province. That New Brunswick previously set up an Energy Institute to study the hydraulic fracturing matters and the Energy Institute will likely keep the idea alive, at least in the short term. On the other hand, New Brunswick's rules for hydraulic fracturing reflect its weak position, limited policy capacity, and limited oil and gas resources.

In Nova Scotia, the decision was made after a six month study by David Wheeler (president of Cape Breton University), and in Newfoundland there is an ongoing independent study of the issue.

Similarly, in the US hydraulic fracturing has been perceived differently in dissimilar states, regions, and communities. While Texas, Pennsylvania, Montana, among other states have enthusiastically embraced the industry and put in rules to encourage its growth, states like California and New York have put moratoria in place. In New York, Governor Cuomo originally supported the idea, but this changed quickly when public opinion changed, and strong opposition mobilized. New York is now in a holding position. It is also worth noting that within states that allow hydraulic fracturing, there are cities and counties seeking bans (for example the City of Dallas).

9.2.6 Politics of Water Management in Canada and the US

Water management is a localized resource but policy decisions are often regional, sub-national, national, or even international in scope, creating a policy and regulatory dilemma for North-American decision-makers. Challenges of interdependence are not easily resolved within policy systems that are silo-based, competitive, and designed for other purposes. The politics of water management and patterns of conflict are unpredictable, even volatile since there are rival claims over usage, quantity, or quality (details of water use for hydraulic fracturing are addressed in Chapter 5).

Processes of energy restructuring, such as hydraulic fracturing involve the production of waste as well as the use of water. It is not surprising that conflict between competing interests over water usage and energy production (such as hydro) has spilled into the political arena. In Canada, there is uncertainty about the right mix of energy production and water usage. It has not been easy agreeing on new rules, just like in the US where energy production and water usage relationships have been controversial.

Conflicts over energy production and water usage are connected with competing province-building/nation-building ideas. For example, in Quebec, there are cultural reasons for not encouraging hydraulic fracturing. But, in addition, since the province is already heavily invested in the production of hydro, there is little incentive to facilitate hydraulic fracturing through regulation (Tomblin and Colgan 2004, forthcoming) because hydraulic fracturing poses a threat to provinces where major investments in developing hydro for regional usage and export have been made.

In the US, regulatory traditions, policies, and approaches are distinctive (see Healey 2014, Kalechi 2013). The cultural and political setting demands that governments pay close attention to individual rights as well as national goals/objectives both within and outside the country. South of the border, there is no tradition comparable to the Canadian experience of exploiting energy policy to promote sub-national jurisdictional boundaries and powers. (see Healey 2014, Kalechi 2013).

On the other hand, there have been huge challenges associated with implementation south of the border (Kalicki 2013). While federal agencies such as the Federal Regulatory Agency have responsibility for ensuring that national rules for water are being followed at the state and local level, there are clear challenges associated with a decentralized system of implementation that makes the states responsible for carrying out the policy and meeting targets set by Congress. Differences in political will, knowledge and policy capacity across states have made the tasks of monitoring and achieving objectives a difficult chore. It has also been difficult to facilitate social/policy learning.

Since there are dissimilarities with respect to geology, technical competencies, water conditions, infrastructure, and so on across states, there has been much focus on identifying these kinds of differences or knowledge gaps, and then, finding ways to work around them. The US federal government has delegated a number of responsibilities for permitting and monitoring of environmental conditions (including water) to the states. But with federal spending power intact and expectations that federal leadership is both necessary and required, it has been much easier south of the border to coordinate policy learning across state boundaries, even though the states have some leeway in the instruments they rely upon to implement policy.

Processes for knowledge brokering and social learning about Landscape Impacts are much more restricted north of the border. In Canada, the combination of a federal party system, highly competitive interprovincial executive-dominated/federal system, and powerful provincial governments that own and control natural resources has produced a different context or way for viewing hydraulic fracturing and other energy issues (Bakvis 2009, Tomblin 1995). It is an elite system of knowledge construction and brokering that is more insulated, and removed from citizens. In such a context, it has been much more difficult to facilitate policy learning across governments, or promote policy capacity and social learning within civil society.

The role of Ottawa in regulating Landscape Impacts is residual, such as in the area of fisheries habitat management, but even here, recent federal legislation has weakened this kind of oversight responsibility. When it comes to energy and water developments within provincial borders, the attitude of the federal government has tended to be “leave it to the provinces.”

In recent times, Canada has gone even further to constrain policy capacity development and knowledge sharing through the creation of a system of intergovernmental coordination that is based on “political accords.” Environmental Accords like the one signed in 1998, which was influenced by ideas of New Public Management (NPM) cannot be contested in court (Graefe 2013, Bakvis and Skogstad, 2008). These accords have tended to be negotiated and signed behind closed doors without parliamentary debate or public engagement. Such attempts to move away from the “rule of law” have likely contributed further to the problem of democratic deficit or illegitimacy.

Hierarchical control over water and integrating knowledge resources has never been a big priority in Canada. Technical decision-making occurs in various departments or agencies, mostly provincial (Clancy 2014). While the opening of first federal Department of Environment in 1971 raised expectation that a more integrated approach to capacity building might be a possibility someday, that kind of systematic water knowledge resource development and management never came to pass. Even though the department originally brought together various people with strong backgrounds in water management, little emphasis was placed on developing a common culture or unity of purpose (Clancy 2014).

Similar problems have plagued efforts to build knowledge resources for water within provinces. The trend has been for environmental departments to take on a number of divergent tasks. All of this made it difficult to integrate pool resources, develop policy capacity, and work together on building knowledge resources essential for policy capacity development, data management, planning, and monitoring of watersheds.

The question of control or lack of control is crucial to the issue of hydraulic fracturing and water/watershed management in Canada. At the federal level, all water-related commercial activities do not fall under the purview of one environmental departmental. In 1985, the appointment of the a Federal Water Inquiry came at a time of free trade discourses when there was movement away from the idea of national policies, and concerns were being raised about protecting water as a valuable resource.

All of this pressure to rethink the importance of water under Canadian control helped facilitate the launching of a new Federal Water Policy (1987). This initiative lost momentum very quickly when the 1990 Green Plan came out. Ongoing federal-provincial conflicts and turf wars over competing hydro development created further complications (Clancy 2014, Bakvis 2009). By 1994, in an era of NPM, the Chretien government put the final nail in the coffin of the Green Plan by cutting policy capacity, laying off staff, and closing offices. The bold vision for pan-Canadian water management lost capacity and leadership.

On another front, the idea of monitoring and preventing environmental problems before projects were built became a popular notion in the 1970s. The *Canadian Environmental Assessment Act*, Agency, and associated processes provided an opportunity to examine energy projects before they were put into play. The intent was to prevent problems and make the public feel confident that environmental (water risks were minimal. The provinces followed up the federal framework by adopting parallel processes for environmental assessment. While the idea was to avoid problems and coordinate action, environmental assessment did not prevent jurisdictional conflicts that emerged as permanent features on the political landscape.

Conditions never improved and conflicts and competition undermined efforts to work together on water governance. In recent times, the federal government has gone even further in reducing its power over water issues and problems. For example, the Harper government passed Bill C-38 with the idea of rebalancing natural resources and environmental priorities (including water). The clear objective of the legislation was to lighten the regulatory obligations of resource developers while devolving more and more responsibility for water management to the provinces (Clancy 2014). While industries in mining, hydro, oil-gas, and pipelines were pressuring for such changes, scientists with much public support and sympathy raised questions about the merits of such an approach. The action a few months later (Bill C-45) that further weakened federal authority over pollution and public right of navigation, further fueled public concerns that the public interests were not being well served. The combination of the weakening the *Navigable Water Protections Act* along with the weakening of the provisions for public consultation on such matters added much to the public cynicism (Clancy 2014).

Much legislative activity has occurred at the provincial level. Among the provinces, BC and Alberta have taken the lead on regulating hydraulic fracturing in order to manage Landscape Impacts. New Brunswick was building management capacity, but that changed with the provincial election.

In BC, a number of laws have been put into place to manage Landscape Impacts within the provincial boundary. For instance, the *Oil and Gas Act* provides a set of rules to regulate casing requirements, substances employed, and what needs to be reported. In a clear effort to protect water quality/quantity, the legislation forbids fracking activity above 600 metres. Anything above this level requires a special permit.

BC also provides a website (www.fracfocus.ca) which maps out in different locations where wells are located and the mix of ingredients being put into the ground. Companies have been required to report this information since January 2012. Alberta has also moved to reporting through FrackFocus.

With the vast range of rules and standards for defining Landscape Impacts, and the kind of data collection, reporting, and evaluation essential to effective implementation and ongoing evaluation of hydraulic fracturing, it is clear that policy and regulatory knowledge gaps in training, skill sets, and core competencies across systems needs attention. But, in Canada's federal system that respects policy diversity and the need to allow local judgements on the risks and benefits of any new economic initiative, there may be differing perceptions on the need for national standards. In such a context, agreeing on standards, or core competencies based on "best practice guidelines" is difficult.

In both Canada and the US, the systems we rely upon to both define problems (agenda-setting) and solve them (combination of implementation and evaluation) are complex and do not always facilitate the kind of knowledge sharing or brokering required for good governance and public control.

Much of the search in the US for knowledge gaps by federal agencies (Environmental Protection Agency, (EPA) Dept. of Interior and Energy) is focused upon finding ways to create new forms of governance required to enhance the legitimacy of many traditional institutions, both private and public. Hydraulic fracturing operates in a complicated regulatory structure where there are complex federal, provincial, regional, even local rules, standards, and systems of enforcement. Operating in an intra-state form of federalism, the federal government administers national standards everywhere in the US with the exception of federally owned land. That domain falls under the auspices of the Department of Interior, and Department of Agriculture (Kalicki 2013, Healy 2014, Gattinger, 2010).

In the US, many of the rules are national and connected with the EPA, which is organized on a regional basis throughout the country. States, however, through a system of contractual relations with various federal agencies, are ultimately responsible for implementation. While there are minimal standards that must be applied, states also have the option have applying different, higher standards if they choose. Each state that allows hydraulic fracturing has one or more regulatory agencies overseeing the design of wells, where they are located, spacing, standards for safety, discharges, water management, impact on wildlife, and so on. Normally, permits are required and companies have to comply with rules, reporting requirements, and behave according to the law.

Given the divergent cultural, institutional, and policy traditions across the country, there have been critical challenges associated with knowledge exchange and capacity-building across states. Context matters and shapes appetites for the pace and direction of regulatory reform. For example, in states like Texas with a long history of oil and gas activity, the fears about Landscape Impacts are not the same as in other states. Differences in policy capacity, public expectations, and even political will, make it a challenge to agree on knowledge gaps and where investments should be made.

There are a number of federal laws that are pertinent to the hydraulic fracturing file (Kalicki 2013, Healey 2014, Gattinger 2010). For example, the *Clean Water Act* (CWA) addresses the question of surface discharges that come about due to hydraulic fracturing. The *Safe Drinking Water Act* (SDWA) deals with challenges associated with fluids injected underground. *National Environmental Policy Act* (NEPA) applies to federal lands and makes sure that there are environmental impact studies done before drilling is undertaken. At the level of agenda setting, the US federal government is much more active than Ottawa in setting national standards for the industry. However, the federal agencies who oversee these rules do not have the resources necessary to ensure that they are administered properly, nor is there much opportunity to construct or share knowledge across systems. Differences in policy capacity, core competencies, reporting, data collection, and other activities essential to good governance, protecting the public interest, ensuring high standards of accountability and integrity are lacking in such a decentralized policy continuum.

In the US, federal laws and agencies have much oversight power and ability to use funds, the constitution, courts and other instruments to effect outcomes. Yet, there are also traditions of granting primacy to states and their agencies. Through a process of intergovernmental agreements, state governments and relevant agencies (usually EPA) work out agreements for managing patterns of policy action. As a result, regional units of the EPA operate in very different worlds which make it difficult to sometimes agree or collaborate across regions, even at the federal level (Kalicki 2013, Healey 2014, Gattinger 2010, Tomblin and Colgan 2004).

Within states, hydraulic fracturing (if it is allowed) is monitored by state agencies that allow practices but also monitor the activity on site. Often there are multiple agencies involved, dealing with various aspects of shale production. While there are clear differences across states with respect to technical competencies, capacity, and data management, and other essential forms of knowledge advancement, and few opportunities to share, there have been voluntary attempts to compare experiences. The Council of States and programs like the Ground Water Protection Council have provided opportunities to discuss and improve such experiments.

The efforts of STRONGER (State Review of Oil and Natural Gas Environmental Regulation) which is a non-profit, multi-stakeholder organization has emerged to help states deal with the issue of hydraulic fracturing regulation (based on interviews). Local governance also plays a role in regulating and monitoring hydraulic fracturing. Additional regulations may be imposed by other levels of governments, but decision-makers need to understand that local communities, under provincial and state laws, may play a significant role in implementing standards as delegated authorities.

Regionalization experiments has proven popular for addressing knowledge gaps, while making it easier to build knowledge networks across rural-urban communities. Regionalization has not only occurred within state boundaries to address water problems. Across states, there have also been experiments. Regional water-permitting authorities such as the Delaware River Basin Commission (DRBC) have emerged to better manage water quality in rivers that go across state boundaries. This federally established organization operates in the states of New York, Pennsylvania, New Jersey, and Delaware. Oil and gas operators who wish to use water from the basin are required to apply for a permit from the DRBC, in addition to state authorities. In the case of New York, the New York Department of Environmental Conservation, Division of Mineral Resources is the state agency that oversees hydraulic fracturing regulation.

9.3 CONCLUSION

Whether to proceed with hydraulic fracturing is a critical energy policy question for Canadian decision-makers. If the decision is made to proceed, then there is a complex suite of decisions about policy, legislation and regulations that need to be made about 'how to proceed.' In both Canada and the US, getting nation-wide consensus on the issue has not been possible. The fact that various states and provinces have imposed moratoria is a clear sign of policy, legal and regulatory knowledge gaps, because the debate is complicated and cannot be resolved by empirical facts alone. Rather, knowledge is power and it does not just come from experts.

Power is complex and has been managed differently over time. In the 1990's, New Public Management, notions placed a focus on cutting policy capacity and formal rules (Howlett 2009, Graefe 2013, Bakvis 2008). Knowledge production became more competitive and fragmented. To survive, politicians relied upon political accords and other mechanisms which were less public, but made it easier to address interdependent problems. These informal structures and processes designed to improve governance and address knowledge gaps are being rethought. There is a growing need to address knowledge gaps through focusing more attention on institutions and researching how to improve them. The public policy/administrative community lost resources essential to explain why formal regulations, integrated structures, and science are necessary to good policy development in the public interest.

The **Key Knowledge Gaps Tables** below identify four priority policy, legal and regulatory knowledge gaps that emerged from the literature review:

1. Comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts;
2. Knowledge about how legal institutions, governance structures, and decision-making processes can either promote or constrain societal patterns of communication, policy learning, networking, citizens engagement, and knowledge brokering about Landscape Impacts;
3. Knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts; and
4. Understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

Comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts

Before decision-makers can embark on new regulatory or non-regulatory systems for managing Landscape Impacts, they need to understand existing approaches in Canada. Comparing these approaches would help decision-makers select "best Canadian approaches" to governance and management.

As shown by the Alberta play-based experiment, there is interest in integrating policy functions, yet creating regional mechanisms and structures that are better designed for the spatial realities of hydraulic fracturing. Addressing the challenges of multi-level governance, and working collaboratively across jurisdictions and policy sectors is essential. Needs-based and asset-based academic frameworks provide examples of processes that are designed to facilitate the active and meaningful engagement of stakeholders, experts, decision-makers and citizens in the struggle to accelerate the uptake of knowledge and encourage the building of capacity essential to the implementation of evidence-informed policy. It is a time of experimentation: for example, Alberta play-based regulation process; BC results-based regulatory framework; and the National Energy Board's goal-oriented rules. Comparison and assessment of the pros and cons of these new processes are required.

Increasing government - society interdependence, regional integration, multi-level governance, and social learning about how to work across silos (whether based on policy sector/jurisdiction) are emerging trends that need further examination and analysis of efficiencies and effectiveness.

Knowledge about how legal institutions, governance structures, and decision-making processes can either promote or constrain societal patterns of communication, policy learning, etc…

The search for knowledge gaps about policy, laws and regulations for managing Landscape Impacts will not likely succeed unless we understand the connection between power, the influence of institutions, and their ability to change individual behaviour. Policy capacity is not equally distributed, nor is power. The distribution of power is socially structured, but also depends on institutions we rely upon to set priorities. Knowledge and power are rooted in resources, strategies, and networks. What is required is more discussion on how to link various interests and how to address the mismatch of scales. There needs to be more discussion on creating systems of knowledge construction and sharing that is more public, inclusive, interactive, and allows both scientific and lay expertise to have a voice.

In the past, there was more discussion on why there were knowledge gaps and what needed to be done to fill them when conditions changed. The ideas of Galbraith, about the need for "technostructure" and creating new forms of communication, legitimization, and patterns of social learning worked well in preparing for a new era of economic restructuring (Galbraith 1967). He was an economist, but also an institutionalist. He focused much of his research on understanding the conditions that made it possible for well-designed institutions to shape human behaviour in the public interest. If hydraulic fracturing is a "game changer" there is a need to rethink future patterns and formal processes for addressing policy, legal and regulatory knowledge gaps.

Institutional and governance traditions shape and determine patterns of knowledge construction and brokering. There are various kinds of gaps associated with hydraulic fracturing, and there are competing theoretical approaches for making sense of these gaps. Internal conditions and institutional configurations are never easy to change even when circumstances change. Silo-based processes outside the public reach have been common by government actors who resist losing power or control. When circumstances change, ideas (both normative and empirical) can play an important role in identifying and filling crucial knowledge gaps.

We need a broader vision or framework that goes beyond the incremental approach that is not working. New, more integrated approaches to policies that deal with technical issues (connecting Landscape Impacts across scales) but involve citizens' knowledge and values are needed.

Knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts

Proponents of structuralism and pluralism offer different perspectives on the conditions and strategies essential for policy transformation. But they do agree that change is not inevitable, and there is a need for public spaces essential for democratic discourse about hydraulic fracturing and regulating Landscape Impacts. Leaders must be motivated and government-societal structures must facilitate the creation of different kinds of public spaces and opportunities to exchange information across communities, policy sectors, and jurisdictions.

Governments must discover better ways to bring different interests together to produce common shared-objectives that have general support. Decision-makers need to understand the conditions that have led to mobilization of social discontent and protest. There needs to be a narrative or vision capable of explaining what needs to be done to both identify and fill key knowledge gaps involving Landscape Impacts. Filling that gap depends on producing a common set of values and norms, a set of ideas that can be used to define what is wrong and what needs to happen.

People have only vague notions of what is wrong, who is responsible, and who benefits and who pays. Who controls these perceptions, forms of knowledge, depends very much on leadership, channels of communication and network relationships. Building processes of decision-making that are more integrated, interactive, and not open to suspicion are crucial. Citizens must no longer be seen as spectators: there needs to be more transparency and accountability. In an era of "political accords" where decisions are reached behind closed doors, and where public bureaucracies and knowledge networks have experienced losses in legitimacy and capacity, it is crucial to reverse these trends. Legitimate governance networks that are regulated, open, and transparent are preferable to social movements that make it difficult to make a decision and reach a consensus on necessary actions.

Understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

Finally, national, provincial, regional and municipal decision-makers need to understand what is, and will be necessary to implement policy, laws and regulations and share sufficient knowledge to promote social learning about Landscape Impacts, and develop budgets accordingly. Not all decision-makers need the same personnel, resources or tools, but what they do need must be provided if effective policy implementation is the goal. All local communities may not have the same knowledge or capacity to enforce rules. In different provinces and regions (particularly rural areas) there are ongoing challenges connected with ensuring that all communities have the knowledge and resources necessary to carry out their responsibilities.

9.4 KEY KNOWLEDGE GAP TABLES

The **Key Knowledge Gap Tables** identify four priority policy, legal and regulatory knowledge gaps. Advancing knowledge through the identified **Research Approaches** could meaningfully inform decision-makers about Landscape Impacts. For each knowledge gap, at least two research approaches are provided. All research approaches in this chapter are qualitative or quasi-qualitative, as policy and law are less about quantification and more about qualification and codification of shared values.

1. Comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts.
2. Knowledge about how legal institutions, governance structures, and decision-making processes can either promote or constrain societal patterns of communication, policy learning, networking, citizens engagement, and knowledge brokering about Landscape Impacts.
3. Knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts
4. Understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

20. Policy, Legal and Regulatory Knowledge Gaps

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Comparative analysis of provincial/territorial approaches to regulating hydraulic fracturing in Canada concerning detecting, predicting and remediating Landscape Impacts.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative research of literature and on-line resources to compile a summary of provincial approaches to regulation, and perform a comparative analysis through university graduate program, consultant, or government regulatory body.	**High** To fully understand how policy is driving legislative change across Canada, comparing regulatory differences is required. Why is Western Canada leading the way while Eastern Canada and Territories are still engaged in studies?	**Low**	**High**	**High** Most post-graduate programs in Canada have capacity to conduct this research. Gov't department could also commission the work or complete in-house. Use of consultants could be costly	**$20-25,000**	**6 month-1 year**	Strong approach for creating a baseline of current knowledge in order to track changes over time. Each province/territory has its own regulatory system for regulating hydraulic fracturing, and a compilation and analysis of the legal systems would inform decision-makers. Codes of practices and BMPs could be compared across the country to determine if there is a possible national code. A major weakness is that the research would present a snapshot in time that would need to be redone when regulatory systems change in each province. However, most qualitative research involving legal systems requires period revisiting and future review. Most efficient and least expensive approach, but may not be thorough.
Qualitative research through online survey of provincial government department decision-makers to compile knowledge and then conduct comparative analysis. Would require pre-survey interview with selected government department	**High** – would require cooperation among government departments across the country	**Low - moderate**	**High** – depends on who does the research and how it is funded.	**High** Most law or science graduate programs in Canada have capacity to perform the survey, but may need multi-	**$100.000 - $150,000** Requires comparative analysis of large amounts of survey data by expert analysts.	**1-2 years**- phased approach as survey design would not be completed until interviews with department respondents is complete.	Overall the strongest research approach including design of survey materials and communication with government experts engaged in regulation and decision-making with the industry. Multi-stage aspect provides opportunities for research refinement at every stage. Ensures that information provided is from best known respondent and therefore reliable information for creating the baseline data

respondents				disciplinary approach with computer technology and social sciences for design and administer		Admin., data collection, interpretation and data analysis would all require further phases.	set to monitor over time. Would represent only a snapshot in time and would require future review**.** Strongest approach to create thorough and robust knowledge.
Qualitative research: national symposium on regulation of the hydraulic fracturing industry in Canada.	**Moderate** Would create baseline or reference condition from which to test or conduct further qualitative research	**Low**	**High**	**High** National ENGOs and symposium organizers could be employed to develop the symposium agenda and find expert speakers and facilitators of workshop component.	**$100,000-200,000 b**ut could be sponsored by gov't and industry to break even	**1 year to organize** 1 year to create symposium proceedings and peer review before publication.	Symposium proceedings would provide baseline materials to inform decision-makers about the diversity, opportunities and barriers to regulation of the industry in Canada. Would provide opportunities to network and dialogue on important matters of regional-scale policy development, national policy development and social learning.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

21. Policy, Legal and Regulatory Knowledge Gaps

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES

Knowledge about how to engage in or create public spaces essential for bringing together diverse interests to share information and co-create knowledge necessary to manage Landscape Impacts

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Qualitative research of literature and on-line resources to create a compilation of all existing regional and provincial "public spaces" currently funding wholly or in part by provincial and federal governments that are actively engaged in multi-stakeholder processes of governance with respect to Landscape Impacts	**High** There are few public spaces in Canada where stake-holders with diverse interests are actively engaged in dialogue to build trust and relation-ships necessary to create recommend policy or legislative amendments or BMPs	**Low**	**High**	**High** Government departments	**$20,000** Depends on whether it is done by an industry member or gov't department	**6 month-1 year**	Strong approach for creating compilation tool for decision-makers and other researchers. Tool could be used to understand how these public places emerge and how they partner and co-create knowledge to inform decision-making processes.
Qualitative research: national symposium to facilitate discussion and creating of new knowledge about the need for public spaces, and to stimulate development of regional scale governance networks to inform decision-makers about Landscape Impacts	**Moderate**	**Low**	**High**	**High** National ENGOs and professional symposium organizers could be employed to develop the symposium agenda and find expert speakers	**$100,000-200,000** but could be sponsored by government and industry to break even	**1 year to organize** 1 year to create symposium proceedings and peer review before publication.	Symposium proceedings would provide baseline knowledge of the "current state" of public spaces in Canada. Opportunities to network and dialogue on important matters of regional-scale policy development, national policy development and social learning.

				and facilitators of workshop component.			

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

22. Policy, Legal and Regulatory Knowledge Gaps

PRIORITY **KNOWLEDGE GAP** TO ADDRESS THE ISSUES
Understanding needs for personnel, training, technical expertise, political will and resources required to implement, monitor regulations, share knowledge and promote social learning about Landscape Impacts by provinces, regions (both within and across provinces) municipalities, and continental institutions.

Research Approaches	**Potential to Address Gap**	**Scientific Complexity**	**Ease of Implementation**	**Research Capacity**	**Cost**	**Timeframe**	**Additional considerations**
Qualitative research of literature and online resources from government departments and municipal governments, and other hydraulic fracturing managers and decision-makers to identify needs and costs associated with meeting those needs.	**High**	**Low**	**High**	**High** Most post-graduate programs in Canada have capacity to conduct this research. Government departments could also commission the work or complete in-house.	**$30,000.00**	**2 years**	Strong approach for creating a baseline of current knowledge. Would need follow-up interviews to test or ratify the results of the study. Cost estimation would inform decision-makers of the extent of budget required to fund needed processes for regulatory design, implementation, and monitoring and trend analysis for recommending new approaches. Weakness would be that study design might not create an accurate representation of true costs because governance structures, regulatory institutions and decision-making processes are currently considered public goods with very little attention paid to input costs to design, implement, monitor and enforce.
Qualitative research through online survey of provincial government department	**High** – would require cooperation	**Low - moderate**	**High** – depends on who does the research and how it is funded.	**High** Most law or science	**$100.000 - $150,000** Requires	**1-2 years-** phased approach as	Overall the strongest research approach including design of survey materials and communication with government experts

decision-makers to compile knowledge about needs and then conduct comparative analysis. Would require pre-survey interview with selected government department respondents	among government departments across the country			graduate programs in Canada have capacity to perform the survey, but may need multi-disciplinary approach with computer technologist and social sciences for design and administer	comparative analysis of large amounts of survey data by expert analysts.	survey design would not be completed until interviews with department respondents is complete. Admin., data collection, interpretation and data analysis would all require further phases.	engaged in regulation and decision-making with the industry. Multi-stage aspect provides opportunities for research refinement at every stage. Ensures that information provided is from best known respondent and therefore reliable information for creating the baseline data set to monitor over time. Would represent only a snapshot in time and would require future review. Strongest approach to create thorough and robust knowledge.
Qualitative research: expert panel Developing the panel and providing space and time for creating panel findings for decision-makers.	**Moderate** Would create baseline or reference condition	**Low**	**High**	**High**	**$50,000**	**1 year** to organize and report on findings of the panel	An expert panel of consultants and industry specialists who work in regulating Landscape Impacts for municipalities, provincials, provincial agencies and others would help determine the state of the industry and provide advise as to capacity of current agencies and identify needed resources. Weakness would be that need the right experts to ensure the accuracy of the panel proceedings.

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Appendix 9-A Legal, Policy, and Regulatory Framework for Hydraulic Fracturing in Alberta compared with British Columbia

Alberta:

In 2013, the Alberta Legislature changed the regulatory system for regulating and controlling the development of energy resources. With the enactment of the Responsible Energy Development Act (REDA), the Alberta Energy Regulator (AER) was created to replace the Energy Resources Conservation Board to regulate the development of energy resources in Alberta, including oil, natural gas, oil sands, coal and pipelines. To receive an approval for proposed hydraulic fracturing projects, proponents must apply to the AER. "Today, the AER is the single regulator of energy development in Alberta -from application and exploration, to construction and development, to abandonment, reclamation, and remediation." (AER, 2014: website). Large hydraulic fracturing projects may require an environmental impact assessment by AER under the *Environmental Protection and Enhancement Act* provisions to enable the AER "to consider the environmental impact assessment when evaluating the overall public benefits of a proposed project."

REDA sets out the "mandate, structure, powers, duties and functions" of the AER. "The regulations (listed below) made by the Lieutenant Governor in Council under REDA provide more details regarding the legislative framework of the AER, including principles governing the transition of the ERCB to the AER, and the transfer of jurisdiction over the specified enactments (also below) to the AER (AER, 2014: website):

- Responsible Energy Development Act General Regulation
- Responsible Energy Development Act General Amendment Regulation
- Responsible Energy Development Act
- Specified Enactments (Jurisdiction) Regulation
- Responsible Energy Development Act Transition Regulation
- Security Management for Critical Upstream Petroleum and Coal Infrastructure Regulation
- Miscellaneous Corrections (Alberta Energy Regulator) Regulation

In addition, several rules were made by the Minister of Energy or the AER under REDA, as follows:

- Alberta Energy Regulator Rules of Practice
- Alberta Energy Regulator Administration Fees Rules
- Enforcement of Private Surface Agreement Rules

The AER provides a "one-window" project approval process. It reviews applications as required under several pieces of Alberta legislation, for example the energy resources development legislation and specific legislation and regulations for conserving and managing the environment, water, and public lands as follows:

- Coal Conservation Act
    - Coal Conservation Rules

    - Agent Exemption Regulation
- Gas Resources Preservation Act
    - Approval of Short Term Permits Regulation
    - Gas Resources Preservation Regulation
- Oil and Gas Conservation Act
    - Oil and Gas Conservation Rules
    - Orphan Fund Delegated Administration Regulation
- Oil Sands Conservation Act
    - Oil Sands Conservation Rules
- Pipeline Act
    - Pipeline Rules
- Turner Valley Unit Operations Act
- Environmental Protection and Enhancement Act (EPEA)
    - Activities Designation Regulation
    - Administrative Penalty Regulation
    - Approvals and Registration Procedures Regulation
    - Conservation and Reclamation Regulation
    - Disclosure of Information Regulation (currently unavailable on Queen' s Printer)
    - Environmental Protection and Enhancement (Miscellaneous) Regulation
    - Ozone Depleting Substances and Halocarbons Regulation
    - Remediation Certificate Regulation
    - Release Reporting Regulation
    - Substance Release Regulation
    - Waste Control Regulation
    - Wastewater and Storm Drainage Regulation
    - Wastewater and Storm Drainage (Ministerial) Regulation
- Mines and Minerals Act (Part 8)
    - Exploration Regulations
- Public Lands Act
    - Exploration Regulations
    - Public Lands Administration Regulations
- Water Act (WA)
    - Water (Ministerial) Regulation
    - Water (Offences and Penalties) Regulation

The application review process is complex and evolving. "The AER has developed an interim (i.e., draft) regulatory guide to explain how the new system to regulate the full life cycle of energy projects in Alberta operates. The guide also provides an overview of the AER's application and decision-making processes (AER: 2014: website).

AER operates a comprehensive website, at http://www.aer.ca/, where a proponent can find monthly energy development statistics, notices of applications, and "regulatory change reports" that reflect adaptions in government oversight of industry practice. Regulatory change reports allow shale gas development proponents to access emerging "directives", bulletins and news releases concerning their operations and practices. For example, on October 31, 2014, under the topic of "hydraulic fracturing, “the following Directives, Bulletins and News Releases were provided, with links to the relevant directives and changes that have occurred:

Directives

Directive 083 Hydraulic Fracturing – Subsurface Integrity
Directive 059 Well Drilling and Completion Data Filing Requirements
Directive 058 Oilfield Waste Management Requirements for the Upstream Petroleum Industry
Directive 055 Storage Requirements for the Upstream Petroleum Industry
Directive 050 Drilling Waste Management
Directive 047 Waste Reporting Requirements for Oilfield Waste Management Facilities
Directive 020 Well Abandonment
Directive 009 Casing Cementing Minimum Requirements
Directive 008 Surface Casing Depth Requirements

Bulletins

Bulletin 2013-19 Directive 083: Hydraulic Fracturing – Subsurface Integrity

News Releases

News Release 2013-05-21 ERCB releases hydraulic fracturing directive

Related Articles.

In April 2014, to provide scientific monitoring, evaluating, and reporting on the cumulative impacts of human activities and industrial growth, for example shale gas development, the Alberta Legislature created the Alberta Monitoring, Evaluation and Reporting Agency (AEMERA) following the enactment of the Protecting Alberta’s Environment Act:

AEMERA is the provincial organization established to monitor, evaluate and report on key air, water, land and biodiversity indicators to better inform decision-making by policy makers, regulators, planners, researchers, communities, industries and the public. AEMERA's mandate is to provide open and transparent access to scientific data and information on the condition of Alberta’s environment, including specific indicators as well as cumulative effects, both provincially and in specific locations (AEMERA, 2014: website).

AEMERA claims to work closely with partners throughout the Province who are already engaged in environmental monitoring activities, such as multi-stakeholder groups like watershed planning and advisory councils, airshed zones and the biodiversity monitoring group. These groups are considered “monitoring organizations” under the Alberta Monitoring Directive, and as such, all their voluntary monitoring activities must follow the directives protocols. This will enable AMERA to roll up monitoring data in a consistent methodology across the Province.

While both AER and AEMERA are evolving systems, AEMERA is currently primarily involved in the Alberta oil sands development projects. Both agencies are touted as responsive to social and industrial feedback, such as the emerging feedback from within the growing shale gas development industry. Both claim a continuous improvement mandate, and both have comprehensive websites where citizens and shale gas development proponents alike can access legally and scientifically relevant information.

In September 2014, Alberta began a pilot for Play-Based Regulation, and industry proponents wanting well approvals within the pilot Duvernay Play are now able to apply under the new system. Current information on the Play-Based Regulation Pilot is provided on the government website.

Compared to British Columbia (BC)

Comparable policy, legislation and institutional systems exist in BC. That province was ahead of Alberta in adopting new policies, and enacting laws and regulatory framework, and processes for hydraulic fracturing. The BC Oil and Gas Commission "was created as a Crown Corporation through the enactment of the *Oil and Gas Commission Act*. In October 2010, the Commission transitioned to the *Oil and Gas Activities Act*. This regulatory model is designed to provide a streamlined one-stop regulatory agency. Regulatory responsibility is delegated to the Commission through the Oil and Gas Activities Act and includes specified enactments under the Forest Act, Heritage Conservation Act, Land Act, Environmental Management Act, and Water Act. The cost of operating the Commission is funded through the application of industrial fees and levies on a cost recovery basis" (BC Oil and Gas Commission, 2014: website).

BC is also well ahead of Alberta in creating knowledge about water sources for hydraulic fracturing. BCOGC has adopted the "NEWT" water sourcing tool as a decision-support tool for approving hydraulic fracturing in north east BC (Chapman, 2010). Alberta has recently followed suit and is in the process of developing a similar model for the West-Central Alberta region to support hydraulic fracturing in the Duvernay and Montney formations. The Duvernay "play" is Alberta's pilot play for the purpose of the "Play-Based Regulation Pilot."

Other Canadian provinces are either taking a wait and see approach to Alberta and BC's pilots and emergent regulatory schemes and approving hydraulic fracturing on an exploratory basis under conventional oil and gas development regulations and frameworks, or they are imposing moratoria until more scientific knowledge provides sufficient knowledge that fracking is in the public interest.

10 Decision-Making and Risk Assessment in the Context of Hydraulic Fracturing and Landscape Effects on Water and Watersheds

10.1 Introduction

When it comes to decision making about unconventional energy development (e.g., hydraulic fracturing, oil sands developments, etc.), it is becoming increasingly clear that improved approaches for assessing risks and making decisions (about development initiatives as well as risk management) are required. However, these calls for improvement raise an important question: What do improved risk assessment and decision-making processes entail?

In our view, the emphasis should be on *process.* That is, improved risk assessments and decisions will arise from a deliberative process designed to guide comprehensive and logical discussions about energy development and delivery. Such a process will encourage involvement from all key stakeholders, and will give them a legitimate voice in the decisions at hand. Moreover, such a process provides a mechanism for organizing information about risks (and benefits), and for dialogue about energy development options and their anticipated consequences. And, such a process provides a mechanism for structuring decision-making about energy choices in a manner that facilitates and easily incorporates learning.

A good analogy for such a process is that of an individual's financial investments: different people have different investment objectives and different tolerances for accepting risks, both of which change through time. So it makes sense that investment strategies will differ across individuals and through time. An energy strategy is also specific to the objectives of the stakeholders in the decision-making process, and a useful strategy is one that establishes a framework for helping people—policymakers, scientists and representatives of industry, and members of the public—to answer questions about which components of an energy system are preferred, and which risks are tolerable.

Specifically, an energy strategy should inform choices about the desired level of investment in each element of an energy portfolio, where these investments should be made geographically, and the signals or tipping points that will trigger the reallocation of funds and attention from one resource (coal, for example) to another (say, renewables) over time. It should distinguish between sources that are ready for development and those that require additional research. Overlaid on these questions, which themselves are not easy to answer, are questions about the level of risk and uncertainty that policy makers and the public are willing to tolerate (Bessette et al. 2014; Kenney et al. 2014).

10.2 BARRIERS TO HIGH QUALITY DECISION-MAKING

Decision-making, while seemingly intuitive, is fraught with complexity. Staying with the example of financial planning, consider the choices that people must make about their investment portfolio. Most people have a sense of what they want to achieve with their decisions—for example, high rates of return, stability, low uncertainty, and social responsibility. People tend also to know what a subset of their options is. But despite this knowledge, the vast majority of people have made investment decisions that they have regretted. In our view, such behaviour has five main causes, as demonstrated by a wealth of research. In essence, these 'causes' indicate the gaps that need to be addressed in order to make better decisions.

First, people are not strict maximizers of overall utility during decision-making (Dawes 1988; Stanovich 2010). Rather than evaluating alternatives by carefully weighing the importance of the various attributes—costs and benefits in terms of economic, environmental, health-related, and social considerations, for example—people take shortcuts (Gigerenzer et al. 2011; Gilovich et al. 2002; Slovic et al. 2002). Even though these shortcuts are commonplace, many people fail to recognize their existence or the systematic biases that accompany them (Kahneman 2011). It is true that these shortcuts are an essential aspect of human decision-making; without them, most of the decisions people face in their daily lives would be overwhelming. On the other hand, as the consequences associated with high-stakes decisions increases, as is the case in making national energy choices, so, too, does the level of effort and accuracy required on the part of decision-makers (Johnson & Payne 1985).

Second, decision-makers typically do a rather poor job of fully characterizing and appropriately bounding the decision problems (or opportunities) they are being asked to confront. In many cases, problems are cast too narrowly, such that single objectives—for example, maximizing economic opportunities or minimizing carbon emissions—become the sole focus, to the detriment of other objectives that also deserve attention (Keeney 1992). In other cases, decisions are cast so broadly, with dozens of competing stakeholders and objectives, that the result is paralysis and, ultimately, inaction (Kellon & Arvai 2011). And for the goals and objectives that are considered during decision-making, people tend not to do a terribly good job of determining accurately and precisely how to measure their performance or achievement (Keeney & Gregory 2005).

Third, people tend to anchor too easily on certain alternatives and typically do not do a good job of thinking broadly and creatively about the full range options they can and should be considering. Too often, decision-makers focus on alternatives that fit neatly with deeply held ideologies, that most easily come to mind, or that have been implemented previously. Related, decision-makers possess a strong bias toward being unnecessarily faithful to existing investments even when trading them in for others makes more sense in light of public, business, or national interests; decision researchers call this the sunk cost bias (Kahneman et al. 1982; Kahneman & Tversky 2000). Each of these tendencies is problematic for decision-making. Given the gravity of decisions related to energy development, the alternatives under consideration must go beyond the status quo, or the obvious and familiar. They should be responsive to markedly different objectives and strategies, thereby presenting decision-makers with real options and choices (Bessette et al. 2014).

Fourth, when these factors—judgmental shortcuts, poorly specified problems, and insufficient creativity when thinking about alternatives—are combined, it becomes difficult, if not impossible, for decision-makers to confront the trade-offs that inevitably arise when choosing among options (Tetlock 2000; Tetlock et al. 2000). Policy makers talk often about "win-win" alternatives and consensus. But the fact is that the design of a defensible energy strategy will always involve trade-offs—giving up something that is valued in exchange for something else that is also valued—and this threatens consensus and renders win-win alternatives impossible (Kenney et al. 2014).

Fifth, decision-makers often fail to adequately learn from their past successes and failures, or the successes and failures of others. Rather than treating decision-making as a series of one-off events, there is need for a more adaptive approach designed specifically to help decision-makers and policy makers learn about systems in which they work by carefully monitoring the outcomes of decisions through time. A good adaptive framework will also help decision-makers draw lessons from multiple decisions across several jurisdictions as a means of identifying the next and best moves in what is viewed as a series of linked policy or energy development decisions (Arvai et al. 2006a; Gregory et al. 2006a; Gregory et al. 2006b).

10.3 Constructed Judgments and Preferences

These observations challenge a common assumption—held by pollsters, social scientists, and policy analysts, among others—that people possess a pool of preexisting preferences that they simply uncover during the process of making judgments. It is true that in a variety of contexts, preexisting preferences can indeed be identified; people prefer scotch whiskey over rye or hockey over curling. However, recent research in the decision sciences has demonstrated that there are also many situations where the preferences or preference orders needed to inform decisions are insufficient or altogether absent (Arvai et al. 2006b).

Generally, these decision contexts share one or more of three characteristics (Lichtenstein & Slovic 2006; Slovic 1995): First, the decision context may be foreign, with the implication that preexisting preferences do not exist. Second, decision-makers may be faced with the relatively common situation in which the evaluation of competing alternatives causes two or more preexisting preferences to conflict. In other words, trade-offs become necessary, which requires the construction of new preferences based on how decision-makers balance, or rebalance, conflicting priorities. Third, decision-makers may be required to translate qualitative expressions of preference into quantitative ones (and vice versa). Moving from the recommendation, for example, that a carbon market be created to actually setting a price on carbon requires a constructive process. Decisions about energy development typically include all three of these features.

Under these conditions, people are unable to evaluate decision problems and alternatives by simply drawing on preexisting and stable preferences. Instead, they must construct their preferences—and by extension, the judgments and decisions that result from them—in response to cues that are available during the decision-making process itself. Some of these cues will be internal, reflecting deeply held worldviews or ideologies. And some will be external, in the sense that they are associated with the information that accompanies a decision problem; for example, these cues may take the form of technical information presented by experts about problems or alternatives, or they may only become apparent in light of recent events (as the risks associated with hydraulic fracturing became more salient following concerns raised by citizens leaving near New York state's Marcellus Formation). From this perspective, deliberative processes convened by researchers and policy makers—be they experimental or practical, or employed by individuals or groups—have the de facto purpose of serving as engineers of judgment and decision making rather than as tools for simply revealing preexisting preferences (Bessette et al. 2014).

The implications of preference construction for decisions about an energy strategy are far reaching. On the one hand, the constructive nature of judgments can be viewed as a "bad news" story, in that it suggests people can be easily manipulated by interest groups or by industry. One need not look far—the protests around "fracking", Canadian oil sands developments, and the Keystone XL pipeline, for example— to see how easily and quickly public opinion and related policy preferences can be shaped by a well-organized social movement or public relations effort (Palen et al. 2014).

On the other hand, the constructive nature of energy strategy judgments is also very much a "good news" story. For example, the notion of constructed judgments means that decision support processes (and institutions) can be designed such that they do a better job of accounting for how information and decision-making strategies are used, or misused, during the construction of judgments. By recognizing that decision-makers rely heavily on contextual cues that are available to them as they construct judgments, it becomes possible for analysts and facilitators to provide a defensible context or structure for decision-making. Indeed, it is our view that those who lead such decision-making processes are obligated to employ decision processes that will help people construct the highest quality judgments possible in light of the various constraints they face, including access to high-quality information, time to think carefully and deliberate options, adequate funding, and information processing capabilities (Gregory et al. 2012).

10.4 Structuring Decisions

If one accepts the argument that decisions about energy development are akin to choices about long-range investments that requires carefully constructed judgments, then a broad-based and iterative decision-making process will be required to engage stakeholders, and evaluate risks and benefits over an extended period of time.

In designing such a process, it is worth noting that many advocates of inclusivity in decision-making worry that too much structure will lead to biased input and will unnecessarily constrain the breadth of ideas and expertise. This is the "error of commission" argument (Fischhoff 2005). While we acknowledge this concern, we argue that when incorporating stakeholder views relating to important energy choices, far more is needed than just an invitation for the interested parties to participate and share their opinions. Such an approach, typical of many public involvement processes, will have substantial shortcomings in terms of helping people to make thoughtful and defensible decisions in complex or unfamiliar contexts (Arvai 2014b; Arvai & Campbell-Arvai 2013). This is called the "error of omission" argument (Fischhoff 2005). To bring this latter point to life, one need only look at the chaos and frustration accompanying the approximately 4,000 10-minute testimonies before by the Joint Review Panel that is considering (on behalf of Canada's National Energy Board) different options for transporting bitumen from the oil sands in Alberta to tidewater in northwestern British Columbia (and then by ship to Asia).

Decision researchers have long demonstrated that in a variety of loosely structured situations, both individuals and groups grapple with a predictable set of difficulties when making complex decisions that are related to how information is framed and how emotions interact with, and often preempt, more in-depth analysis. One of the fundamental conclusions is that people often end up making decisions that, at best, only partially address the full range of their concerns and, subsequently, fail to confront required trade-offs when evaluating competing alternatives (Gregory 2000; Gregory et al. 2001a).

These findings also suggest that along with the provision of information about the likely consequences of proposed actions, a carefully structured framework for decision making is needed to help provide the necessary context needed to better understand the complex social, economic, and environmental issues that are commonplace in discussions about energy. Such a framework is comprised of six basic elements, each one supporting the others in ways that are dictated by the specific decision context. These elements serve to (Arvai 2014a; Bessette et al. 2014; Gregory et al. 2012):

1. Define clearly the decision problem that is to be the focus of analysis while taking into account the bounds and constraints under which decisions must be made;
2. Identify objectives that will guide the decision-making process, including the performance measures that will be used to gauge success or failure in terms of meeting them;
3. Create logical and creative alternatives that directly address these objectives;
4. Establish the predicted consequences that are associated with alternative courses of action, including key sources of uncertainty;
5. Confront inevitable trade-offs when selecting among alternatives; and
6. Implement decisions, monitor outcomes (as measured by the achievement of objectives), and adapt to changing conditions.

10.5 Examples of Practice

These lessons are evident in recent research in which Bessette et al. (2014) developed and tested a framework for crafting an energy strategy for Michigan State University (MSU). MSU has a cogeneration facility located on campus that converts the thermal energy from burning coal, natural gas, and biomass into electricity and steam. With a peak electrical output of 99.3 megawatts and a pressurized steam generation capacity of up to 1.3 million pounds per hour, it is the largest on-campus coal-burning power plant in the United States. The facility is the principal energy provider to the main campus and is capable of meeting approximately 97% of all electricity demand. Steam that is generated is distributed at high pressure to the campus to provide heating and cooling to a campus spread over approximately 5,000 acres.

In 2008, MSU commissioned development of a process for developing a new strategy for long-range energy generation on the campus. The goal was to transition away from a fossil fuel-based (coal and natural gas) energy strategy to one based entirely on renewables by approximately mid-century. A parallel goal was to help establish a multi-stakeholder decision support process that could serve as a template for similar energy strategy decisions in Michigan, elsewhere in the Unites States, and abroad.

Bessette et al. (2014) began by holding a series of meetings with university officials to define the decision problem (for example, the desire to transition from fossil fuels to renewables) and identify the boundary conditions for the decision making process (for example, identifying stakeholders whose ideas would be critical to the process). They followed these meetings with several workshops and focus groups to identify the range of objectives that were important to key stakeholders on and off campus (for example, students, staff, faculty, and neighboring communities) and potential performance measures that would be useful for tracking their achievement. Through additional workshops and a lengthy engineering review process, we narrowed the objectives and their associated performance measures to a short list of critical considerations that would be used as part of a strategy development process cast widely across the community.

In a critical step at this stage, Bessette et al. (2014) relied upon colleagues (Compass Resource Management in Vancouver, BC, and Black and Veatch of Overland Park, Kansas) who developed an energy system model capable of forecasting the anticipated outcomes of alternative energy strategies in terms of the key objectives and related performance measures. This model became the centerpiece of an online decision support platform that people—policy makers, experts, and the public—would use as a means of participating in the development of the energy strategy. The online platform built on recommendations from the National Research Council (1996, 2009) about how best to present information relevant to decisions about energy in a decision-focused environment. As such, the platform was designed to engage people in the process of learning about energy systems, including their environmental, economic, and social considerations.

Beyond simply educating people, however, the decision support framework provided users with an opportunity to design their own energy development portfolios. In constructing their portfolios, users could mix and match individual energy generation (and supporting) technologies for deployment at different times over the course of the energy strategy. The technologies for consideration included centralized power plant options (for example, coal, natural gas, biomass, or nuclear power), decentralized options (solar, natural gas, micro turbines), energy from the national power grid (relying on either conventional fuels or renewables), carbon management techniques (for example, carbon capture and storage), and levels of effort expended on building efficiency. As users built their energy strategies, they were able to monitor their ability to meet future energy demand, and they could track, via the energy system model, the forecasted performance of their strategy, as measured against the agreed-on objectives and performance measures.

In addition to simply suggesting a desired energy strategy, this decision support framework also challenged users to evaluate their portfolios in comparison with a broad array of others representing markedly different priorities. In doing so, people were required to be explicit about the pros and cons of each of the energy strategy options under consideration; for example, how much additional cost were they willing to bear in exchange for reduced greenhouse gas emissions or the warm glow that comes with being at the leading edge of innovation? Conversely, to what extent were users willing to comprise on air quality or employment as a means of keeping costs near the status quo?

In order to inform these comparisons, the decision support system included a module that helped users confront trade-offs and make internally consistent choices (that is, choices that reflected objectives of greatest concern). Bessette et al. (2014) built this module, which uses tools from multi-criteria decision analysis, on the notion that internally consistent choices begin by having a clear sense of how important individual objectives are to decision-makers. With this information in hand, users could apply the energy system model and determine a rank order of energy strategy alternatives based on the degree to which each one best satisfied the most important objectives.

Approaching decisions about energy in this way may seem like a tall order and, worse, a recipe for making large investments (for example, in infrastructure) that cannot easily be reversed. It is true that energy strategies will require large investments of this type. But technically speaking, there are ways forward. In the case of the work by Bessette et al. (2014), for example, energy alternatives that incorporated flexible infrastructure, such as swappable fuel power generation units, were favoured over technologies that would lock decision-makers into a particular fuel type for decades. Practically speaking, this meant that flexibility and reversibility became high-priority objectives—trumping others related to cost, for example—in the eyes of planners and policy makers.

In a second example, Kenney et al. (2014) worked with policy makers in the Northwest Territories on developing a framework for decision making about northern energy investments. Prior to the work of Kenney et al. (2014), government decision makers and analysts relied upon a wide range of consultation processes to engage stakeholders in risk assessment and decision-making processes for energy development.

However, Kenney et al. (2014) argue that good listening, education, and negotiations on their own are insufficient for making the kinds of complex decisions that are commonplace in the development of energy strategies. They also raised concerns about what is often a rush to minimize conflict and build consensus around energy development initiatives because, in the search for agreement, intractable issues were often downplayed in favour of those where agreement was easy. Kenney et al. (2014) argue that this strategy contributes to incremental, and often insignificant, changes or cursory agreements that disintegrate when stakeholders and decision makers come to realize that concerns central to decisions were either ignored or handled superficially.

None of Kenney et al.'s (2014) arguments are meant to suggest that providing stakeholders and decision makers with timely and useable information, or a forum in which to communicate, are unimportant ingredients in decision-making; they clearly are. But so too is a well-structured process for decision aiding: One that engages diverse stakeholders in decision-focused discussion, levels the playing field between facts and values, and facilitates deliberation and analysis when comparing alternatives and confronting tradeoffs.

This is especially relevant in energy-related decisions in developing communities, where such decisions can have significant consequences—positive *and* negative—in terms of economic and natural-resource development. For example, hydroelectric dams generate electricity and income for their owner-operators; however they also alter river flows, affecting ecosystems and the services they provide. Building oil or gas pipelines or increasing the use of biomass all contribute to energy production, but each reduces forest areas that might be used for livestock grazing or as sacred spaces. Decision makers also need to consider the greenhouse gas (GHG) emissions that accompany their decisions, especially in developing communities that tend to be more vulnerable to the effects of climate change (Mertz et al. 2009).

A third example of this kind of decision support framework comes from the hydroelectric utility siting in British Columbia, where the provincial energy strategy was designed to include regular reviews of all decisions pertaining to water releases (and, therefore, electricity generation) at hydroelectric dams. These reviews are required to ensure that energy projects remain in line with the objectives of key stakeholders and the changing state of scientific knowledge about the broader social and environmental systems in which energy infrastructure resides (Gregory & Failing 2002; Gregory et al. 2001b; McDaniels et al. 1999).

In sum, the decision support examples outlined here encapsulate the five critical decision support elements: clarifying problems, thinking clearly about objectives, designing creative alternatives, modelling consequences, and confronting trade-offs. It works by breaking what is a very complex decision—the creation of an energy strategy—into a series of smaller, more manageable parts that are less prone to error and bias. Research conducted to evaluate this framework has shown that it leads to higher quality decisions (measured by the degree to which users choices are internally consistent), more satisfied and better educated decision makers, and, importantly, greater trust and transparency in the process (Arvai et al. 2014; Arvai & Post 2012; Arvai & Gregory 2003; Arvai et al. 2001; Bessette et al. 2014; Wilson & Arvai 2006).

10.6 Next Steps

Because of complexities associated with decisions of the type faced by policy makers and society around energy, we recommend strongly that policy makers (and researchers) turn their attention toward enhancing decision support capabilities around energy and related concerns, such as climate change. Many of the current calls for improved decision-support capabilities around energy development emphasize placing up-to-date information about risks, benefits, and opportunities in the hands of decision-makers. However, thoughtful and defensible decisions concerning energy development strategies will require more than high-quality scientific information. Energy development decisions—whether local, regional, or national—will also require a process for incorporating the values and risk tolerances of stakeholders and for linking values and facts as part of a series of thoughtful decisions over time and space.

Even under the best circumstances, people—members of the public and policy makers alike—will need help in making these kinds of complex and interlocking decisions. As we have argued, decision processes are often prone to shortcuts, error, and bias. In the case of choices as important as those concerning energy developments, failing to address these challenges in a credible way is as irresponsible as relying on out-of-date and substandard technologies.

In the end, the real need in terms of decision-support is not just better science; it is the need is to provide people with a mechanism for making a series of difficult and interrelated choices among them over time. Only through this kind of approach will we be able to move past the impasses we currently face in Canada and abroad when it comes to choices about whether to invest in certain energy development initiatives.

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

23. Research and Development of Decision-Support Tools

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

1. What are the underlying judgmental patterns and behaviours (i.e., "heuristics") that drive decisions about energy development in Canada? To what extent to representatives of industry and the public differ in terms of their intuitive approaches to decision-making.
2. How can industry better understand the range of objectives that guide decisions about energy development?
3. How can industry better model alternative development and management scenarios in a manner that is responsive to the multitude of stakeholder objectives?
4. To what extent can decision-support tools be developed to help people confront tradeoffs when objectives and alternatives will inevitably conflict?
5. To what extent might improved decision-support approaches, that involve multiple stakeholders, contribute to the development of "social license" for energy development initiatives?

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Experimental work to addresses Priority Knowledge Gaps 1 and 5. Experiments to address these gaps would follow established quantitative methods in the cognitive sciences.	High potential to fully address these gaps.	Standard and accepted experimental (quant.) research methods.	Moderate	Capacity in Canada and internationally.	$100-200K	2 to 3 years of initial work, with the potential for ongoing research if necessary.	Focus on Canada with generalizability to other countries.
Qualitative research study to elicit objectives and performance measures (Gap 3).	This will be context specific. Gaps may be fully addressed in each context for which the research is undertaken.	Standard and accepted qualitative research methods in the decision sciences.	Moderate	Capacity in Canada and internationally.	$50-100K per resource development context.	1 year per resource development context.	The focus would be context-specific within Canada. Elicitation approaches for this kind of work are already well-established. The focus would be on expanding context-specific knowledge (vs. methods development).
Quantitative Research study to develop and test tradeoff support tools (Gap 4).	Valuable but Partial	Standard and accepted quantitative research methods.	Low. This would be challenging work requiring a dedicated and knowledgeable team.	Limited Capacity in Canada; greater capacity in US.	$250-400K	3 to 4 years	Focus would be on developing computational tools (which may be automated) so that decision-makers and stakeholders could confront challenging tradeoffs. Work would build in existing research and development (e.g., Bessette et al. 2014). Benefits from this work would be internationally applicable and would span multiple resource development (and risk management) contexts

KEY ISSUE OF RELEVANCE TO DECISION MAKERS:

24. Training and capacity building within industry.

PRIORITY KNOWLEDGE GAP TO ADDRESS THE ISSUES

There is a need for industry to develop and maintain capacity in the arena of decision-support. Too often, industry relies on consultants with little or no understanding of the decision-support capabilities that are required. The strategy, therefore, would be to the industry to become more sophisticated in their understanding of decision-making, as well as in terms of decision-support.

ADDITIONAL CONSIDERATIONS INCLUDING RISK OF UNCERTAINTY OR LACK OF AGREEMENT ON RESEARCH RESULTS, REGIONAL VS. NATIONAL APPLICABILITY, SPECIFIC SOCIOPOLITICAL CONSIDERATIONS, ETC.

Research Approaches	Potential to Address Gap	Scientific Complexity	Ease of Implementation	Research Capacity	Cost	Timeframe	Additional considerations
Rather than pure research, the emphasis here would be on developing and testing a series of training modules that could be provided to industry.	Significant on a “client-by-client” basis.	Standard and accepted training and evaluation methods.	Moderate	Capacity in Canada	$50-100K per industry “client”	6-12 months per industry “client”	Local training sessions for industry clients. Modeled after work by Arvai and colleagues for EcoCanada, as well on a bespoke basis through university executive education programs.

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Appendix A Sample Scenario Analysis of Hydraulic Fracturing – Western Alberta Case Study

The Cumulative Effects of Hydraulic Fracturing in Alberta's Eastern Slopes

Matthew Carlson and Brad Stelfox (12/2/2014)

INTRODUCTION

Horizontal drilling with multistage fracturing is allowing production of oil and gas from previously inaccessible tight and shale gas and oil deposits, and adoption of the technology is increasing rapidly across Canada. One such example is Alberta where, as recently as 2008, horizontal drilling accounted for only 18% of oil well completions and 3% of gas well completions (ERCB 2009). By 2012, horizontal drilling was used for 77% and 53% of oil and gas well completions, respectively (ERCB 2013). The shift towards horizontal drilling has both positive and negative consequences. The technology has given new life to conventional oil and gas development production and is enabling the emergence of the shale gas sector. High well productivities achieved through horizontal fracturing is stimulating economic activity and may reduce the amount of landscape disturbance relative to previous hydrocarbon development in the province. At the same time, by opening up previously uneconomic reserves to production, horizontal fracturing may increase the extent of industrial footprint with negative implications to wildlife. Also of concern are implications to water availability and water quality due to the large volume of water used during the fracturing process. Whereas a vertical shale gas well requires 100 to 400 m^3 of water during fracturing, several thousand m^3 of water can be required during fracturing of a horizontal shale gas well (ALL Consulting 2012).

As part of the project "CWN Hydraulic Fracturing and Water – Landscape Impacts", a scenario analysis was completed to assess the impacts of a shift towards horizontal multistage fracturing in recent and coming decades. The analysis focused on the eastern slopes of Alberta, a region conducive to hydraulic fracturing due to the abundance of tight and shale deposits. Using the eastern slopes as a case study, the intent was to demonstrate how scenario analysis can inform regional management of hydraulic fracturing through the identification of risks and mitigation opportunities, as well as knowledge gaps that impede assessment of management options.

STUDY AREA

The study area for the scenario analysis was Petroleum Services Association of Canada Region 2 for Alberta (hereafter referred to as AB2). The region spans 72,000 km^2 along the eastern slopes of the Rocky Mountains, and accounts for more than one third of the province's population including the Calgary metropolitan area. The region has become a focal point for horizontal drilling in Alberta (Figure 1), due to an abundance of tight gas and oil formations. In 2013, AB2 accounted for 59% of completed conventional gas wells (AER 2014), of which approximately 90% utilized horizontal drilling[6]. As such, the region accounts for a large proportion of horizontal gas well completions in the province[7]. Given that AB2 has the lowest natural gas supply cost in Alberta, horizontal drilling for conventional gas in the region is expected to continue to grow (AER 2014). The region is also of interest due to the emergence

[6] 91% of productive conventional gas wells receiving drilling activity in 2013 according to the AER total well list are identified as horizontal by the AER horizontal well list.
[7] According to information obtained from the AER total and horizontal well lists, horizontal drilling occurred at 526 active conventional gas wells in AB2 in 2013. In comparison, the total number of horizontal conventional gas well completions in the province that year was 629 (st98-2014).

of shale gas extraction, which relies almost exclusively on horizontal multistage fracturing[8] and requires large water volumes for the fracturing process[9]. Shale gas development is in its infancy in Alberta, but it is expected to increase to offset declines in conventional gas production. AB2 incorporates portions of numerous shale gas formations, including the prolific Duvernay and Montney deposits (ERCB 2012).

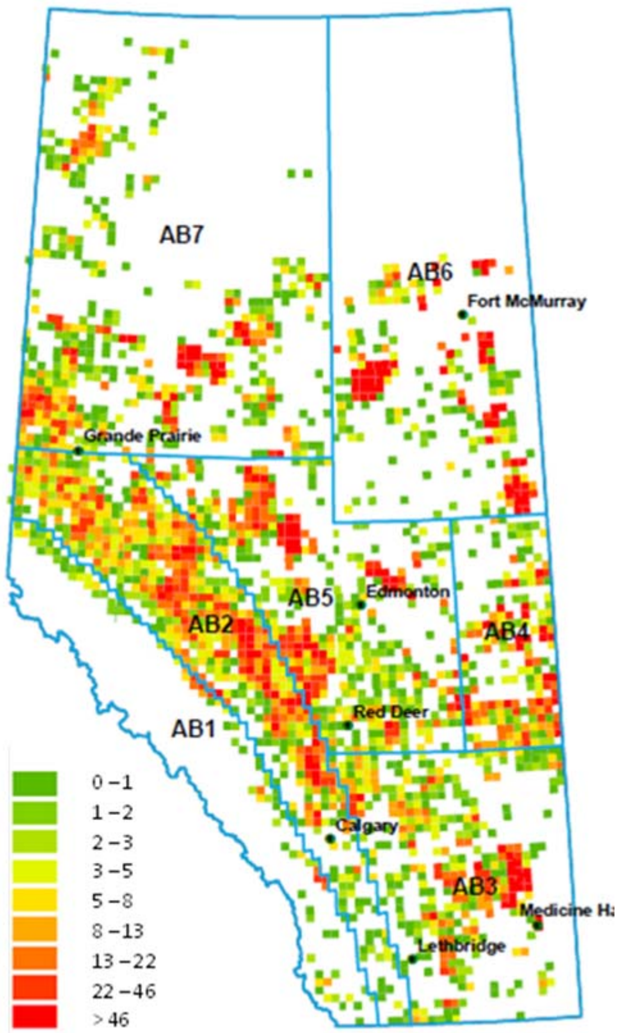

Figure 1. Horizontal well count relative to Alberta PSAC regions (AB1, AB2, etc.). PSAC region AB2 was selected as the study area due to its high density of horizontal wells.

The study area's dominant land cover[10] is forest, accounting for 52% of the region and concentrated to the north. Covering 20% of the study area, farmland is the second most abundant land cover and is

[8] In 2013, all shale gas wells with drilling activity in AB2 according to the AER total well list were identified as horizontal by the AER horizontal well list.
[9] As described in the methods, water use during fracturing of shale gas wells was found to be an order of magnitude higher water use during fracturing of conventional gas or oil wells.
[10] The composition of the study area was calculated using 2010 landcover and footprint data derived by ABMI from Earth Observation for Sustainable Development and Agriculture and Agri-Food Canada land cover datasets and

dominant to the south with smaller amounts in the vicinities of Grande Prairie and Edson. Much of the remaining land cover is accounted for by wetland to the north (12% of the study area) and grassland to the south (6% of the study area). Anthropogenic footprint covers 6% of the study area, not including farmland. The most abundant footprints are roads (1.8% of the study area), urban and rural residential areas (1.8% of the study area), and energy sector footprints such as well sites, pipelines, and seismic lines (1.5% of the study area).

HISTORICAL AND FUTURE LAND USE

The scenario analysis explored historical land-use patterns and potential future patterns over the next three decades to assess implications to water use, landscape composition, and wildlife. While the focus was hydraulic fracturing, other land uses were also incorporated to explore hydraulic fracturing in a cumulative effects context.

The scenario analysis was completed by integrating ALCES Online with information gathered regarding historical and potential future horizontal drilling rates and associated water requirements. ALCES Online is a web-delivered scenario analysis tool for assessing the cumulative effects of past and potential future land-use trajectories in Alberta (Carlson et al. 2014). The tool is equipped with a range of scenario options which provide a holistic perspective through incorporation of a diverse set of drivers and indicators. Simulated land uses include energy, agriculture, mining, forestry, and human settlements. Dynamics are simulated spatially, and consequences to environmental and socioeconomic indicators are presented using maps and regional summaries. ALCES Online was customized for the project to accommodate the project's study area and to incorporate information about horizontal drilling rates and water demand.

HYDRAULIC FRACTURING

Horizontal well completions have risen dramatically in recent years, driven by growing exploration of tight oil and conventional gas formations as well as the inception of shale gas exploration. AER's (2014) list of horizontal wells indicates that the number of productive horizontal wells drilled per year[11] in the study area increased from 45 in 2007 to 1309 in 2013 (Figure 2). By 2013, horizontal drilling was being used for the vast majority of oil (728 of 736 productive wells drilled), conventional gas (526 of 581 productive wells drilled), and shale gas (55 of 55 productive wells drilled) well completions[12]. Although coal bed methane is also produced in the study area, it does not contribute to horizontal well completions because the relevant deposit (Horseshoe Formation) is not suited for horizontal drilling technology. The assumed future horizontal drilling trajectories for oil, conventional gas, and shale gas are now described. The trajectories were for a base case scenario that is considered likely based on

satellite imagery. The ABMI landcover dataset does not include a wetland class, so the Ducks Unlimited Hybrid Wetlands dataset was used to classify wetlands.

[11] The field "FIN-DRL-DATE" in the horizontal well list was used to identify the drilling date for horizontal wells. Only wells with a "FLUID_DESC" of crude oil, gas, or shale gas were included. For each of those hydrocarbon types, only those wells with a "MODE-DESC" of pumpling, flowing, or gas-lift were included.

[12] The provincial total well list (AER 2014) was used to identify the total number of productive crude oil, gas, and shale gas wells drilled each year (based on FIN-DRL-DATE) in AB2.

available information. In addition, high and low trajectories were simulated as part of a sensitivity analysis, as described in the sensitivity analysis section.

The future drilling trajectory for conventional gas wells was parameterized by replicating the ERCB's (2013) production trajectory for the period of 2013 to 2022[13], and extrapolating thereafter. According to ERCB (2013), 670 new wells are drilled in 2013, increasing gradually to 780 by 2022. The majority of these wells are expected to be horizontal. Sixty-seven percent of conventional gas well completions in PSAC region AB2 are expected to be horizontal in 2014, increasing moderately to 71% by 2023[14] (ERCB 2013). Although ERCB (2013) projects the drilling rate to increase between 2013 and 2022, it seems unlikely that the upward trend will continue given the maturing state of the resource. NEB (2011) projects the rate of drilling for conventional gas wells in Alberta to decline by 0.6% between 2022 and 2035, respectively. The drilling rate was assumed to decline by this amount between 2021 and 2035. The rate of decline in 2035 was then assumed to apply for the remaining years of that decade. The simulated location of drilling was informed by the location of gas deposits according to the Geological Survey of the Western Canadian Sedimentary Basin (Mossop and Shetsen 1994).

The drilling trajectory for oil wells was based on AER's (2014) trajectory for the period of 2014 to 2023, and extrapolating thereafter. Unlike for gas, however, a trajectory was only available for the province and not also at the scale of AB2. Thirty percent of the provincial drilling trajectory was allocated to AB2 based on the proportion of provincial oil well completions occurring in AB2 in 2013 (AER 2014). At the provincial scale, AER (2014) expects completions to decline from 2700 in 2014 to 2600 by 2023. When extending the trajectory beyond 2023, it was assumed that completions would decline at the faster rate of 2% per year, which is consistent with NEB's (2011) expectation that oil production in Alberta will decline by an average of 2% per year between 2024 and 2035. As per AER (2014), 81% of conventional oil well completions were assumed to be horizontal in 2014, increasing slightly to 83% by 2023 and remaining at that level for the remainder of the simulation period. The simulated location of drilling was informed by the location of oil deposits according to the Geological Survey of the Western Canadian Sedimentary Basin (Mossop and Shetsen 1994).

Shale gas production in Alberta is in its infancy, but expected to become a major component of the province's gas production[15]. However, due to the limited availability of information, AER (2014) and NEB (2011) do not provide projections for shale gas production. In western Canada, shale gas production is expected to grow to offset the decline in conventional gas production (Richardson 2013, Natural Resources Canada 2008). In the absence of better information, a shale gas trajectory was developed to gradually offset a portion of the decline in gas production in Alberta from conventional wells[16]. The

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[13] Although ERCB (2014) provides a production trajectory for the period 2014-2023, the trajectory from ERCB 2013 was used because production and drilling trajectories are provided separately for each PSAC, thereby making it possible to extract production and drilling trajectories for the study area (i.e., PSAC2).

[14] Horizontal wells were assumed to account for 71% of conventional gas well completions in PSAC2 for the remainder of the simulation.

[15] http://www.energy.gov.ab.ca/NaturalGas/944.asp; http://www.epmag.com/Production/DUG-Canada-2012-Alberta-Offers-Tremendous-Unconventional-Resource-Upside_102561

[16] The assumed shale gas production trajectory may be conservative. Although detailed projections are not available, a recent presentation by CAPP on the outlook of Canada's oil and gas sector includes a figure suggesting that production from Alberta's shale deposits can be expected to grow to a level moderately less (approximately two-thirds) that expected from the Horn/Cordova deposit. NEB (2011) projects production from the Horn shale deposit to reach 114.3 million m^3/day by 2035. A reasonable estimate of future production from Alberta shale

completion rate began at 50 wells per year in the study area, similar to the 55 completions that occurred in AB2 in 2013 according to AER's horizontal well list. The completion rate then increased gradually to 350 wells per year over the next decade and a half, and remained at 350 wells per year thereafter. The simulated location of drilling was based on the approximate distribution of shale gas reserves across the study area (ERCB 2012). All wells were assumed to be horizontal, given that all shale well completions in 2013 were horizontal (AER 2014). In 2013, the average productivity of a shale gas well in Alberta was 5556 m^3/day (AER 2014). When this productivity is combined with the drilling trajectory and an assumed productive lifespan of 30 years, the annual shale gas production in the study area is simulated at 3 billion m3/year after 10 years, 10 billion m3/year after 20 years, and 17 billion m3/year after 30 years. In contrast, conventional gas production in the province is projected to decline by 16.4 billion m3/year over the next 10 years (AER 2014), and is likely to continue to decline thereafter. The shale gas trajectory assumed for AB2 may therefore be conservative, as it accounts for only a portion of expected drop in conventional gas production in the coming decades. AB2 contains large portions of the most prolific shale gas deposits in Alberta, including the Montney and Duvernay, which likely explains why the region accounted for 70% of shale gas completions in 2013 (AER 2014). If AB2 continues to play a dominant role in provincial shale gas production in the future, as seems likely, a more aggressive development trajectory than assumed here would be required in order to offset the expected provincial decline in conventional gas production.

The simulated growth in hydrocarbon sector infrastructure (wells, pipelines, seismic lines, industrial plants) was influenced by assumptions regarding the intensity off each footprint type per production well, as well as the lifespan of the footprints. The length of pipeline and seismic line, the number of exploratory wells, and the area of industrial plant associated with each well was based on the relationships between these features in Alberta. From 1991 to 2005, an estimated 128,920 wells were completed in Alberta (CAPP 2010) and 225,276 km of pipeline was constructed (Alberta Energy and Utilities Board 2007), for an average rate of 1.75 km of pipeline per well[17]. From 1997 to 2009, 136,876 wells were completed (CAPP 2010) and 1,021,391 of seismic line was created[18], for an average rate of 7.5 km of seismic line per well. Since 1955, 0.5 exploratory wells have been created for each new well connection. There is currently 0.13 ha of industrial facilities per ha of well site in the province, not including nonproducing wells[19]. Each productive conventional oil and gas well and nonproducing well occupied a 1 ha well pad, with the exception of gas and nonproducing wells in farmland and grassland which had a reduced area of 0.1 ha. For shale gas, it was assumed that four production wells occupied each 2 ha pad (Nishi and Antoniuk 2010).

Based on a retrospective analysis of seismic line reclamation in northeastern Alberta (Lee and Boutin 2008)[20], existing conventional seismic lines had a lifespan of 60 years. New seismic lines were assumed

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deposits may therefore be 75 million m^3/day by 2035 (i.e., two-thirds of that expected from Horn deposit). This is higher than what was assumed here (~45 million m^3/day by 2035).

[17] In simulations, 1.75 km of pipeline was created per new production well pad, rather than production well, to reflect efficiencies in the pipeline network that can be achieved by drilling multiple wells per pad.

[18] Calculated from ABMI footprint data. The calculation will underestimate the length of seismic created over that period if any seismic created since 1997 has subsequently reclaimed.

[19] For comparison, Wilson et al. (2008) assumed 0.24 ha of industrial facilities per ha of production well in northeastern Alberta.

[20] Lee and Boutin (2008)'s retrospective analysis of seismic line reclamation in northeastern Alberta over the past 35 years found that seismic was lost from the landscape at a median rate of 0.8% per year. This implies that

to be low impact with a lifespan of 20 years[21]. Pipelines were assumed to be permanent within the context of the 30 year simulation (Southern Alberta Sustainability Strategy 2003, Nishi et al. 2013), as were well pads. Research from boreal Alberta suggests regeneration of abandoned wells may be delayed several decades (Osko and Glasgow 2010). Seismic lines did not persist in farmland and grassland, and pipeline right of ways did not persist in farmland.

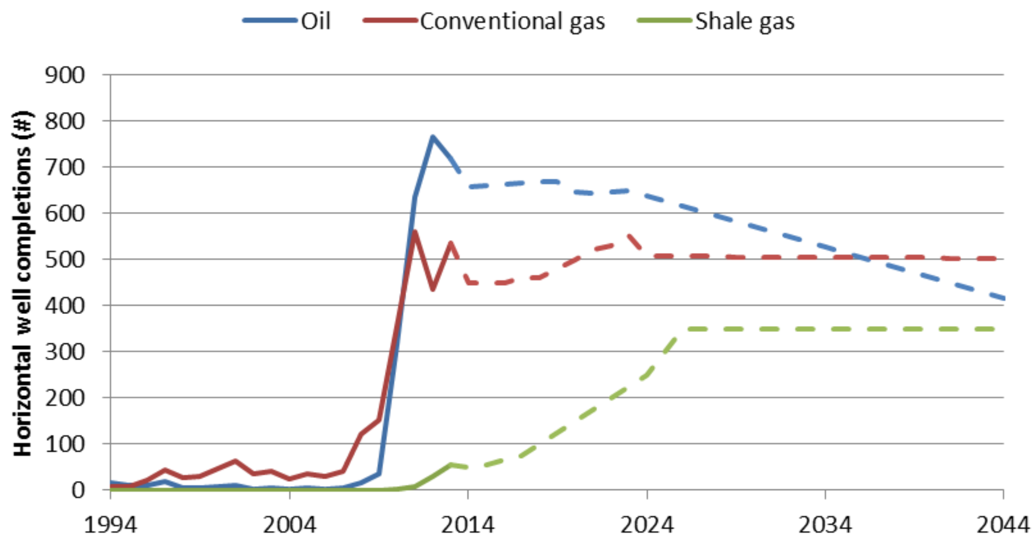

Figure 2. Past (solid line) and potential future (dashed line) annual horizontal well completions within AB2.

Other Land Use

Other land uses incorporated into the simulation to assess cumulative effects were settlements, forestry, coal mining, and roads.

Simulated population growth was based on observed population growth in relevant census divisions over the past 15 years. Within each census division, population growth was divided between urban and rural populations based on their current relative size. Expansion of town and rural residential footprint

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approximately 50% of seismic is lost after 60 years. This may underestimate the lifespan of existing seismic lines because Lee and Boutin (2008) found that much of the seismic was "lost" to tracked access rather than natural vegetation.

[21] New seismic was assumed to have an average lifespan of 20 years. Wilson (2008) assumed a lifespan of 10 years for low impact seismic in northeastern Alberta, but this may underestimate seismic lifespan if 4D seismic programs become prevalent (Athabasca Landscape Team 2009). 4D seismic involves active use of seismic lines for multiple years, implying that the initiation of reclamation is delayed and that reclamation is slower due to vegetation disturbance and soil compaction associated with multiple visits (i.e., across years). Therefore, the lifespan of 4D seismic is likely multiple decades in length. About 25% of seismic activity in Alberta is 4D (Godfrey 2010). This is likely to increase over time given its utility for exploring in situ bitumen and shale gas reservoirs (Gray 2011, Uffen 2011).

to accommodate the growing population was based on the current population density of the urban and rural portions of the population in each census division. The expansion of residential footprint into agricultural land, especially in the vicinity of Calgary, caused farmland to exhibit a moderate decline.

Simulated timber harvest volume was based on the annual allowable cuts of Forest Management Units occurring within the study area. The area harvested to achieve the desired annual harvest was informed by growth and yield curves from Alberta, the location of FMU's, and minimum harvest ages of 60 and 80 years for deciduous and coniferous forest, respectively. Cutblocks regenerated immediately to forest with the exception of inblock roads which accounted for 3% of cutblock area and whose persistence ranged from 10 to 40 years depending on topography. Salvage harvest from forest fires contributed to the annual harvest volume, although only in a minor way because the simulated fire rate was low (0.19%/year) based on the assumption that suppression will continue to be effective in the region. Another natural resource industry included in the simulation was coal mining. Production at the study area's two coal mines, Obed and Coal Valley, was simulated to remain at current levels, resulting in an expanding mine footprint through time.

Minor roads were assumed to expand at the same rate as other land-use footprints that are correlated with the current spatial distribution of minor roads across Alberta. The relationship between minor roads and other footprint types was estimated through regression. According to the relationship, at the scale of 10 x 10 townships: each hectare of rural residential footprint is associated with 0.3944 ha of minor road; each hectare of well is associated with 0.2881 ha of minor road; and each cutblock ha is associated with 0.03424 ha of minor road. These coefficients were applied to simulated land-use rates to determine future minor road growth.

In addition to forecasting possible future expansion in anthropogenic footprint, historical footprint growth was reconstructed using available information on the rate and location of land use in previous decades. Information used when creating a "backcast" of anthropogenic footprint included energy well spud dates (energy sector), soil scientist reports (agriculture), population growth trajectories as well as historical town boundaries and water well spud dates (settlements), coal mine and highway histories.

SIMULATED IMPACTS OF HORIZONTAL DRILLING

Horizontal drilling with hydraulic fracturing has made it economic to produce tight and shale hydrocarbon deposits, facilitating increased energy development in the study area. Hydrocarbon production and associated economic benefits were assessed to evaluate economic impacts of the growth in energy development. Assessment of environmental impacts focused on water use due to the substantial water input required during fracturing. Rising energy development also requires more anthropogenic footprint, potentially leading to habitat loss and increased human access. Footprint area and edge were tracked in the simulations to assess the cumulative effects of hydraulic fracturing and other land uses to landscape composition. A grizzly bear exposure index was also tracked to evaluate implications of to a species that is sensitive to anthropogenic footprint.

RESOURCE PRODUCTION AND ASSOCIATED ECONOMIC BENEFITS

Historical and potential future hydrocarbon production was estimated using productivity information obtained from AER (previously ERCB) reports. Production estimates incorporate production from horizontal as well as vertical wells in the study area. Future conventional gas production was calculated by combining the drilling trajectory described previously with productivity assumptions used by ERCB (2013) for their gas production forecast. These assumptions included: production from existing wells declined by 14%/year; initial productivity of new horizontal conventional gas wells was 40000 m3/day and declined thereafter; and initial productivity of new vertical conventional gas wells was 14300 m3/day and declined thereafter. Future shale gas production was calculated by assuming that simulated wells will continue to exhibit the average shale gas well productivity in 2013 (5556 m^3/day; AER 2014). Future oil production was calculated by combining the drilling trajectory described previously with productivity assumptions used by AER (2014) for their oil production forecast. These assumptions included: production from existing horizontal oil wells declined by 21% per year; production from existing vertical oil wells declined by 14% per year; initial productivity of new horizontal oil wells was 7.5 m^3/day in 2014; by 2023, initial productivity of new horizontal wells was 6 m^3/day; initial productivity of new vertical oil wells was 3 m3/day; productivity of new wells declined through time.

Conventional gas production has increased gradually over the past two decades in response to increased drilling activity and the adoption of horizontal drilling. Continued use of horizontal drilling, with its high associated well productivity, is expected to stabilize production into the future (Figure 3) despite production declines expected for the province as a whole (ERCB 2013). Shale gas production, while minimal at present, was simulated to increase over the next three decades due to projected growth in well completions (Figure 3). Oil production was in slow decline until recently when a sharp increase in horizontal well completions resulted in a jump in production. The growth in production is projected to be short-lived, however, due to an expected gradual decline in both horizontal drilling rates and well productivity.

To assess the economic impacts of past and simulated future hydrocarbon production, contributions to gross domestic production (GDP) and direct employment were calculated using coefficients derived from provincial economic and resource production data (Appendix 1). Estimated contributions to GDP have increased slightly over the past two decades, with increased gas production offsetting losses from reduced oil production. A recent increase in hydrocarbon development associated with horizontal drilling caused a spike in GDP. Although GDP is simulated to decline slightly over the next decade due to a drop in oil production, thereafter GDP begins to increase in response to growth of the shale gas sector (Figure 5). Patterns exhibited by direct employment are similar to those of GDP (Figure 6). Among hydrocarbon sectors, conventional gas was the dominant contributor to GDP and employment, and contributions of the shale gas sector eclipsed those of conventional oil partway through the forecast.

Economic contributions of the hydrocarbon sector substantially exceed those of other natural resource sectors in the region. The estimated GDP generated by energy development in the study area alone ($7 to $10 billion per year) is greater the GDP generated across the entire province by crop and animal production ($3.6 billion[22]) and forestry ($0.5 billion[23]).

[22] GDP generated by crop and animal production is for the year 2012 but in chained 2007 dollars (Statistics Canada table 379-0030) and incorporates crop production, animal production, and support activities for crop and animal production.

[23] GDP generated by forestry is for the year 2012 but in chained 2007 dollars (Statistics Canada table 379-0030) and incorporates forestry and logging as well as support activities for forestry.

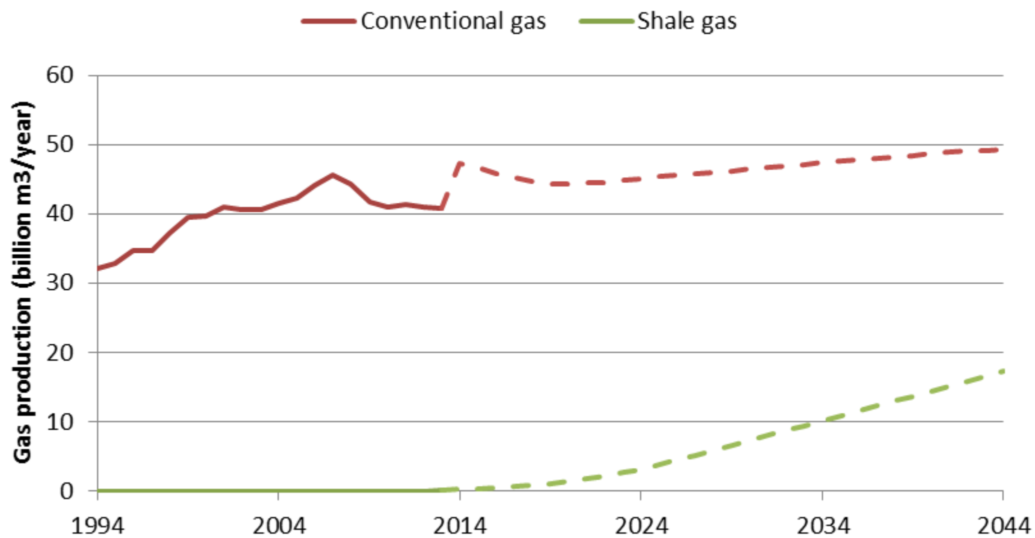

Figure 3. Past (solid line) and potential future (dashed line) gas production in AB2.

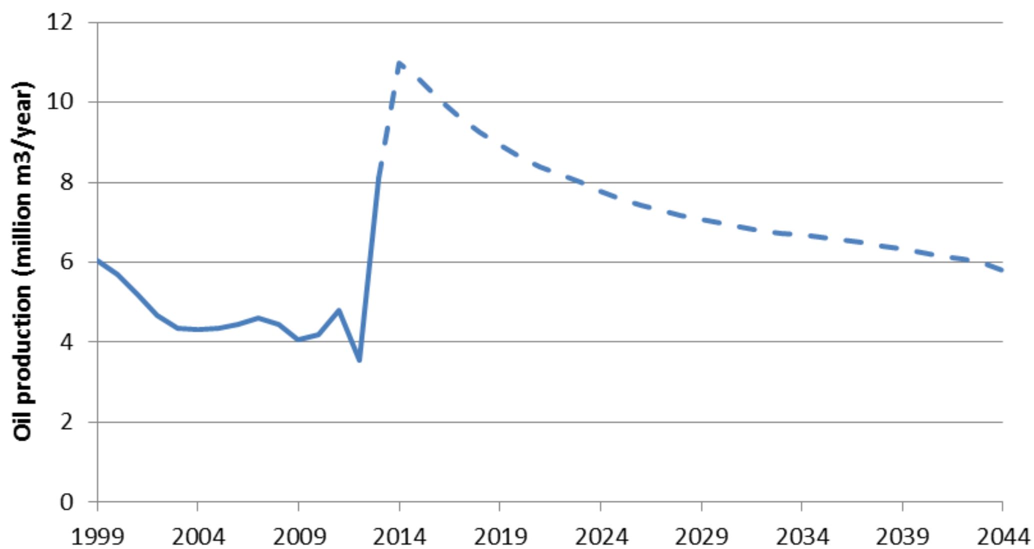

Figure 4. Past (solid line) and potential future (dashed line) oil production in AB2.

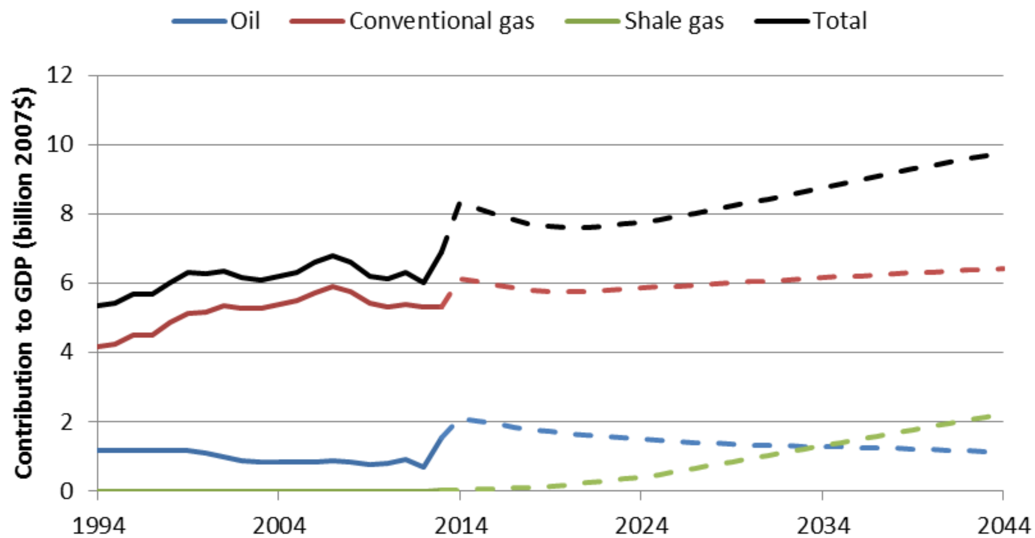

Figure 5. Estimated past (solid line) and potential future (dashed line) contributions of AB2 hydrocarbon production to gross domestic production (GDP).

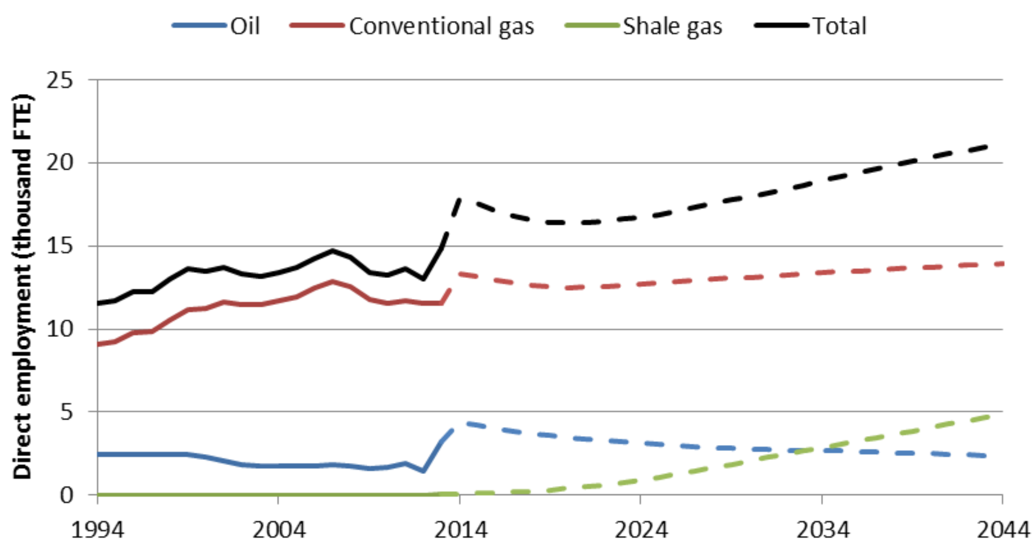

Figure 6. Estimated past (solid line) and potential future (dashed line) direct employment (full time equivalents) generated by AB2 hydrocarbon production.

Water Use

The volume of water required during the fracturing process depends on the number of fractures as well as the type of treatment, which in turn depends on characteristics of the formation (Johnson and Johnson 2012). To derive an estimate of water demand that is suited to the study area's formations, water use rates were obtained for a subset of the study area's horizontal wells. Over 5,600 horizontal wells exist within the study area[24] (Table 2), the majority of which produce conventional oil and gas with a smaller number producing shale gas. Fracturing records for approximately 1% of the conventional oil and gas wells and 20% of the shale gas wells were obtained from www.fracfocus.ca[25]. The fracturing records provide information on the usage of water as well as various additives and proppants, although only the water usage information was analyzed for this study. For each hydrocarbon type (i.e., oil, conventional gas, and shale gas), fracturing records were obtained as a systematic random sample of wells to ensure that the sampled wells were distributed across the study area relative to the distribution of horizontal wells across the study area. Water use per well in the sample was sensitive to the hydrocarbon type and the number of stages (Figure 7). Estimated water use for horizontal fracturing increased rapidly over the past five years due to increased horizontal drilling across all hydrocarbon types. Simulated water use continued to increase rapidly during the forecast (Figure 8), driven by growth in shale gas development with its high water use per well.

Water use data from fracfocus.ca does not differentiate by various sources including fresh surface water, saline and non-saline groundwater, and reused flowback/produced water. Although companies are required to report water use by source (ERCB Bulletin 2012-25), the data are not publicly available. As a result, water use by source is uncertain. Based on data obtained from its members, CAPP reported 5% reuse of fracturing water (Alberta WaterSmart 2013). It is likely that much of the remaining 95% of water was sourced from surface fresh water. The Canadian Council of the Academies (2014) reports that fresh water is the primary source of water used in hydraulic fracturing and most water used for fracturing in northeastern British Columbia is from surface water sources (Campbell and Horne 2011). For the purpose of the simulations, it was assumed that 69.3% of the water use reported by www.fracfocus.ca was fresh water based on the use of freshwater for fracturing relative to other water sources in British Columbia (BC Oil & Gas Commission 2013).

This assumption, when was combined with the simulated rate of horizontal drilling and water requirement per well, implied annual water use for horizontal fracturing increasing by 6.5 million m^3 over the next three decades. Simulated water use for horizontal fracturing was dispersed across the study area, with the exception of the far south where horizontal drilling is expected to be low due to less abundant reserves (

2011 to 2020	2021 to 2030	2031 to 2040

[24] based on information obtained from AER total and horizontal well lists.
[25] Water records were only obtained for a small sample of horizontal wells in the study area because records must be downloaded individually from fracfocus.ca, which is a time consuming process.

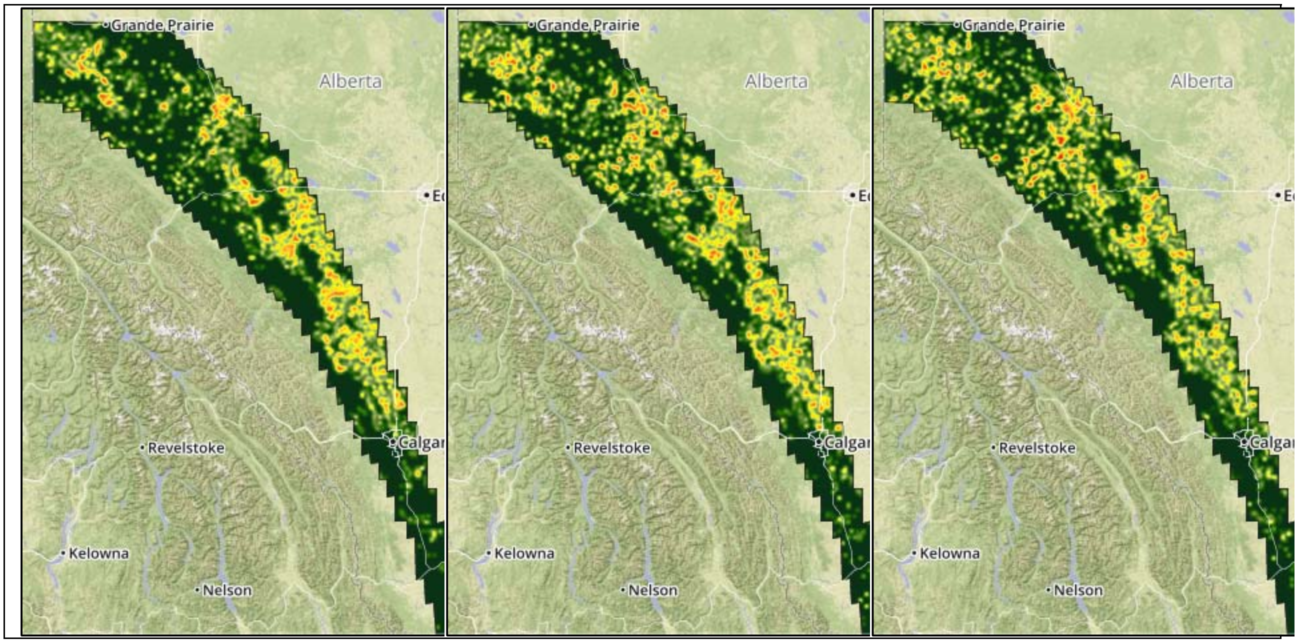

Figure 9).

Table 2. Fracturing water usage rates assumed in the analysis, based on the average water use across a sample of horizontal wells from the study area. Water use data obtained from www.fracfocus.ca.

Hydrocarbon Type	Average water use for hydraulic fracturing	Number of sampled wells
Conventional oil	2256 m^3	29 of 3029
Conventional gas	3018 m^3	26 of 2636
Shale gas	32448 m^3	20 of 102

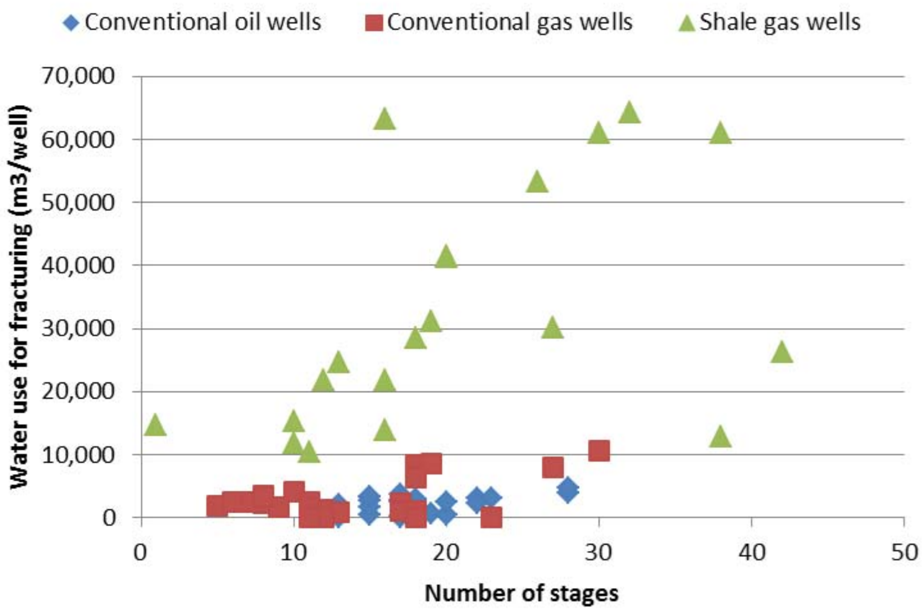

Figure 7. Fracturing water use for a sample of horizontal wells located within AB2. Water use data were obtained from fracfocus.ca.

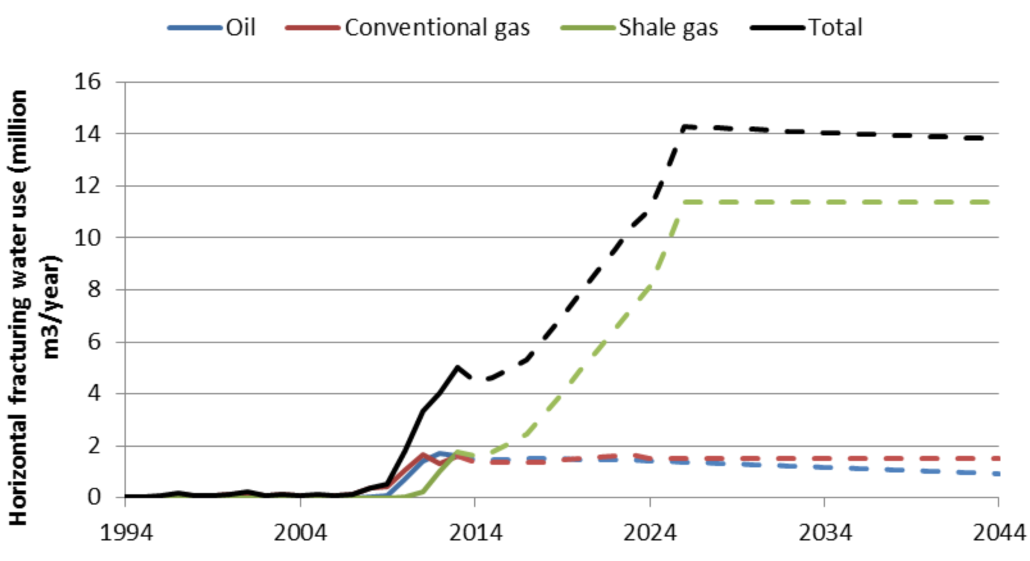

Figure 8. Estimated past (solid line) and potential future (dashed line) water use for horizontal fracturing in AB2.

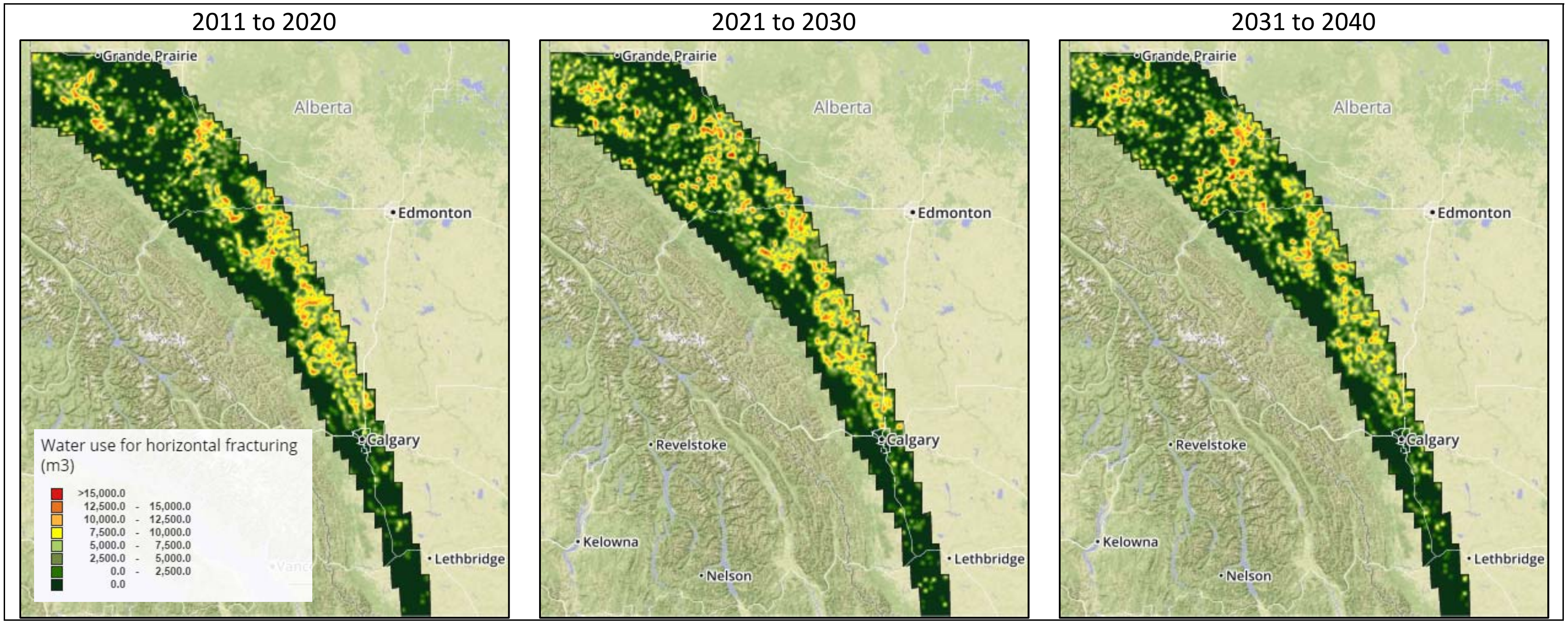

Figure 9. Simulated future water use for horizontal fracturing by decade in AB2.

INDUSTRIAL FOOTPRINT

Energy sector footprint (wells, pipelines, seismic lines, and industrial facilities) tripled over the past two decades, as high well decades, as high well productivities attracted exploration to the region (Figure 10). With the advent of horizontal fracturing in recent years, productivity has increased and the region's reserves have become more economical to produce. In 2013, AB2 had the lowest natural gas supply cost ($/GJ) in the province and attracted 59% of provincial gas well completions. The high productivity of wells, combined with the emergence of the shale gas sector, is expected to continue to draw high levels of energy development to the study area. Over the next three decades, energy exploration was simulated to almost triple from 1,112 km^2 to 3,010 km^2, accounting for 50% of the total simulated growth in anthropogenic footprint (not including farmland and cutblocks). Prior to the 1990's, energy sector footprint in the study area was focused in the vicinity of Drayton Valley but has since expanded spatially in the central and northern portions and is simulated to continue to do so in the coming decades (

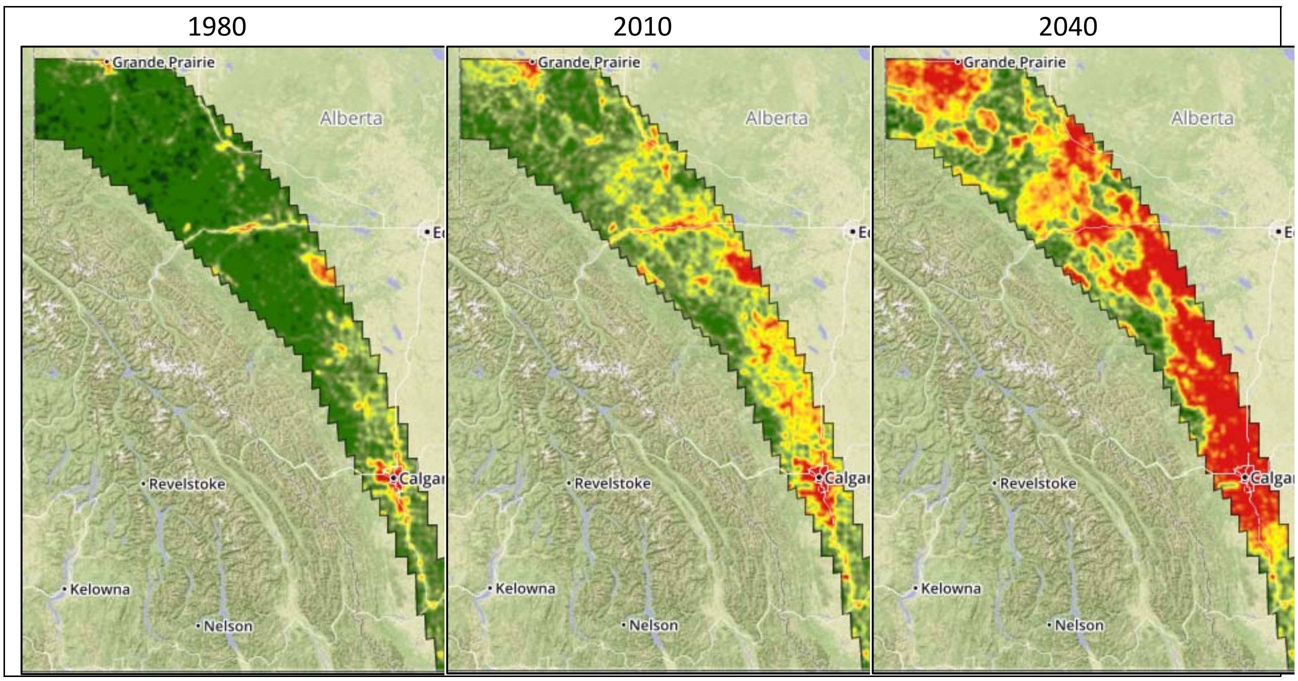

Figure 12). The expansion of energy footprints, which are characterized by a high edge to area ratio, results in a disproportionately high increase in anthropogenic edge. The energy sector contributed 85% of the simulated growth in anthropogenic edge over the next three decades (Figure 11). Anthropogenic edge is problematic for many wildlife species because it fragments core habitat and, in the case of linear footprints such as pipelines, seismic lines, and roads, facilitates hunting and fishing access. Indeed, the above discussion under-represents the contribution of energy development to edge because roads are not included[26].

As discussed in the previous paragraph, horizontal fracturing is attracting energy development to the study area by enabling high well productivity, and is thereby contributing to the ongoing expansion of anthropogenic footprint. It is important to note, however, that high production rates achieved through horizontal fracturing imply that less land disturbance is required per unit of energy production than is typical elsewhere in the province. In 2012, conventional gas average productivity in AB2 was 7,200 m^3/day/well, more than three times higher than the provincial average of 2,300 m^3/day/well (ERCB 2013).

[26] Roads were not tracked as energy sector footprint because of the difficulty in separating energy vs non-energy roads. However, energy development did contribute to road growth in the forecast simulation.

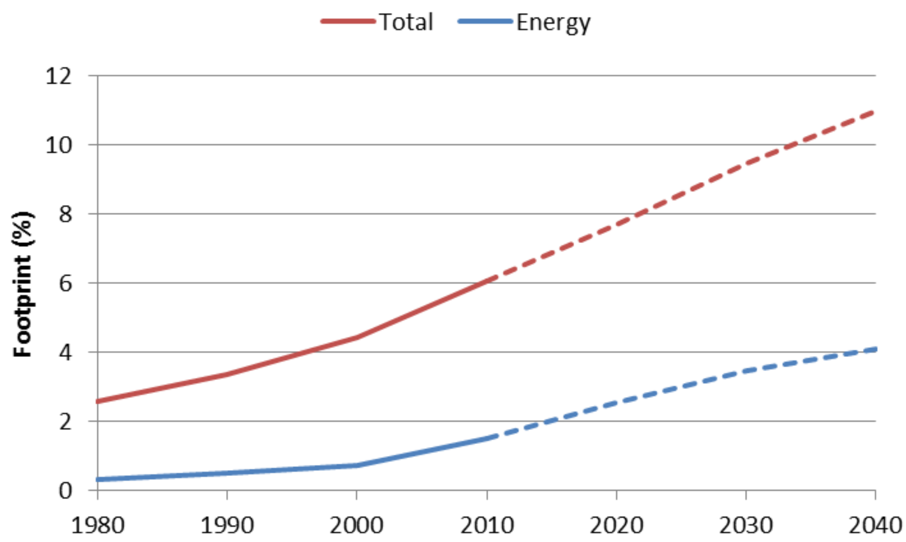

Figure 10. Estimated past (solid line) and potential future (dashed line) anthropogenic footprint associated with the energy sector (not including roads) and all sectors (not including farmland and cutblocks) in AB2.

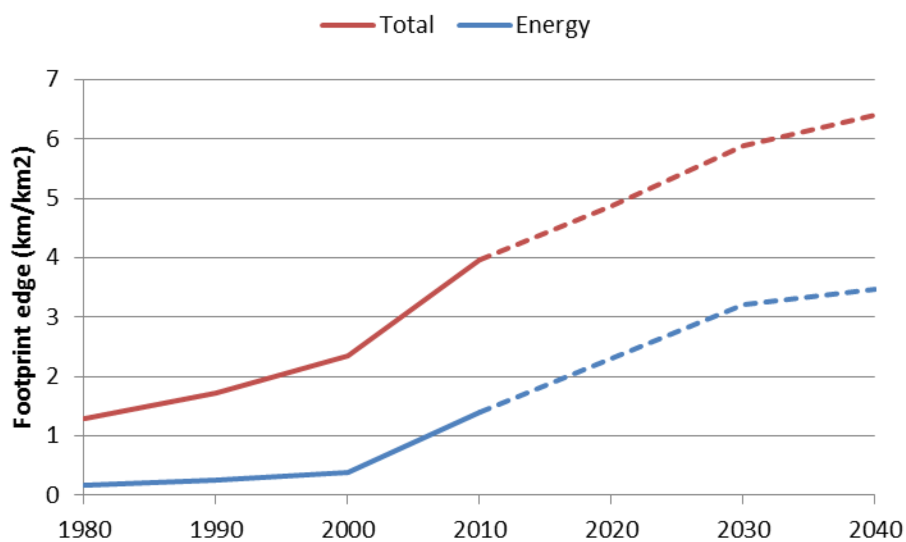

Figure 11. Estimated past (solid line) and potential future (dashed line) anthropogenic edge associated with the energy sector (not including roads) and all sectors (not including farmland and cutblocks) in AB2.

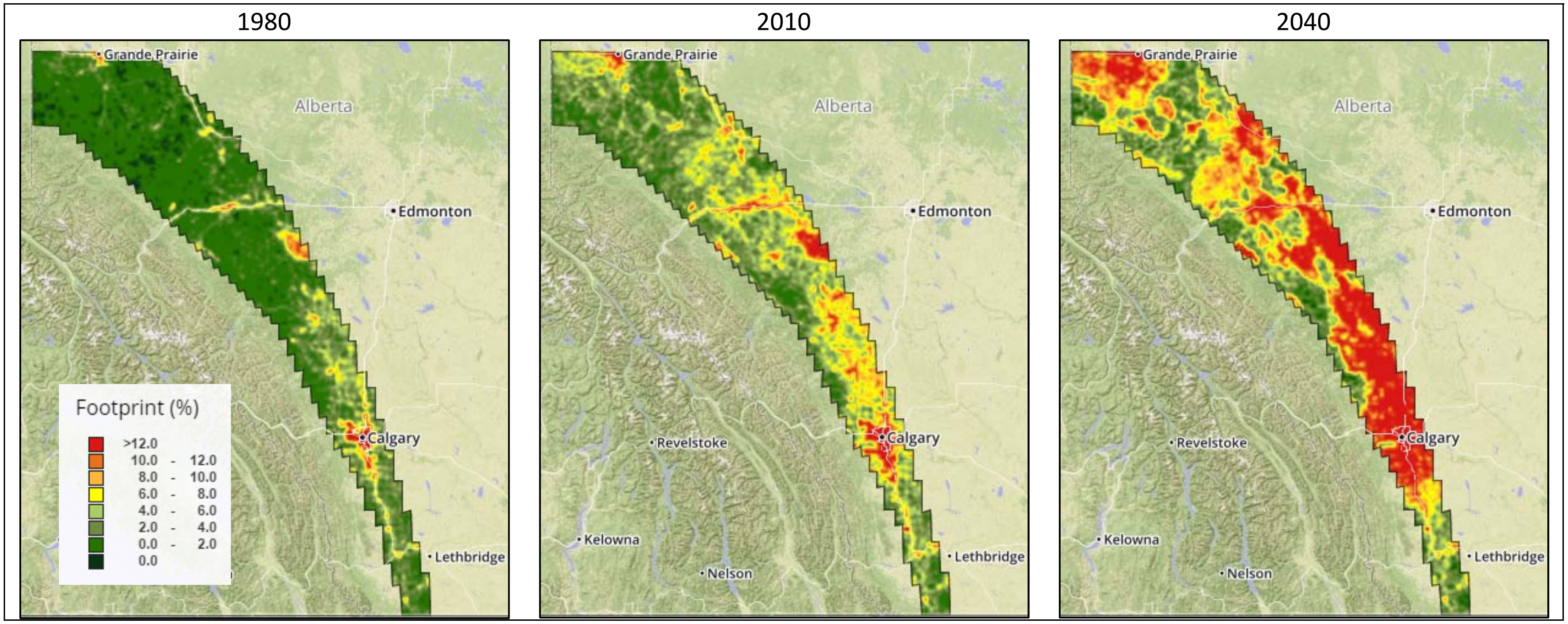

Figure 12. Simulated past and potential future growth in anthropogenic footprint in the study area, not including farmland and cutblocks.

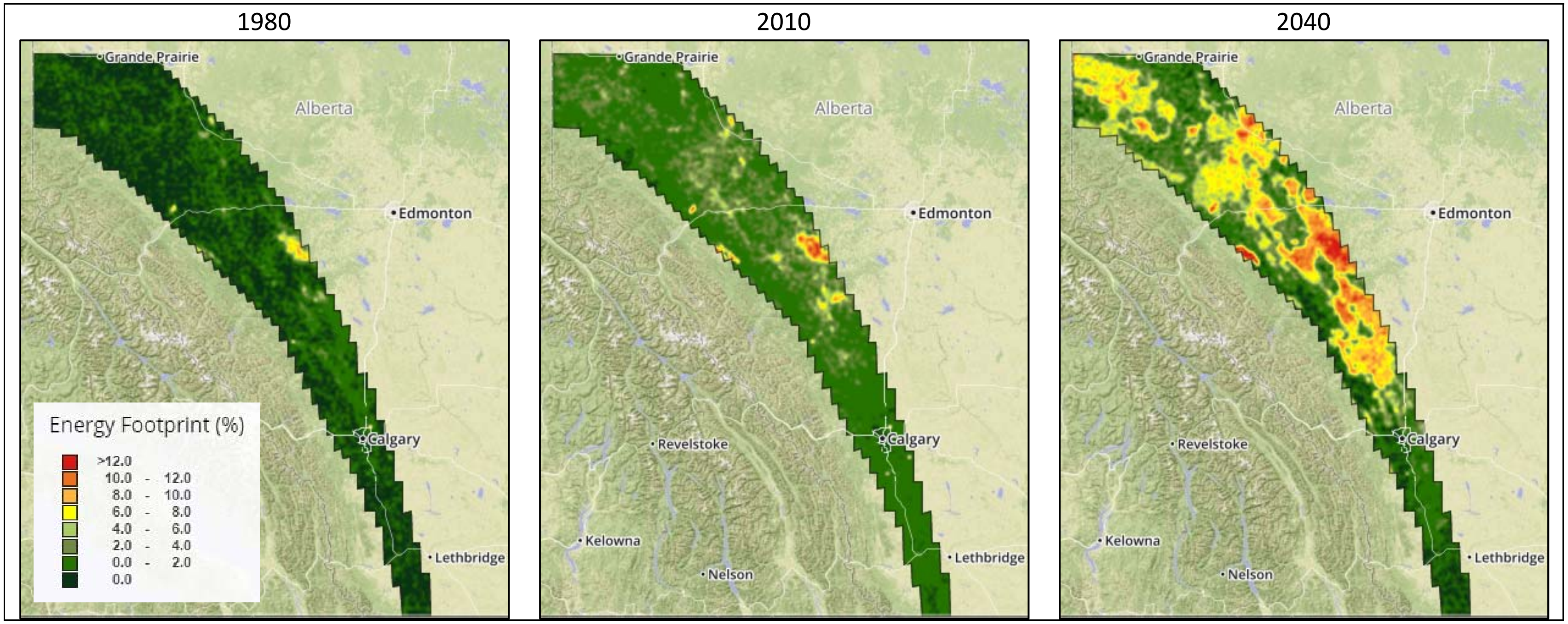

Figure 13. Simulated past and potential future growth in energy sector footprint, not including roads.

GRIZZLY BEAR EXPOSURE INDEX

Developed from southwestern Alberta radiotelemetry and mortality data (Nielsen and Boyce 2003), the exposure index identifies areas that are selected by grizzly bears but that also present high mortality risk (i.e., mortality traps), with higher index values indicating higher levels of risk (Appendix 2). The results should be interpreted with caution because the index coefficients were estimated using radiotelemetry and mortality data collected outside of the study area. However, by identifying anthropogenic footprint, especially roads and other linear footprints, as contributing to mortality risk, the exposure index is consistent with research from the study area and elsewhere in Alberta that identifies human-caused mortality associated with motorized access as the primary contributor to grizzly bear decline (ASRD and ACA 2010). As anthropogenic edge has increased in recent decades, in part due to expanding energy development, risk to grizzly bears in the region has increased as shown by the upward trend in the exposure index (Figure 14). The rise in the exposure index during recent years in the central portion of the study area is consistent with the outcomes of a population viability analysis that suggests a population decline in the Yellowhead grizzly bear population unit, which is located in the foothills to the west of Edmonton (ASRD and ACA 2010). In the forecast, the grizzly bear exposure index was simulated to continue to increase, although at a reduced rate relative to previous decades. Of greater concern, however, is the increase in the exposure index in the northern portion of the study area. The northern portion of the study area overlaps with part of the Grande Cache population unit, which is estimated to account for over half of the provincial population and supports a higher than average population density due to low anthropogenic footprint (ASRD and ACA 2010). Energy development expansion in the northern portion of the study area, which seems likely due to its overlap with the Montney, Duvernay, and Nordegg shale deposits, may be to the detriment of a grizzly bear subpopulation that plays an important role in maintaining the viability of the provincial population.

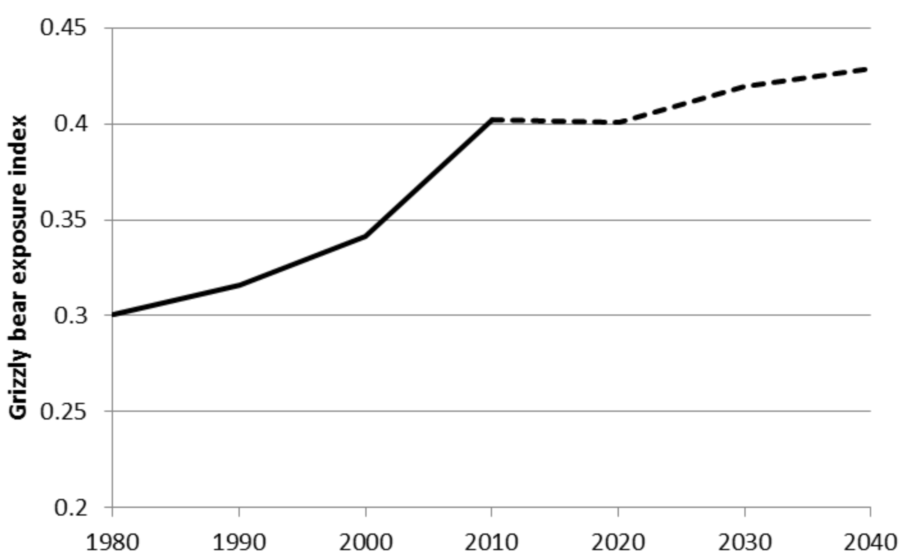

Figure 14. Estimated past (solid line) and potential future (dashed line) grizzly bear exposure index status in AB2.

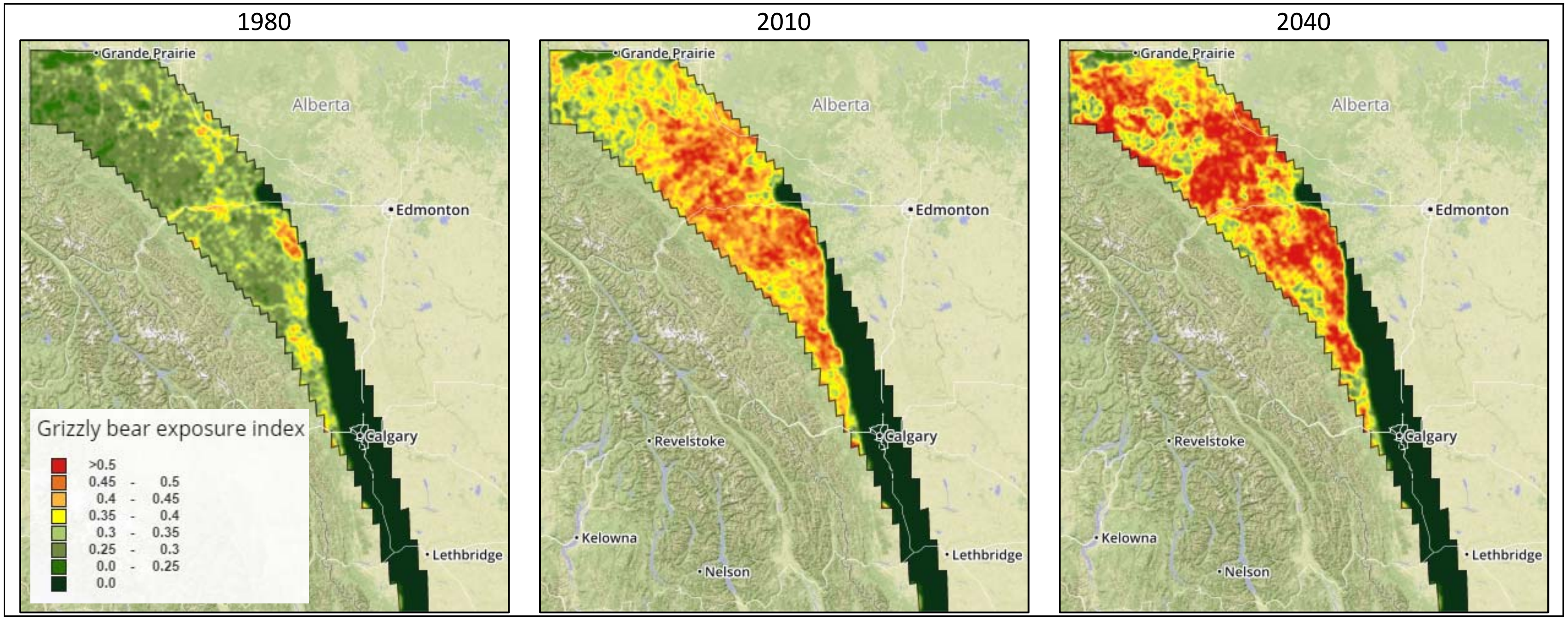

Figure 15. Simulated past and potential future grizzly bear exposure index status in AB2.

SENSITIVITY ANALYSIS

The previously described base case scenario was intended to portray regional impacts that are consistent with projected development rates. It is important to note, however, that substantial uncertainty surrounds the various assumptions that were adopted for the base case scenario, such as the future rate and location of hydrocarbon extraction, the size and lifespan of industrial footprints, and water demand per unit of resource production. These assumptions were manipulated to define a set of scenarios that represented a range of strategies for mitigating negative consequences of hydraulic fracturing. The scenarios were simulated and their outcomes compared to assess the relative influence of the assumptions and potential effectiveness of strategies for mitigating impacts to water and biodiversity.

The sensitivity analysis assessed opportunities to reduce fresh water use and strategies to limit industrial footprint and associated impacts to biodiversity. The simulated effect of the strategies was compared to the base case as well as high and low development scenarios. The rate of energy development is uncertain, as it is influenced by factors such as energy prices and the pace of economic growth. To bracket this uncertainty, high and low development scenarios were simulated whereby the rate of drilling increased and decreased by 25% relative to the base case. This range is similar to that adopted by the NEB (2011) when projection energy supply and demand out to the year 2035. The NEB (2011) developed five 5 scenarios: reference (moderate energy prices and economic growth); high and low energy prices; and fast and slow economic growth. The pace of projected energy development was more sensitive to energy price than economic growth, with the high and low energy price scenarios resulting in a 23% increase and 20% decrease relative to reference in the cumulative number of gas wells drilled in the Western Canadian Sedimentary Basin.

FRESH WATER SENSITIVITY ANALYSIS

Opportunities for reducing the intensity of fresh water use during fracturing include: increased use of water from sources other than freshwater such as saline groundwater and flowback; and adopting fracturing treatments that require less water.

Although no specific targets have been set for reducing freshwater use in hydraulic fracturing, the provincial government intends to update the oilfield injection policy to incorporate fracturing[27]. The oilfield injection policy includes the objective of reducing use of freshwater relative to saline water, especially in watersheds where water availability is limited (Government of Alberta 2006). From 2000 to 2010, 1/3 of the freshwater used for oilfield injection was replaced by saline water[28]. As a coarse exploration of the volume of freshwater that could be conserved by switching to other sources (e.g., saline) for fracturing, it was assumed that freshwater's share of total water use for fracturing could also be reduced by one-third. In the base case scenario, it was assumed that the use of freshwater relative to other sources during fracturing was the same as reported for British Columbia (69.3%) because the use of freshwater for fracturing relative to other water sources in Alberta is not reported. Reducing

[27] http://esrd.alberta.ca/water/water-conversation/hydraulic-fracturing.aspx
[28] Freshwater accounted for about 40% of the water used for oilfield injection in 2010, down from 60% a decade previous. http://esrd.alberta.ca/focus/state-of-the-environment/water/surface-water/pressure-indicators/water-used-for-oilfield-injection-purposes.aspx

freshwater's share of fracturing water use by one-third resulted in the assumption that freshwater accounted for 46.2% of total water use in the reduced freshwater use scenario.

Energized fracturing treatments is an opportunity to reduce the total volume of water required per well. In energized treatments, compressed gases such as CO_2 and N_2 create foams that are relied upon to suspend sand within fractures. A study of shale gas wells in British Columbia found that slickwater treatments (i.e., water and proppants) used an average of 2100 m^3/stage whereas hybrid treatments that combined slickwater with compressed gases required only 800 m^3/stage. Energized treatments that relied more heavily on compressed gases required only 155 m^3/stage. The performance of the various treatments is affected by the geological environment. Slickwater is the most cost-effective treatment when fracturing brittle rock with higher clay content, whereas enegized treatments perform better when fracturing softer rock such as siltstone (Johnson and Johnson 2012). Due to differences in geology, adoption of energized treatments has been more prevalent in the Montney basin than the Horn River basin which at least partially accounts for the dramatically lower water use per well in Montney (1900 m^3) and Montney North Trend (5900 m^3) basins compared to the Horn River Basin (30,000 m^3) (Johnson and Johnson 2012). Another study comparing energized and non-energized wells in the Montney basin found that energized treatments, while more expensive, used 50% less water and achieved higher gas recovery (Burke and Nevison 2011). The use CO_2 or N_2 during fracturing of shale gas wells does not appear to be prevalent in Alberta. A review of fracturing records for 20 wells in PSAC2 did not identify any wells where the practice was followed. As a coarse exploration of the volume of freshwater that could be conserved through use of energized treatments, water use per well was reduced by 50%.

By the end of the 30 year simulation, the energized treatment scenario reduced fresh water consumption by 4.8 million m^3/year relative to the base case scenario, whereas the alternative water sources scenario reduced water consumption by 3.2 million m^3/year. For context, as of 2007 water use (i.e., withdrawal minus return) by the city of Grande Prairie was approximately 0.5 million m^3/year [29] and water use by the city of Calgary was approximately 50 million m3/year[30]. Both strategies had a larger influence on future fresh water use than did uncertainty surrounding the future pace of development. In the final year of the simulation, fresh water consumption was 2.4 million m^3/year higher and lower than base case.

[29] Estimated water use (withdrawal minus return) by urban areas in Alberta's Peace/Slave River basin was estimated by Alberta Environment (2007) to be 911,000 m^3/year. Grande Prairie accounted for about 50% of the basin's urban population, suggesting that Grande Prairie's water use was approximately 0.5 million m^3/year in 2007.

[30] Estimated water use (withdrawal minus return) by urban areas in Alberta's Bow River basin was estimated by Alberta Environment (2007) to be 57,265,000 m^3/year. Calgary accounted for about 91% of the basin's urban population, suggesting that Calgary's water use was approximately 52.4 million m^3/year in 2007.

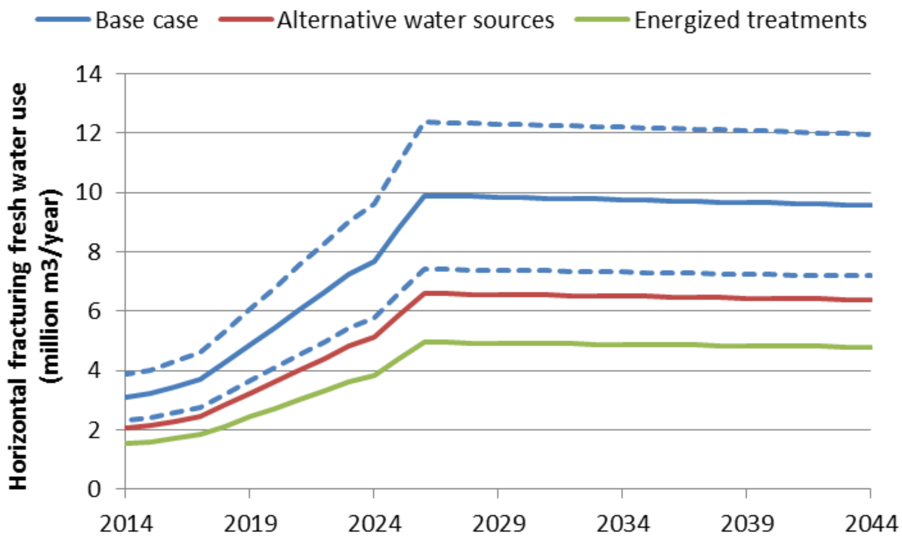

Figure 16. Simulated future water use for horizontal fracturing in AB2 under three scenarios: current practices (Base case, along with Low and High development scenarios shown as dashed lines); increased use of alternative water sources as opposed to fresh water (Alternative water sources); and use of energized fracturing treatments (Energized treatments).

Industrial Footprint Sensitivity Analysis

The primary motivation for limiting the expansion of industrial footprint is to protect species that are sensitive to anthropogenic activity. One such example is grizzly bear, a species at risk for which loss and degradation of wilderness habitat poses the greatest threat. When exploring strategies to limit industrial footprint, the sensitivity analysis focused on the Grande Cache grizzly bear range. As described previously, the Grande Cache range is a stronghold for grizzly bear in Alberta, supporting over half of the provincial population and a higher than average population density due to low anthropogenic footprint. In addition to focusing on important wildlife habitat, an additional benefit of assessing strategies at the scale of the Grande Cache range is that energy development is the dominant land use. As such, the range is sensitive to energy development and useful for demonstrating the consequences of alternative strategies for mitigating energy sector footprint. In contrast, the southern half of AB2 as well as the northern portion in the vicinity of Grande Prairie has been heavily altered by cultivation and settlement. In these areas, the role of the energy sector in shaping landscape composition is secondary to agriculture and settlement, making them less useful for assessing the relative influence of strategies for managing energy sector footprint.

A portion of the Grande Cache grizzly bear range lies to the west of AB2. Although the portion outside of PSAC AB2 accounts for 30% of the range, it contains a much smaller proportion of existing (15%) and potential future footprint due to less overlap with hydrocarbon deposits. Future land use within the portion of the range occurring outside of AB2 was simulated using the same methodology as described previously but customized to respect expected development rates in the region such as: drilling rates in PSAC AB1 (ERCB 2014); annual allowable cuts in overlapping forest management units; and ongoing development of the Grande Cache coal mine. Drilling activity outside of PSAC AB2 accounted for only 10% of the completions simulated to occur in the Grande Cache range over the next 30 years.

A variety of factors will influence the future amount of energy sector footprint, including the rate of development, the extent of protected areas, and whether management practices such as multi-pads and accelerated reclamation of footprint are adopted. These factors were assessed in a sensitivity analysis to demonstrate their relative importance as sources of uncertainty and mitigation opportunities. The management strategies were implemented one at a time, allowing their individual effects to be compared. The approach for simulating each strategy is now described and their impacts on landscape composition and grizzly bear exposure are then compared.

Reduced Rate of Development and Protection

As described previously, the sensitivity of simulation outcomes to uncertainty surrounding the future pace of development was assessed by increasing and decreasing the development rate by 25% relative to the base case. The high and low scenarios were simulated by modifying development intensity across the region. Alternatively, a reduction in the pace of development could be implemented by protecting a portion of the region from industrial activity. To explore the consequences of protection, the core portion of Grande Cache range was removed from development. Grizzly bear ranges are delineated as core or secondary, with core referring to areas of high habitat value and low mortality risk. The core area covers 52% of the Grande Cache range, but encompasses only 25% of simulated future drilling due to reduced overlap with hydrocarbon deposits compared to the remainder of Grande Cache range. As such, the regional reduction in energy sector development associated with protection of the core range is equivalent to that associated with the low development rate scenario (i.e., 25%).

Multi-well Pads

Horizontal drilling makes it possible to locate multiple production wells on a single well pad, thereby reducing the area that is disturbed. Although multi-well pads are larger than single-well pads, the area per well is less. In addition, less pipeline and access road is required to access a smaller number of multi-well pads. Although the beneficial role of multi-well pads in reducing land disturbance is generally recognized, specifics are lacking regarding the magnitude of the benefit and the extent to which multi-well pads are utilized. A study of the benefits of multi-well pads by Devon Energy, as summarized by Dawson et al. (2012), determined that using 16 to more than 35 wells per pad reduced the amount of roads and pipelines required by 40 to 50 percent and the total footprint of the project by 50 percent. The Canadian Council of the Academies (2014) concluded that multi-well pads can reduce road and total footprint, but also noted that shale gas development requires more well pads, roads, and pipelines relative to conventional development because of the limited reach of wells in low-permeability rock and faster declines in production. Further, it appears that the high well-to-pad ratios (i.e., 16 or greater) have not yet been widely adopted during horizontal drilling. Multi-well pads accounted for only 24% of horizontal well licenses in west-central Alberta in 2011, and the majority of multi-well pads contained only two or fewer wells (Dawson et al. 2011). Similarly, the National Energy Board (2011) reported that drilling for tight oil in the Western Canada Sedimentary Basin is characterized by pads with three or fewer wells. Weak adoption of high well-to-pad ratios has also occurred elsewhere; in Pennsylvania, shale gas well pads developed since 2006 contained an average of just over 2 wells (Ladless and Jacquet 2011).

It is apparent that research is needed to assess reductions in land disturbance that can be achieved through multi-well pads, and it is unclear the extent to which high well-to-pad ratios will be adopted. As such, multi-well pads and their effect on land disturbance is an uncertainty. In the absence of better information, the potential benefit of extensive adoption of high well-to-pad ratios was simulated by reducing the required area of pipeline, access road, and production wells by 50%, as per the findings of the Devon Energy study described previously.

Accelerated Footprint Reclamation

Slow reclamation has resulted in energy sector footprint remaining long after it is needed for hydrocarbon production. Provincially, reclamation of wells is occurring at a substantially slower pace than abandonment (i.e., formal well closure), resulting in an accumulation of unreclaimed wells and an assessment by Alberta Environment and Sustainable Resource Development that oil and gas well reclamation is deteriorating[31]. Adding to the buildup of well pad footprint in Alberta are the tens of thousands of inactive wells that are not formally abandoned but instead remain suspended for years, thereby further delaying reclamation (Robinson 2010). Reclamation of other types of energy sector footprint has also been slow. For example, in their study of seismic lines in northeastern Alberta, Lee and Boutin (2008) found that only 8% had reclaimed to woody vegetation after 35 years with the remainder staying in a cleared state or converting to truck trails or other footprint types. The base case simulation assumed that effort to reclaim energy sector footprint is minimal. In contrast, an accelerated reclamation scenario was simulated to assess the consequences of a concerted but realistic effort to accelerate the reclamation of energy sector footprint (Table 3).

Table 3. Lifespans assumed for energy sector footprint under the basecase and accelerated reclamation scenarios

Footprint	**Lifespan**	
	Basecase	**Accelerated reclamation**
Well site	Permanent	20 years post-production
Pipeline	Permanent	60 years
Conventional seismic line	60 years	40 years
Low impact seismic line	20 years	10 years

Industrial Footprint Sensitivity Analysis Results

Increased adoption of multi-well pads and efforts to accelerate footprint reclamation achieved similar reductions in the rate of anthropogenic footprint expansion in the Grande Cache grizzly bear range. The effect of these strategies, while approximate, was also similar to the effect of uncertainty surrounding the development rate. During the base case scenario, the percent of the range covered by anthropogenic footprint almost doubled from 2.9% to 5.6%. Footprint coverage at the end of the simulation was limited to 4.8% under the multi-well pad and accelerated footprint reclamation scenarios, and 5.0% under the low development scenario. Of greater influence was protection of the core portion of the Grande Cache grizzly bear range. Protection resulted in substantially less footprint at the end of the simulation relative to the low development scenario (3.8% compared to 5.0%), despite having the same consequences for the regional development rate. A benefit of protection was that footprints were able to reclaim faster in the absence of factors that prolong the lifespan of footprints, such as orphaned wells and motorized traffic. Perhaps more important was the effect of protection on footprint

[31] http://esrd.alberta.ca/focus/state-of-the-environment/land/response-indicators/oil-and-gas-wells-reclamation.aspx

distribution. With the protection of the core zone, about 50% of the Grande Cache range had low levels of footprint (i.e., less than 1% coverage) at the end of the simulation.

The grizzly bear exposure index increased during the simulation, with the size of the increase being positively affected by the pace of development. Risk to the grizzly bear population was reduced in response to the capacity of the management strategies to limit the expansion of industrial footprint. Grizzly bear exposure actually declined relative to current conditions when the core portion of the range was protected due to the scenario's ability to create a large, contiguous zone of relative intactness. Accelerated footprint reduction and increased adoption of multi-well pads also reduced grizzly bear exposure, but to a lesser extent than protection. Accelerated reclamation was more influential than multi-well pads because it had a larger impact on the overall length of linear footprint due to the scenarios capacity to reduce the area of seismic lines.

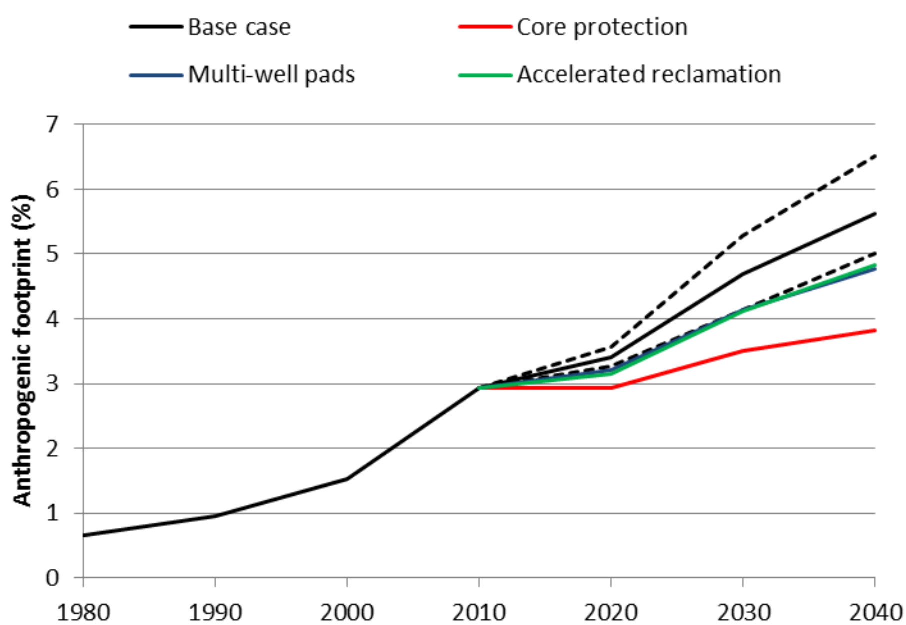

Figure 17. Estimated past and simulated future anthropogenic footprint within the Grande Cache grizzly bear range under a range of management scenarios: current practices (Base case, with low and high development scenarios shown as dashed lines); increased adoption of multi-well pads (Mutli-well pads); increased effort to reclaim footprint (Accelerated reclamation); and protection of the core zone within the Grande Cache grizzly bear range (Core protection).

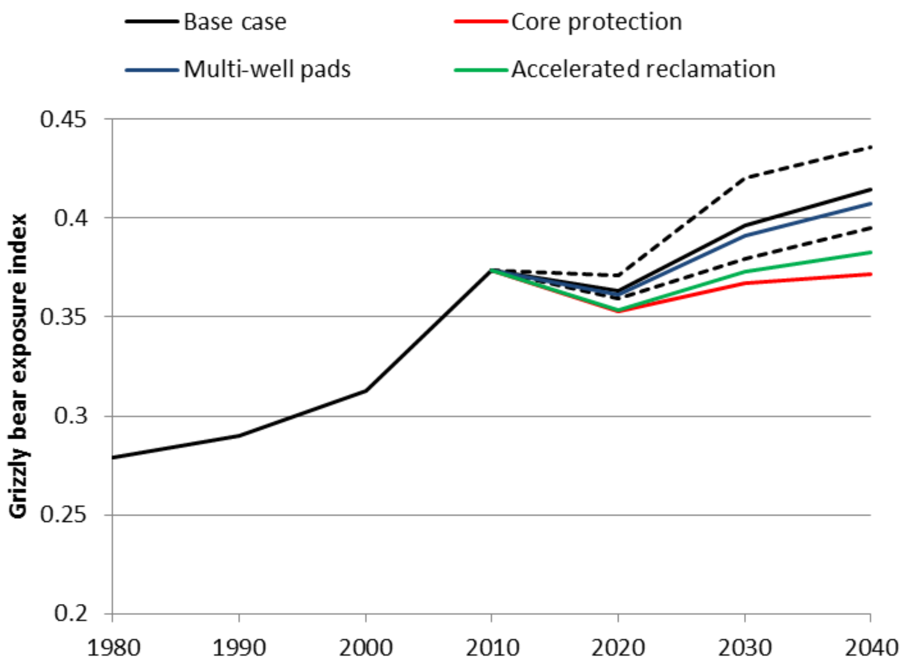

Figure 18. Response of the grizzly bear exposure index to estimated past and simulated future landscape composition of the Grande Cache grizzly bear range under a range of management scenarios: current practices (Base case, with low and high development scenarios shown as dashed lines); increased adoption of multi-well pads (Mutli-well pads); increased effort to reclaim footprint (Accelerated reclamation); and protection of the core zone within the Grande Cache grizzly bear range (Core protection).

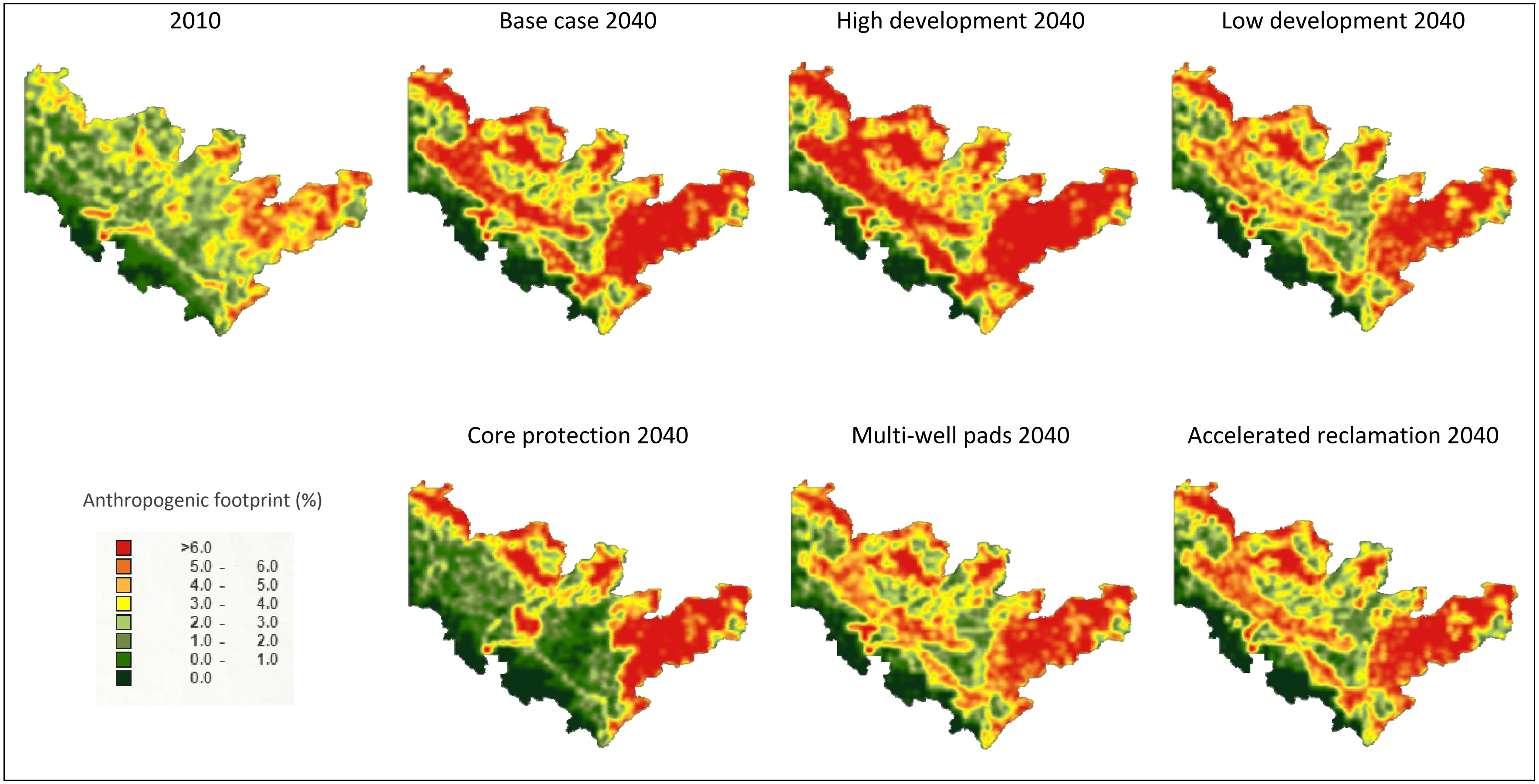

Figure 19. Current and simulated future anthropogenic footprint in year 2040 in the Grande Cache grizzly bear range under six land-use scenarios.

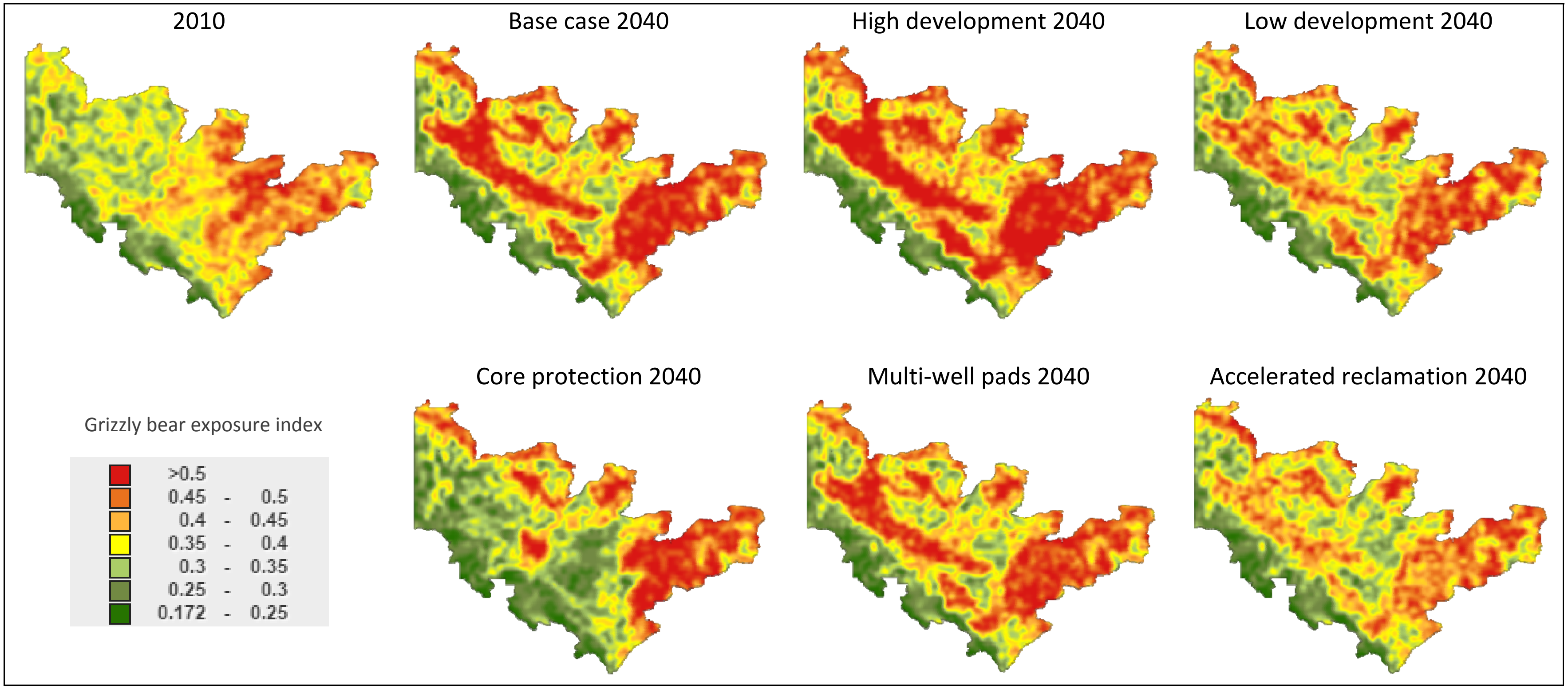

Figure 20. Current and simulated future grizzly bear exposure index in year 2040 in the Grande Cache grizzly bear range under six land-use scenarios.

Discussion

The adoption of horizontal hydraulic fracturing in Alberta is driving increased development of both conventional and unconventional hydrocarbon deposits. As illustrated by recent trends in AB2, the shift to hydraulic fracturing is delivering substantial economic benefits but at a cost to water and wildlife resources. Simulation of future horizontal fracturing suggests that the trade-off between economic benefits and environmental costs will increase in the coming decades as horizontal drilling continues to expand. The simulation described in this report should not be viewed as a prediction, but rather as an opportunity to explore strategic implications of fracturing. Key issues illustrated by the simulation include: a) previously expected production declines in the face of a maturing resource may be offset by production from new horizontal wells; b) water use by fracturing is likely to be substantial but below that of other major water consumers including municipalities and agriculture; and c) development of previously uneconomic reserves may cause industrial footprint to expand into previously intact regions, with negative implications for sensitive wildlife.

Substantial uncertainty surrounds the future impacts of hydraulic fracturing, as demonstrated by the sensitivity of simulated outcomes to management scenarios. Contributing to the uncertainty is the limited tracking of current impacts. Data on water use by source (fresh surface and groundwater, saline groundwater, reuse, etc.), for example, is surprisingly scarce given that companies are required to report water consumption by source for each fractured well in the province. Another gap in publicly available data is the cumulative industrial footprint per well (i.e., well pads but also pipelines, seismic lines, roads, and other industrial features) and the typical lifespan of these features. In the absence of such data, a precautionary approach was followed for the base case scenario whereby conservative assumptions were applied regarding the area and lifespan of footprints. For example, well pads were assumed to be permanent and the number of wells per pad was limited to four for shale gas and one for conventional oil and gas. Information is insufficient to assess whether these assumptions overlook efforts to control the extent of footprint, such as reclamation initiatives and high well to pad ratios. More research, monitoring, and reporting are needed to determine the extent to which mitigation strategies are being adopted and to assess their effectiveness.

A positive implication of the sensitivity of simulation outcomes to management assumptions is that substantial opportunity exists to mitigate the environmental impacts of hydraulic fracturing. The capacity of simulated strategies to limit environmental impacts typically exceeded the influence of the assumed range in development rate, suggesting that management strategies can play a large role in achieving desired outcomes. Water use appears to be very sensitive to the fracturing method, and approaches with lower water requirements such as energized treatments should be adopted where geological conditions permit. Opportunities also exist to limit terrestrial impacts, if high well to pad ratios are implemented and concerted effort is made to reclaim footprint rapidly following the end of its productive life. Indeed, with these strategies, hydraulic fracturing can likely have less impact relative to previous conventional hydrocarbon developments due to the ability to reduce the dispersion of footprint through horizontal drilling. However, failure to adopt practices to mitigate water demand and landscape disturbance will cause environmental impacts to accumulate unnecessarily, with implications for ecological integrity and perhaps also social license to operate.

Although the simulated drilling rates for conventional oil and gas were based on projections developed by government agencies, such projections were not available for shale gas. The potential environmental implications of shale gas development are substantial due its expected rapid growth, its high water demand for fracturing, and the location of deposits in relatively intact regions such as the Grande Cache grizzly bear range. Given these impacts, as well as shale gas development's potential economic benefits, it would be prudent for government agencies to develop projections for the sector despite the associated uncertainty. It is important to keep in mind, however, that projected drilling rates for conventional and unconventional hydrocarbons are uncertain given the sensitivity of drilling activity to volatile energy prices. The volatility, combined with the sector's dispersed footprint and numerous actors, makes oil and gas plays susceptible to cumulative effects. An appropriate response is to take a regional perspective when managing energy sector impacts, similar to how the forestry sector is managed at the scale of forest management areas. With a regional approach comes improved capacity to manage development in support of regional objectives. In the sensitivity analysis, protecting the core zone of the Grande Cache grizzly bear range had substantial environmental benefit, despite having the same economic effect as implementing the low development rate across the entire range. This is but one example of the opportunity presented by regional planning to reduce the trade-off between economic benefit and environmental risk. A promising development in Alberta is the Alberta Energy Regulator's interest in play-based regulation, whereby collaborative planning occurs across operators within a play area to better manage risks and achieve desired environmental, economic, and social outcomes (ERCB 2012).

The transition from activity and project-based management to regional planning demands approaches that accommodate complexity and uncertainty. The cumulative effects of multiple activities over large temporal and spatial scales must be assessed, and multiple potential futures need to be considered. Land-use simulation tools such as ALCES are useful in this regard due to their ability to integrate diverse information to explore the long-term consequences of land-use options at regional scales. ALCES has been applied in numerous regional planning initiatives due to its ability to track the long-term consequences of multiple overlapping land uses to regional economic and environmental performance. Examples include informing the development of regional land-use plans under Alberta's Land-Use Framework (Carlson and Stelfox 2014), exploring the consequences of future development in Ontario's Far North (Carlson and Chetkiewicz 2013) and the Western Canadian Sedimentary Basin (Brown and Carlson 2013), and a web-based scenario analysis tool that is being used by government, First Nations, and non-government organizations for various planning purposes in Alberta and elsewhere (Carlson et al. 2014). For this case study, ALCES was applied to demonstrate risks associated with increased hydraulic fracturing in Alberta's eastern slopes, identify opportunities to mitigate these risks, and highlight uncertainties that require attention in order to better assess environmental impacts. The analysis could be expanded by incorporating additional environmental and economic indicators, and a wider range of scenarios. More importantly, however, the general approach could be applied in other regions of ongoing or potential hydraulic fracturing activity to provide planners with a strategic perspective when seeking opportunities to balance the economic benefits of energy development with its detrimental environmental impacts. Such an approach, if transparent and inclusive, could help shift debate surrounding hydraulic fracturing from entrenched conflict to informed compromise.

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Appendix A-1 – Economic Coefficients

Coefficients relating GDP and employment to hydrocarbon production were calculated from Statistics Canada data, and other sources when required. GDP coefficients were based on 2007 dollars. The Statistics Canada tables did not provide energy sector GDP and employment data in sufficient detail to be broken down by hydrocarbon type. The relative contribution of conventional oil, oil sands, and gas production to Alberta's GDP is provided by Timilsina et al. (2005) for the years 1990, 1995, 2000, and 2003. The relative contribution of the hydrocarbon types in 2000 and 2003 was combined with GDP data for oil and gas extraction and support activities (Statistics Canada table 379-0025) and hydrocarbon production data from the same years to estimate GDP contribution per unit of hydrocarbon production. Hydrocarbon-specific employment information could not be identified. Instead, the relative contribution of hydrocarbon types to GDP in 1990, 1995, 2000, and 2003 was combined with employment and hydrocarbon production data from the same years to estimate employment contribution per unit of hydrocarbon production. Energy employment as calculated from: employment data (Statistics Canada table 282-0008) for "mining, quarrying, and oil and gas extraction"; and the portion of mining, quarrying, and oil and gas extraction employment associated with oil and gas extraction (Statistics Canada table 281-0024).

Table 4. GDP and employment coefficients for energy production.

Land use	GDP coefficient	Employment coefficient
Oil	192.25 $\$/m^3$	0.00040 $jobs/m^3$
Gas	0.1299 $\$/m^3$	2.82e-07 $jobs/m^3$

Appendix A-2 – Grizzly Bear Exposure Index

The grizzly bear exposure index was based on an empirical modeling process undertaken to develop grizzly bear habitat relationships for use in ALCES (Nielsen and Boyce 2003). The index integrates selection and mortality probabilities to identify areas that are selected by grizzly bears but that also present high mortality risk. As such, the index identifies mortality traps, with higher index values indicating higher levels of risk. Nielsen and Boyce (2003) developed resource selection functions for both selection and mortality from southwestern Alberta radiotelemetry use and mortality data. The resource selection functions were applied in ALCES Online to calculate relative selection and mortality probabilities by applying the equation:

$$y = e^{(b_1x_1+b_2x_2+b_3)} \Big/ \left(1 + e^{(b_1x_1+b_2x_2+b_3)}\right)$$

where b_1 is the coefficient for road density coefficient, x_1 is the cell's road density (km/km^2), b_2 is the coefficient of other linear density, x_2 is the cell's density of other linear footprints, and b_3 is the area-weighted coefficient across landscape types. A cell's exposure was calculated by multiplying the selection and mortality probabilities together. Calculation of the exposure index was limited to the montane and foothills natural regions.

Table 5. Coefficients for grizzly bear selection and mortality, based on Nielsen and Boyce (2003).

Landscape Type	Selection	Mortality
Deciduous forest	-0.017	-0.293
Coniferous forest	0.194	-0.261
Shrubland	0.502	0.985
Grassland	0.357	1.045
Rock/Snow/Exposed	-1.249	-0.123
Water/wetland	-0.777	1.229
Farmland and rural residential	-1.51	2.281
Roads	0.347	0.755
Other footprints	-0.99	2.081
Road density	-0.009	0.681
Other linear density	0.045	0.314

APPENDIX B ANNOTATED BIBLIOGRAPHY

Abdalla, et al. (2014). "Municipal officials' decisions to lease watershed lands for Marcellus shale gas exploration." Journal of Environmental Studies and Sciences **4**(1): 28-36

This paper provides insight into municipalities' decisions to lease watershed lands for Marcellus shale gas exploration in Pennsylvania. The focus was on officials' motivations to lease subsurface mineral rights; knowledge on expected benefits and risks of leasing, including public drinking water supply contamination; and decision-making processes for balancing benefits and risks. The data were collected through personal interviews. Municipalities' decisions to lease watershed lands were found to be influenced by the following: when they were approached about leasing, what was learned from their or other municipalities' past experiences, communications with other parties, their resources and networking, water monitoring actions and plans, and ability to balance the goals of providing safe affordable water with the desire for leasing revenues. Study recommendations included as follows: municipal officials should provide timely information to citizens in advance of decisions; resources should be increased for public education and participation; increased efforts should be directed toward networking among municipalities, staff training, and water protection plan development; government agencies and other organizations should increase funding of water quality baseline studies; and municipalities should include the full cost of water monitoring in leases and consider other actions to ensure that their original mission to provide safe affordable water to customers is met.

Accenture, (2012). "Water and Shale Gas Development: Leveraging the US experience in new shale developments"

Shale gas development has transformed the US energy landscape and global development of shale gas resources has the potential to expand significantly outside the United States. However, there continue to be environmental concerns, particularly with respect to water use. There are many lessons that can be taken from the United States' experience. Accenture's study "Water and Shale Gas Development: Leveraging the US experience in new shale developments" focuses on three key aspects of water and shale gas development. These are water regulation, water management and water movements. The report highlights areas that operators of new shale developments should consider. It also includes an analysis of considerations for Argentina, China, Poland and South Africa. The report concludes with lessons learned for new shale developments and implications for operators.

Adams (2011). "Land Application of Hydrofracturing Fluids Damages a Deciduous Forest Stand in West Virginia" Journal of Environmental Quality. **40**(4):1340-1344

In June 2008, 303,000 L of hydrofracturing fluid from a natural gas well were applied to a 0.20-ha area of mixed hardwood forest on the Fernow Experimental Forest, West Virginia. During application, severe damage and mortality of ground vegetation was observed, followed about 10 d later by premature leaf drop by the overstory trees. Two years after fluid application, 56% of the trees within the fluid application area were dead. *Fagus grandifolia* Ehrh. was the tree species with the highest mortality, and *Acer rubrum* L. was the least affected, although all tree species present on the site showed damage symptoms and mortality. Surface soils (0–10 cm) were sampled in July and October 2008, June and October 2009, and May 2010 on the fluid application area and an adjacent reference area to evaluate the effects of the hydrofracturing fluid on soil chemistry and to attempt to identify the main chemical constituents of the hydrofracturing fluid. Surface soil concentrations of sodium and chloride increased 50-fold as a result of the land application of hydrofracturing fluids and declined over time. Soil acidity in the fluid application area declined with time, perhaps from altered organic matter cycling. This case study identifies the need for further research to help understand the nature and the environmental impacts of hydrofracturing fluids to devise optimal, safe disposal strategies.

AEA (2013). “Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe.” Report for European Commission, AEA/R/ED57281, Issue Number 11, Revision 17c

This report sets out the key environmental and health risk issues associated with the potential development and growth of high volume hydraulic fracturing in Europe. The study focused on the net incremental impacts and risks that could result from the possible growth in use of these techniques. This addresses the impacts and risks over and above those already addressed in regulation of conventional gas exploration and extraction. The study distinguishes shale gas associated practices and activities from conventional ones that already take place in Europe, and identifies the potential environmental issues which have not previously been encountered, or which could be expected to present more significant challenges.

The study reviewed available information on a range of potential risks and impacts of high volume hydraulic fracturing. The study concentrated on the direct impacts of hydraulic fracturing and associated activities such as transportation and wastewater management. The study did not address secondary or indirect impacts such as those associated with materials extraction (stone, gravel etc.) and energy use related to road, infrastructure and well pad construction.

The study has drawn mainly on experience from North America, where hydraulic fracturing has been increasingly widely practised since early in the 2000s. The views of regulators, geological surveys and academics in Europe and North America were sought. Where possible, the results have been set in the European regulatory and technical context.

The study includes a review of the efficiency and effectiveness of current EU legislation relating to shale gas exploration and production and the degree to which the current EU framework adequately covers the impacts and risks identified. It also includes a review of risk management measures.

AGI (2004). “Coalbed Methane Hydraulic Fracturing Poses Little Threat to Groundwater.” Environmental Geology. **47**(155)

In late June 2004, the Environmental Protection Agency (EPA) released a report stating that there is little threat of pollution to underground drinking water sources from the injection of hydraulic fracturing fluids in coalbed methane (CBM) wells. The report was issued partly in response to a court decision that declared the EPA was responsible for CBM issues under the Safe Drinking Water Act. CBM producers inject a mixture of water and other fluids at high pressure into a well to crack the rocks, which increases the flow of oil and gas and makes it possible to extract hydrocarbons that were previously inaccessible. Often diesel fuel is used as a fracturing fluid, which introduces benzene, toluene, ethylbenzene, and xylenes into the ground and potentially into underground drinking water supplies. The largest CBM producers have agreed to voluntarily stop using diesel as a fracturing fluid, but say that most of the fluids they inject either biodegrade or remain stationary.

AGS (2014). “Energy Briefing Note, The Ultimate Potential for Unconventional Petroleum from the Montney Formation of British Columbia and Alberta”

The Montney Formation’s marketable, unconventional petroleum potential has been evaluated for the first time in a joint assessment by the National Energy Board, the British Columbia Oil and Gas Commission, the Alberta Energy Regulator, and the British Columbia Ministry of Natural Gas Development. The thick and geographically extensive siltstones of the Montney Formation are expected to contain 12,719 billion m3 (449 Tcf) of marketable natural gas, 2,308 million m3 (14,521 million barrels) of marketable NGLs, and 179 million m3 (1,125 million barrels) of marketable oil.

Al et al. (2012). “Opinion: Potential Impact of Shale Gas Exploitation on Water Resources”

The motivation for writing this article was to offer science-based opinions on the water-related concerns that have been prominent in the New Brunswick shale-gas debate. It should be clear from the previous discussion that, if the choice of technology is hydraulic fracturing with water, then we share some of the concerns regarding water consumption and waste water treatment and disposal. With the goal of providing a positive contribution, if a shale gas industry is to develop in New Brunswick then several suggestions are offered. One thing that is surprising is the lack of debate on hydraulic fracturing with water versus CO2 or LPG. Our focus in this article is on water so we do not address the pros and cons of CO2 and LPG fracturing. However, the one very obvious benefit of CO2 or LPG fracturing is that it does not require water. Most of the concerns about water consumption and contamination are consequently diminished. In the interest of getting it right, we believe the CO2 and LPG fracturing technologies deserve serious consideration.

Alberta ERCB, (2012) “Regulating Unconventional Oil and Gas in Alberta: A Discussion Paper”

Alberta’s existing oil and gas regulations have served the province well. Not only do they help protect Albertans and safeguard the environment, they also make certain that our valuable energy resources are developed without waste. While the current regulatory framework for oil and gas development provides a solid foundation, the ERCB understands that it can build upon this base to address the unique issues, risks, opportunities, and challenges posed by unconventional resource development. As with all energy regulation, this new framework aims to; clearly identify and mitigate potential risks to public safety, the environment, and the resource; ensure orderly development; and avoid imposing unnecessary regulatory burden on industry. The new framework recognizes the distinct challenges associated with developing unconventional resources. For example, unconventional developments typically extend over broad areas and require a greater concentration of infrastructure to make production economically viable. Other challenges relate to protecting water, issues around high-pressure hydraulic fracturing, and the regional effects such activities can have on the landscape. To meet these challenges, the ERCB’s new framework is based on two basic principles: 1. Risk-based regulation—regulatory responses that are proportional to the level of risk posed by energy development. 2. Play-focused regulation—regulatory solutions that are tailored to an entire “play” to achieve specific environmental, economic, and social outcomes.

All Consulting (2010). “NY DEC SGEIS Information Requests”. Project No.: 1284

By letter dated April 12, 2010, the New York State Department of Environmental Conservation (DEC), Division of Mineral Resources, requested additional technical information from the Independent Oil and Gas Association of New York (IOGA) regarding high volume hydraulic fracturing (HVHF) as it is addressed by the draft Supplemental Generic Environmental Impact Statement (dSGEIS). Additional technical questions were received from DEC in communications dated April 20, 2010, and May 27, 2010. ALL Consulting facilitated this collaborative effort between IOGA member companies to address DEC’s information requests. ALL Consulting compiled responses from the participants in the preparation of this report. This report summarizes DEC’s questions and responses by presenting each question as phrased by DEC followed by the applicable composite response representing IOGA’s industry perspective. The table of contents of this report refers to each question in the order presented by DEC. A complete copy of the Marcellus Shale Coalition study —Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas‖ dated December 31, 2009, and which is discussed herein, is provided in Attachment A.

All Consulting (2012). “The Modern Practices of Hydraulic Fracturing: A Focus on Canadian Resources”

Tremendous natural gas resource potential has been identified in shale basins in Western Canada. Producing natural gas from these areas has become economically feasible principally due to technological advancements in horizontal drilling and the use of hydraulic fracturing. While hydraulic fracturing of shale gas wells has been in use since the 1950’s, its wide spread application in the last several years has raised questions about potential environmental and human health risks. To address these questions on the potential risks from hydraulic fracturing a research project was undertaken by the Petroleum Technology Alliance Canada (PTAC) and the BC Science and Community Environmental Knowledge (SCEK) Fund. Involvement and support was provided by the Canadian Association of Petroleum Producers (CAPP) and its member companies and the Canadian Society of Unconventional Resources (CSUR).

Given the public concern about contamination of ground water from hydraulic fracturing, it is important to examine the pathways through which contamination could theoretically occur. The analysis in this report considers only the subsurface pathways that would potentially result from the hydraulic fracturing operation, and not those events that may occur in other phases of oil and gas activities. Five pathways were examined and analysis of each of these pathways demonstrates that it is highly improbable that fracture fluids or reservoir fluids would migrate from the production zone to a fresh water source as a result of hydraulic fracturing.

Numerous instances of environmental contamination across North America have been attributed in the popular media to hydraulic fracturing. In fact, none of these incidents have been documented to be caused by the process of hydraulic fracturing. The term “hydraulic fracturing” is often confused, purposefully or inadvertently, with the entire development lifecycle. Environmental contamination can result from a multitude of activities that are part of the oil and gas exploration and production process, but none have been attributed to the act of hydraulic fracturing. All of these activities are distinct from the process of hydraulic fracturing. This report presents a summary of many of those incidents, along with information that shows why they have not been caused by hydraulic fracturing, or why further study is needed to determine a cause.

All Consulting (2014). “Spatial and Statistical Analysis of Hydraulic Fracturing Activities in US Shale Plays and the Effectiveness of the FracFocus Chemical Disclosure System”

The FracFocus chemical disclosure registry provides public disclosure of hydraulic fracturing chemical additives used in more than 55,000 wells by over 600 companies in the United States. The large number of well sites that have been entered into the registry present a rich population of hydraulic fracturing jobs over a wide geographic area and spanning a period of almost three years. As FracFocus evolved, the authors conducted an internal project to compile the disclosures into a database format more suited to analysis. This has entailed considerable resources to capture the PDFs available, assess the quality of the data in FracFocus, detect and correct data errors and inconsistencies, and convert PDF submittals to a database format. The resulting database can be used to analyze a number of research questions about hydraulic fracturing and related environmental concerns and public disclosure issues.

This paper will demonstrate the effectiveness of the FracFocus database in investigating a variety of questions concerning hydraulic fracturing, including: water use trends across plays, among plays, among companies, and over time; chemical makeup of fracturing jobs, again within and between plays, and among companies; geographic distributions of disclosures (where are submissions being made?); company distributions of disclosures (who is making them?); how the volume of fluids and the number and type of fracture fluid additives vary by company, by region and play, and even within plays. The analysis of the data from FracFocus can help bring a scientific, data-driven approach to addressing many of the concerns expressed by the public, non-profit organizations, and regulatory agencies regarding hydraulic fracturing

Al-Muntasheri (2012). “A Critical Review of Hydraulic Fracturing Fluids over the Last Decade”

Hydraulic fracturing is a well-established process to enhance productivity of oil and gas wells. Fluids are used in fracture initiation and the subsequent proppant and/or sand transport. Several chemistries exist for these fluids. This paper summarizes the published literature over the last decade (90+ technical articles) and captures the advances in the design of water-based fracturing fluids. Despite their old introduction, guar-based polymers are still being used in fracturing operations for wells at temperatures less than 300oF (148.9oC). In order to minimize the damage associated with this class of polymers, the industry attempted several approaches. The paper highlights the first use of breakers that were introduced to improve the cleanup of these drag reducers. For foamed fluids, new viscoelastic surfactants (VES) that are compatible with CO_2 are discussed. The paper also sheds light on the use of emerging technologies such as nanotechnology in the design of new efficient hydraulic fracturing fluids. For example, nanolatex silica was used to reduce the concentration of boron used in conventional crosslinkers. Another advancement in nanotechnology was the use of 20 nm silica particles suspended in guar gels. The paper provides a thorough review on all of these advancements.

Almond et al. (2013). “The flux of radionuclides in flowback fluid from shale gas exploitation”. Centre for Research into Earth Energy Systems (CeREES), Department of Earth Sciences, Durham University, UK

This study considers the flux of radioactivity in flowback fluid from shale gas development in three areas: the Carboniferous, Bowland shale, UK; the Silurian shales, Poland; and the Carboniferous Barnett shale, USA. The radioactive flux from these basins was estimated given estimates of the number of wells developed or to be developed; the flowback volume per well; and the concentration of K (Potassium) and Ra (Radium) in the flowback water. For comparative purposes the range of concentration was itself considered within four scenarios for the concentration range of radioactive measured in; each shale gas basin; the groundwater of the each shale gas basin; global groundwater; and local surface water. The study found that: For the Barnett shale and the Silurian shale, Poland, the 1% exceedance flux in flowback water was between 7 and 8 times that which would be expected from local groundwater. However, for the Bowland shale, UK, the 1% exceedance flux (the flux that would only be expected to be exceeded 1% of the time, i.e. a reasonable worst case scenario) in flowback water was 500 times that expected from local groundwater. In no scenario was the 1% exceedance exposure greater than 1 mSv – the allowable annual exposure allowed for in the UK. The radioactive flux of per energy produced was lower for shale gas than for conventional oil and gas production, nuclear power production and electricity generated through burning coal.

Ambellia Consultancy (2014). “Unconventional Gas Water Management: What Can be Applied From Decades of Experience With Conventional Oil Produced Water Management?”

Shale gas wells can each require 100,000 m^3 of frac water, with up to 25% of that water being returned to the surface during production.Effective asset life cycle water management is key to the technical and economic success of both unconventional gas and conventional oil developments. Unconventional gas resource development in densely populated Europe presents different frac water management challenges to those in sparsely populated areas of the USA. How can decades of worldwide experience of onshore conventional oil produced water management be applied to improve water management for unconventional gas wells in the areas of; Sourcing frac water supplies, Obtaining permits for water abstraction and disposal, Resolving stakeholder environmental concerns, Investigating frac water related formation damage, Understanding returned frac water composition, Treating and recycling frac water, Minimising frac water requirements. Onshore water management for unconventional gas and conventional oil production are compared and contrasted with the objective of optimising frac water life cycle management for unconventional gas resources in Europe. A step by step flow chart frac water life cycle management guide is presented along with how it can be effectively integrated into the overall unconventional gas resource development plan.

Anderson and Theodori (2009). “Local Leaders perceptions of Energy Development” Southern rural sociology. **24**(1): 113–129

In recent decades, the production of natural gas from unconventional reservoirs (i.e., tight gas sands, coalbed methane resources, and gas shales) has become commonplace within the U.S. energy industry. The Newark East Fort Worth Basin field–called in the vernacular, the Barnett Shale–in north-central Texas is one of the largest unconventional natural gas fields (by production volume) in the United States. Unlike many conventional energy development projects, which typically occurred in small rural areas, much of the Barnett Shale production is occurring in and around a highly urbanized geographical setting. In spite of recent efforts to assess the economic effects of Barnett Shale production, little attention has been directed toward understanding the social impacts associated with this immense unconventional energy development. In this article we use key informant interview data collected in two Barnett Shale counties to investigate the reported positive and negative outcomes of unconventional energy development, as well as the similarities and differences in perceptions between respondents from each of the study counties. We then discuss practical applications and future research implications of our findings.

Andrews and McCarthy (2014). “Scale, shale, and the state: political ecologies and legal geographies of shale gas development in Pennsylvania”. Journal of Environmental Studies and Sciences. **4**: 7–16

Recent work on legal geographies has arguably paid far too little attention to the environment as both an object of governance and a terrain of struggle with respect to the law. Conversely, political ecology as a field, with its focus on informal and extra-legal dynamics, has arguably engaged too little with the legal geographies that are central to environmental conflicts in many locations. This paper examines and theorizes the legal geographies that have been essential elements of the recent boom in extraction of natural gas from the Marcellus Shale in Pennsylvania. Specifically, it examines the ways in which laws and the authority of the state more broadly have been changed, deployed, and invoked, particularly through the passage of Act 13, to enable the extraction of the gas in the shale and its circulation as a viable commodity. This analysis of the relevant multiscalar legal geographies illustrates the productivity of a more direct engagement between political ecology on one hand, and legal geography on the other.

API (2009). “Hydraulic Fracturing Operations-Well Construction and Integrity” API Guidance Document HF1. 1st Edition

The purpose of this guidance document is to provide guidance and highlight industry recommended practices for well construction and integrity for wells that will be hydraulically fractured. The guidance provided here will help to ensure that shallow groundwater aquifers and the environment will be protected, while also enabling economically viable development of oil and natural gas resources. This document is intended to apply equally to wells in either vertical, directional, or horizontal configurations. Many aspects of drilling, completing, and operating oil and natural gas wells are not addressed in this document but are the subject of other API documents and industry literature (see Bibliography). Companies should always consider these documents, as applicable, in planning their operations. Maintaining well integrity is a key design principle and design feature of all oil and gas production wells. Maintaining well integrity is essential to isolate the well from the surface and sub-surface environment. Although there is some variability in the details of well construction because of varying geologic, environmental, and operational settings, the basic practices in constructing a reliable well are similar. These practices are the result of operators gaining knowledge based on years of experience and technology development and improvement. These experiences and practices are communicated and shared via academic training, professional and trade associations, extensive literature and documents and, very importantly, industry standards and recommended practices.

API (2010). “Water Management Associated with Hydraulic Fracturing” API Guidance Document HF2. 1st Edition

The purpose of this guidance document is to identify and describe many of the current industry best practices used to minimize environmental impacts associated with the acquisition, use, management, treatment, and disposal of water and other fluids associated with the process of hydraulic fracturing. This document focuses primarily on issues associated with the water used for purposes of hydraulic fracturing and does not address other water management issues and considerations associated with oil and gas exploration, drilling, and production. This document provides guidance and highlights many of the key considerations to minimize environmental and societal impacts associated with the acquisition, use, management, treatment, and disposal of water and other fluids used in the hydraulic fracturing process.

API (2011). "Practices for mitigating surface impacts associated with hydraulic fracturing" API Guidance Document HF3. 1st Edition

This guidance document identifies and describes best practices currently used in the oil and natural gas industry to minimize potential surface environmental impacts associated with hydraulic fracturing operations. While hydraulic fracturing does not introduce new or unique environmental risks to exploration and production (E&P) operations, concerns have been raised due to the potential scale of operations where this technology is applied, especially with regard to emerging developments in shale gas in the United States. Many of the best practices for E&P operations are the same as those applicable to hydraulic fracturing operations. Moreover, where shale gas development intersects with urban settings, regulators and the industry have developed special practices to alleviate potential nuisances and sensitive environmental resources impacts, along with interference with existing commercial activity. Operators need to be vigilant and proactive in mitigating potential environmental impacts from E&P operations, including hydraulic fracturing operations.

API (2014). "Hydraulic Fracturing Unlocking America's Natural Gas Resources"

Hydraulic fracturing and horizontal drilling are safely unlocking vast U.S. reserves of oil and natural gas found in shale and other tight-rock formations. Developing energy from shale is an advanced process that uses the latest drilling technologies and equipment. As for what fracking means to the United States – the answers are security, economic growth and jobs, jobs, jobs. This report concisely describes what fracking is and then discusses issues surrounding the fracking process, safety and the environment.

API (2014). "Community Engagement Guidelines". ANSI/API BULLETIN. 100-3;1st edition

These guidelines outline what local communities and other key stakeholders can expect from operators. Oil and gas operators acknowledge the challenges associated with industry activities, which can include challenges important to a community. Principles of integrity, transparency and consideration for community concerns underpin responsible operations. Conscientious operators are committed to helping communities achieve positive and long-lasting benefits. Both local stakeholders and operators can use this guidance. It is designed to acknowledge challenges and impacts that occur during the industry's presence in a given region. It provides flexible and adaptable strategies, recognizing that application will vary from operator to operator and community to community. Many operators already apply similar guidelines or processes within their operations. These suggested guidelines are typical and reasonable and generally apply under normal operating circumstances. The use of these guidelines is at each individual operator's discretion. Operators recognize that stakeholders within the community can have different interests, issues and levels of concern. Some of these interests can be in direct conflict with one another. Working together with stakeholders to seek mutually agreeable solutions is an important aspect of community engagement. Operators can have different approaches to addressing the concerns and issues. These guidelines are intended primarily to support onshore oil and gas projects in the United States for shale developments; however, they can be adapted to any oil and gas projects in the United States.

Associated Press (2012). “Marcellus Shale gas drillers recycling more waste”. Wall Street Journal.

Pennsylvania's Marcellus Shale gas drilling companies are recycling more and more of their briny, chemical-laden wastewater, in most cases complying with a request from state officials to keep the pollutants from being discharged into rivers that supply drinking water. But experts are wondering if a loophole in disposal regulations is still allowing significant quantities of one of the worrisome compounds— salty bromides— into rivers and streams, or if shale gas drillers were only part of the problem.

An analysis by The Associated Press of 2011 state data released Friday found that of the 10.1 million barrels of shale wastewater generated in the last half of 2011, about 97 percent was either recycled, sent to deep-injection wells, or sent to a treatment plant that doesn't discharge into waterways. Shale drillers sent about 2.8 million barrels of waste —or 118 million gallons— to numerous treatment plants that discharge into rivers and streams. Those discharges raised alarms when the plants reported soaring levels of bromides in rivers that year. Though not considered a pollutant by themselves, the bromides combine with the chlorine used in water treatment to produce trihalomethanes, which can cause cancer if ingested over a long period of time.

Atherton (2014). “Discussion Paper: Hydraulic Fracturing and Public Health in Nova Scotia. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process”

The prospect of development of unconventional gas and oil resources in Nova Scotia has implications for the health of individuals and communities. Economic productivity, improved energy security, and a shift away from coal-based energy generation could improve population health. Exposures to industrial materials and processes constitute risks to health which would need to be carefully assessed, monitored, managed, and mitigated if the practice of hydraulic fracturing was ever to be pursued in Nova Scotia. This discussion paper summarises the current state of knowledge about potential benefits and harms to human health and provides a set of candidate recommendations which should be considered if Nova Scotia should ever decide to develop its energy resources in this way.

Australian council of learned academies (2013). “Engineering Energy: Unconventional Gas Production”

Many Australian sedimentary basins are prospective for unconventional gas and the undiscovered resource base is very large. The technology (such as horizontal wells, multi-well pads and hydraulic fracturing) is available to produce shale gas (and shale oil and tight gas) in Australia, but production costs are likely to be significantly higher than those in North America and the lack of infrastructure will further add to costs. Shale gas will not be cheap gas in Australia, but it is likely to be plentiful and it has the potential to be an economically very important additional energy source. Increased use of shale gas (and other gas) for electricity generation could significantly decrease Australia’s greenhouse gas emissions based on gas replacing coal. Because of the manner in which shale gas is produced it has the potential to impact on the landscape, on ecosystems, on surface and groundwater, on the atmosphere, on communities, and rarely may result in minor induced seismicity. It will be vital for industry and government to recognise the complexity of the challenges posed by these possible impacts. However, most can be minimised where an effective regulatory system and best monitoring practice are in place and can be remediated where they do occur. If the shale gas industry is to earn and retain the social licence to operate, it is a matter of some urgency to have such a transparent, adaptive and effective regulatory system in place and implemented, backed by best practice monitoring in addition to credible and high quality baseline surveys. Research into Australia's deep sedimentary basins and related landscapes, water resources and ecosystems, and how they can be monitored, will be essential to ensure that any shale gas production is effectively managed and the impacts minimised.

AWWA (2013). "Water and Hydraulic Fracturing, A White Paper from the American Water Works Association"

In recent years, there has been substantial public scrutiny of the process of hydraulic fracturing, commonly known as "fracking." Citizens' groups, environmental advocates, municipal leaders, and others have expressed concern that the process and activities associated with fracking could result in the contamination of water resources. Media has elevated these concerns in many national and local stories, but the facts and risks surrounding hydraulic fracturing are not widely understood. AWWA has produced this white paper in response to growing public awareness and concern about hydraulic fracturing and related activities. The paper provides water utilities with background, facts, and resources to help them understand and communicate fracking processes, risks, and regulations. Additionally, the paper considers both hydraulic fracturing itself and other components in the life cycle of oil and natural gas development that may present concerns to drinking water utilities. Although this document primarily discusses drinking water utility risks and concerns and ways to mitigate them it is important to remember that any policy decisions regarding energy development must take both risks and benefits into account. Although summarized briefly, the benefits of energy development, which can be substantial, are not discussed in detail in this paper.

Baccante (2012). "Hydraulic Fracturing: A Fisheries Biologist's Perspective". Fisheries, **37**(1): 40-41

As fisheries biologists, why do we need to know about this process or even care? Because it uses large and significant amounts of water, and because water is increasingly becoming a more precious resource globally, we need to be aware of the potential impacts of this use on the aquatic ecosystem. It is not the intent of this short article to go into great detail on the science, technology, and operations of hydraulic fracturing, the main objective is to make all of us aware of the demand for water in this process and what some of the implications might be on future research and management of water resources in areas of significant unconventional natural gas production.

Baker and McKenzie (2013). "Shale Gas—Global Environmental Law and Regulation"

This newsletter outlines key environmental regulatory and litigation issues impacting the shale oil and gas and hydraulic fracturing industry around the world. This covers; the U.S., Canada, the EU, France, Italy, the UK, Australia and China.

Baldassare et al (2014). "A geochemical context for stray gas investigations in the northern Appalachian Basin: Implications of analyses of natural gases from Neogene-through Devonian-age strata". AAPG Bulletin. **98**(2): 341-372

As the pace of drilling activity in the Marcellus Formation in the northern Appalachian Basin has increased, so has the number of alleged incidents of stray natural gas migration to shallow aquifer systems. For this study, more than 2300 gas and water samples were analyzed for molecular composition and stable isotope compositions of methane and ethane. The samples are from Neogene- to Middle Devonian-age strata in a five-county study area in northeastern Pennsylvania. Samples were collected from the vertical and lateral sections of 234 gas wells during mud gas logging (MGL) programs and 67 private groundwater-supply wells during baseline groundwater-quality testing programs.

Evaluation of this geochemical database reveals that microbial, mixed microbial and thermogenic, and thermogenic gases of different thermal maturities occur in some shallow aquifer systems and throughout the stratigraphy above the Marcellus Formation. The gas occurrences predate Marcellus Formation drilling activity. Isotope data reveal that thermogenic gases are predominant in the regional Neogene and Upper Devonian rocks that comprise the potable aquifer system in the upper 305 m (1000 ft) and typically are distinct from gases in the Middle Devonian Marcellus Formation. Additionally, isotope geochemistry at the site-specific level reveals a complex thermal and migration history with gas mixtures and partial isotope reversals ($\delta^{13}C_1 > \delta^{13}C_2$) in the units overlying the Marcellus Formation.

Identifying a source for stray natural gas requires the synthesis of multiple data types at the site-specific level. Molecular and isotope geochemistry provide evidence of gas origin and secondary processes that may have affected the gases during migration. Such data provide focus for investigations where the potential sources for stray gas include multiple, naturally occurring, and anthropogenic gases

Bamberger and Oswald (2012). “Impacts of gas drilling on human and animal health”. New Solutions, **22**(1): 51-77

Environmental concerns surrounding drilling for gas are intense due to expansion of shale gas drilling operations. Controversy surrounding the impact of drilling on air and water quality has pitted industry and leaseholders against individuals and groups concerned with environmental protection and public health. Because animals often are exposed continually to air, soil, and groundwater and have more frequent reproductive cycles, animals can be used as sentinels to monitor impacts to human health. This study involved interviews with animal owners who live near gas drilling operations. The findings illustrate which aspects of the drilling process may lead to health problems and suggest modifications that would lessen but not eliminate impacts. Complete evidence regarding health impacts of gas drilling cannot be obtained due to incomplete testing and disclosure of chemicals, and nondisclosure agreements. Without rigorous scientific studies, the gas drilling boom sweeping the world will remain an uncontrolled health experiment on an enormous scale.

Barati and Liang (2014). “A Review of Fracturing Fluid Systems Used For Hydraulic Fracturing of Oil and Gas Wells”. Journal of Applied Polymer Science **131**(40735)

Hydraulic fracturing has been used by the oil and gas industry as a way to boost hydrocarbon production since 1947. Recent advances in fracturing technologies, such as multistage fracturing in horizontal wells, are responsible for the latest hydrocarbon production boom in the US. Linear or crosslinked guars are the most commonly used fluids in traditional fracturing operations. The main functions of these fluids are to open/propagate the fractures and transport proppants into the fractures. Proppants are usually applied to form a thin layer between fracture faces to prop the fractures open at the end of the fracturing process.

Chemical breakers are used to break the polymers at the end of the fracturing process so as to provide highly conductive fractures. Concerns over fracture conductivity damage by viscous fluids in ultra-tight formations found in unconventional reservoirs prompted the industry to develop an alternative fracturing fluid called “slickwater”. It consists mainly of water with a very low concentration of linear polymer. The low concentration polymer serves primarily to reduce the friction loss along the flow lines. Proppant-carrying capability of this type of fluids is still a subject of debate among industry experts. Constraints on local water availability and the potential for damage to formations have led the industry to develop other types of fracturing fluids such as viscoelastic surfactants and energized fluids. This article reviews both the traditional viscous fluids used in conventional hydraulic fracturing operations as well as the new family of fluids being developed for both traditional and unconventional reservoirs.

Barbot et al (2013). “Spatial and Temporal Correlation of Water Quality Parameters of Produced Waters from Devonian-Age Shale following Hydraulic Fracturing”. <u>Environmental Science & Technology</u>, **47**: 2562-2569.

The exponential increase in fossil energy production from Devonian-age shale in the Northeastern United States has highlighted the management challenges for produced waters from hydraulically fractured wells. Confounding these challenges is a scant availability of critical water quality parameters for this wastewater. Chemical analyses of 160 flowback and produced water samples collected from hydraulically fractured Marcellus Shale gas wells in Pennsylvania were correlated with spatial and temporal information to reveal underlying trends. Chloride was used as a reference for the comparison as its concentration varies with time of contact with the shale. Most major cations (i.e., Ca, Mg, Sr) were well-correlated with chloride concentration while barium exhibited strong influence of geographic location (i.e., higher levels in the northeast than in southwest). Comparisons against brines from adjacent formations provide insight into the origin of salinity in produced waters from Marcellus Shale. Major cations exhibited variations that cannot be explained by simple dilution of existing formation brine with the fracturing fluid, especially during the early flowback water production when the composition of the fracturing fluid and solid−liquid interactions influence the quality of the produced water. Water quality analysis in this study may help guide water management strategies for development of unconventional gas resources.

Batley and Kookana (2012). “Environmental issues associated with coal seam gas recovery: managing the fracking boom”. <u>Environmental Chemistry</u>, **9**: 425-428

Coal seam gas reserves represent a major contribution to energy needs, however, gas recovery by hydraulic fracturing (fracking or fraccing), requires management to minimise any environmental effects. Although the industry is adapting where possible to more benign fracking chemicals, there is still a lack of information on exposure to natural and added chemicals, and their fate and ecotoxicity in both the discharged produced and flow-back waters. Geogenic contaminants mobilised from the coal seams during fracking may add to the mixture of chemicals with the potential to affect both ground and surface water quality. The research needs to better assess the ecological risks from gas recovery are discussed.

Battelle (2011). “Review of EPA Hydraulic Fracturing Study Plan EPA/600/R11/122”

The American Petroleum Institute (API) and America’s Natural Gas Alliance (ANGA) requested Battelle Memorial Institute (Battelle), an independent non-profit, science and technology research and development organization, to perform a critical review of the EPA Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources (study plan). A multidisciplinary Battelle project team with expertise in oil and gas operations, engineering, geosciences, chemistry, modeling, quality assurance/quality control (QA/QC), statistics, toxicology, impact analysis and other relevant disciplines took part in this review.

BCOGC (2012). “Investigation of Observed Seismicity in the Horn River Basin”

This report provides the results of the BC Oil and Gas Commission’s (Commission) investigation into anomalous seismicity within geographically confined and remote areas in the Horn River Basin between April 2009 and December 2011. The investigation was commenced immediately after the Commission became aware of a number of anomalous, low-level seismic events which were recorded by Natural Resources Canada (NRCan) near areas of oil and gas development. Only one of the events under investigation had been reported by NRCan as “felt” at the earth’s surface. In undertaking the investigation, the Commission notes that more than 8,000 high-volume hydraulic fracturing completions have been performed in northeast British Columbia with no associated anomalous seismicity. None of the NRCan reported events caused any injury, property damage or posed any risk to public safety or the environment.

The investigation concludes that the events observed within remote and isolated areas of the Horn River Basin between 2009 and 2011 were caused by fluid injection during hydraulic fracturing in proximity to pre-existing faults. The Commission also provides seven recommendations based on the investigation.

BCWWA (2012). “Hydraulic Fracturing - Focus on Water”

This paper is a follow up to a knowledge sharing workshop conducted to improve our understanding of the impact of the use of hydraulic fracturing on water resources. This paper provides an overview of hydraulic fracturing in British Columbia with a focus on water demand, water quality, water usage and regulatory issues as well as community and agricultural perspectives, as it relates to water supply, water demand and water quality A further aim of the workshop was and to work with regulators, the industry and other water users to ensure effective management of water resources. Where applicable, information gaps or areas for further information gathering have been identified or flagged and recommendations to inform BCWWA of are made for the next steps in our pursuit of sustainable water management in areas of British Columbia where hydraulic fracturing is taking place.

Beaver (2014). “Environmental Concerns in the Marcellus Shale” <u>Business and Society Review</u>. **119**(1):125–146

Hydraulic fracturing used to remove natural gas from the Marcellus Shale has raised environmental concerns in the region both in terms of air and water pollution. This article will examine those concerns and how the natural gas industry has responded to them. After discussing the issues related to groundwater contamination and air quality. I discuss industry responses and how the costs and harm associated with fracking could be reduced, with the knowledge that despite opposition from environmental groups, fracking will continue. The hope is that more drillers will begin to operate in a socially responsible manner that will allow companies to be profitable while limiting harm to the environment and to individuals

living near drilling sites.

Begos (2014). “Some states confirm water pollution from drilling” The Associated Press

The Associated Press requested data on drilling-related complaints in Pennsylvania, Ohio, West Virginia and Texas and found major differences in how the states report such problems. Texas provided the most detail, while the other states provided only general outlines. And while the confirmed problems represent only a tiny portion of the thousands of oil and gas wells drilled each year in the U.S., the lack of detail in some state reports could help fuel public confusion and mistrust.

Bengston et al (2012). “Strengthening Environmental Foresight: Potential Contributions of Futures Research”. Ecology and Society. **17**(2): 10

The need for environmental foresight has increased in recent decades as the pace of change has accelerated and the frequency of surprise has increased. Successfully dealing with the growing impacts of change on social-ecological systems depends on our ability to anticipate change. But traditional scientific tools are blunt instruments for studying a future that does not exist. We propose that futures research, a transdisciplinary field of inquiry that has been developing for more than 50 years, offers an underused but fruitful set of approaches to address this important challenge. A few futures research methods—notably several forms of scenario analysis—have been applied to environmental issues and problems in recent years. But futurists have developed an array of other useful methods for exploring possible, plausible, and preferable futures, important insights into the nature of change, and perspectives for thinking creatively and deeply about the future. We present an overview of futures research and its potential to enrich environmental planning and policy by offering a cross-fertilization of new ideas and approaches, providing a more complete view of emerging environmental problems, and facilitating the development of strategies to increase adaptive capacity and deal more effectively with surprises.

Bennett (2013). “The impact of hydraulic fracturing on housing values in Weld County, Colorado: A Hedonic Analysis”. Thesis, Colorado State University

Oil and gas production using hydraulic fracturing has rapidly spread across the US and moved into suburban and urban neighborhoods. Proximity to residential areas has generated significant concerns by homeowners about water pollution, air pollution, aesthetics, and hence property values. However, the increase in drilling activity has generated sizable gains in local employment and a subsequent increase in demand for housing. In spite of controversies, there is almost no research evaluating whether proximity and level of drilling activity affects house prices on net. We apply the hedonic property method to a sample of 4035 housing transactions between 2009 and 2012 in Weld County, Colorado, the county at the forefront of oil and gas drilling activity in the state. Results across both the semi-log OLS and semi-log spatial GLS model specifications are consistent. While the count of wells being hydraulically fractured within a half mile of a house has a negative effect on houses in Greeley and other towns, rural households are statistically unaffected by the density of hydraulic fracturing in their immediate area. Employment in the oil and gas sector has a positive and significant effect on house prices in the Full County and Greeley model specifications, but not in the rural model specifications. The overall lack of negative effect of hydraulic fracturing on housing prices in Weld County may be a result of the increase in employment associated with drilling operations potentially offsetting some of the disamenity associated

with oil and gas drilling.

Benusic (2013). “Fracking in BC: A public health concern”. BC Medical Journal. **55**(5)

Much of the controversy surrounding fracking lies in the largely unknown health effects, particularly given the potential for drinking water contamination with toxic and carcinogenic chemicals. Concerns and anecdotal evidence of already-present deleterious health outcomes have led to precautionary bans in the Sacred Headwaters region of BC and reviews at both the provincial and federal level. While we await the results of these comprehensive analyses, the Environmental Health Committee has created the following outline of the fracking process and its potential health effects.

Bergmann et al. (2014) “Potential water-related environmental risks of hydraulic fracturing employed in exploration and exploitation of unconventional natural gas reservoirs in Germany”. Environmental Sciences Europe. **26**(10)

On behalf of the German Federal Environment Agency we have investigated the potential water-related environmental risks for human health and the environment that could be caused by employing hydraulic fracturing in unconventional gas reservoirs in Germany. Here we provide an overview of the present situation and the state of the debate in Germany and summarize main results of the conducted risk assessment.

We propose a concept for a risk assessment considering the site-specific analysis of the geosystem, the relevance of possible impact pathways and the hazard potential of the fracking fluids employed. The foundation of a sound risk analysis is a description of the current system, the relevant impact pathways and their interactions. An evaluation of fracking fluids used in Germany shows that several additives were employed even in newer fluids that exhibit critical properties or for which an assessment of their behaviour and effects in the environment is not possible or limited due to lack of current knowledge. The authors propose an assessment method that allows for the estimation of the hazard potential of specific fracking fluids, formation water, and the flowback based on legal thresholds and guidance values as well as on human- and eco-toxicologically predicted no-effect concentrations. The assessment of a previously employed and a prospectively planned fracking fluids shows that these fluids exhibit a high hazard potential. The flowback containing fracking fluid, formation water, and possibly reaction products can also exhibit serious hazard potentials, requiring environmentally acceptable techniques for its treatment and disposal.

The risk analysis must be conducted always site-specifically and consider regional groundwater flow conditions. The study concludes that currently missing knowledge and data prevent a profound assessment of the risks and their technical controllability in Germany. Missing knowledge and information includes data on the properties of the deep geosystem and of the behaviour and effects of the deployed chemical additives. In this setting the authors propose several recommendations for further action and procedures regarding the application of hydraulic fracturing in unconventional gas reservoirs in Germany.

Bibby et al. (2013). “Suggested Reporting Parameters for Investigations of Wastewater from Unconventional Shale Gas Extraction”. Environmental Science and Technology. **47**:13220−13221

The unique characteristics of flowback and produced water have created challenges in utilizing conventional treatment and management approaches. Although similar wastes have long been produced in the oil and gas industry, high volume fracturing approaches have increased the scale of water management challenges and drawn the attention of the environmental research community. In this viewpoint, we argue that specific parameters regarding flowback and produced water samples, namely the location and depth of a well, fracturing approach, well age, and water quality, should be reported in research communications. Inclusion of these details will facilitate cross-study validation and comparison, future meta-analyses, and extrapolation of existing results to emerging resource plays. The authors suggestions are summarised and discussed in the paper.

Biello (2010). “What the Frack? Natural gas from subterranean shale promises U.S. energy independence -- with environmental costs”. Scientific American

Five facilities perched on the north Texas town's outskirts compress the gas newly flowing to the surface from the cracked Barnett Shale more than two kilometers beneath the surface, collectively contributing a brew of toxic chemicals to the air. A set of seven samples collected throughout the town analyzed for a variety of air pollutants last August found that benzene was present at levels as much as 55 times higher than allowed by the Texas Commission on Environmental Quality (TCEQ). Similarly, xylene and carbon disulfide (neurotoxicants), along with naphthalene (a blood poison) and pyridines (potential carcinogens) all exceeded legal limits, as much as 384 times levels deemed safe. There's never been a documented case of contaminated water supply, however Houston-based Cabot Oil and Gas has spilled fracturing fluid, diesel and other fluids, according to Pennsylvania's Department of Environmental Protection. And elsewhere in the state fracturing fluid contamination has been detected in the Monongahela River, which is a source of drinking water. In more common practice, companies dump used fracking fluid back beneath the surface, usually injecting it into other formations beneath the shale. For example, in the case of the Barnett Shale, disposal wells send that water into the deeper Ellenburger Formation. A New York City analysis of fracking has found that whereas a single fractured natural gas well may do no harm, the hundreds required to exploit shale gas "brings an increased level of risk to the water supply".

Bishop (2011). “Chemical and Biological Risk Assessment for Natural Gas Extraction in New York”. Chemistry & Biochemistry Department State University of New York, College at Oneonta Sustainable Otsego

Over the last decade, operators in the natural gas industry have developed highly sophisticated methods and materials for the exploration and production of methane from unconventional reservoirs. In spite of the technological advances made to date, these activities pose significant chemical and biological hazards to human health and ecosystem stability. Overall, proceeding with any new projects to extract methane from unconventional reservoirs by current practices in New York State is highly likely to degrade air, surface water and ground-water quality, to harm humans, and to negatively impact aquatic and forest ecosystems. Mitigation measures can partially reduce, but not eliminate, the anticipated harm.

Boersma and Johnson (2012). “Risks and Potentials of the Shale Gas Revolution, Consequences for

Markets and the Environment". SWP Comments, **39**

The shale gas revolution, which until now has been mainly a North American phenomenon, is poised to go global. Geologists have long known about large quantities of methane trapped in shale rock, but it took favorable price signals and technological innovations to make it feasible to get shale gas out of the ground. Are European business elites and policy makers ready for these developments? What can be learned from the North American experience? If regulators allow it – and most importantly if industry finds it lucrative enough to pursue it in places such as Poland and Ukraine – the use of hydraulic fracturing as a technique for extracting natural gas from gas shale will carry with it consequences for the environment, the marketplace, and energy security, but the magnitude of those consequences is uncertain.

Boudet et al. (2014) ""Fracking" controversy and communication: Using national survey data to understand public perceptions of hydraulic fracturing".Energy Policy. **65**: 57–67

The recent push to develop unconventional sources of oil and gas both in the U.S. and abroad via hydraulic fracturing ("fracking") has generated a great deal of controversy. Effectively engaging stakeholders and setting appropriate policies requires insights into current public perceptions of this issue. Using a nationally representative U.S. sample (N=1061), we examine public perceptions of hydraulic fracturing including: "top of mind" associations; familiarity with the issue; levels of support/opposition; and predictors of such judgments. Similar to findings on other emerging technologies, our results suggest limited familiarity with the process and its potential impacts and considerable uncertainty about whether to support it. Multiple regression analysis (r2=.49) finds that women, those holding egalitarian world views, those who read newspapers more than once a week, those more familiar with hydraulic fracturing, and those who associate the process with environmental impacts are more likely to oppose fracking. Incontrast, people more likely to support fracking tend to be older, hold a bachelor's degree or higher, politically conservative, watch TV news more than once a week, and associate the process with positive economic or energy supply outcomes. Based on these findings, we discuss recommendations for future research, risk communication, and energy policy.

Boyer et al. (2012). "The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies". Pennsylvania State University

This research looked to provide an unbiased and large-scale study of water quality in private water wells in rural Pennsylvania before and after the drilling of nearby Marcellus Shale gas wells. It also looked to document both the enforcement of existing regulations and the use of voluntary measures by homeowners to protect water supplies. For the study, the researchers evaluated water sampled from 233 water wells in proximity to Marcellus gas wells in rural regions of Pennsylvania in 2010 and 2011. Among these were treatment sites (water wells sampled before and after gas well drilling nearby) and control sites (water wells sampled though no well drilling occurred nearby). According to the study results, approximately 40 percent of the water wells failed at least one Safe Drinking Water Act water quality standard, most frequently for coliform bacteria, turbidity and manganese, before gas well drilling occurred. This existing pollution rate and the general characteristics of the water wells, such as depth and construction, in this study were similar to past studies of private water wells in Pennsylvania. The study's pre-drilling results for dissolved methane also provided new information that documented its occurrence in about 20 percent of water wells, although levels were generally far below any advisory levels.In this study, statistical analyses of post-drilling versus pre-drilling water chemistry did not suggest major influences from gas well drilling or hydrofracturing (fracking) on nearby water wells, when considering changes in potential pollutants that are most prominent in drilling waste fluids. Only one drinking water well appeared to be affected by drilling as evidenced by subtle increases in many of its constituents after drilling and fracking, including bromide, chloride, sodium, barium, total dissolved solids, hardness, and more. The presence of these constituents suggests possible mixing of the well water with waste fluids, flowback waters, or naturally occurring brine.

Branosky (2012). "Defining the shale gas life cycle: A framework for identifying and mitigating environmental impacts". WRI Working Paper, World Resources Institute.policy

Life cycle assessments of shale gas activities differ in their findings. Among the various studies, researchers estimate different greenhouse gas emissions, rates of water use, and rates of wastewater production. Some of the variation in findings is due to the parameters of each study, particularly the life cycle boundary. The life cycle boundary determines which life cycle stages—and which processes attributable to those stages—are included in the assessment. For example, a life cycle boundary for shale gas often includes stages for exploration, drilling, fracturing, well production, processing, and combustion. Attributable processes further define the activities in those stages. However, some assessments omit stages—such as exploration, processing, or combustion—or do not delineate between stages and processes at all. The variations make it difficult to compare assessments and begin a constructive dialogue on strategies that reduce impacts. This working paper proposes a life cycle boundary for shale gas spanning exploration to well closure/site remediation and from natural gas production to use. It follows the boundary setting guidance given in the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard, which builds and expands on the ISO 14044 standard for life cycle assessment. In addition, WRI compares its life cycle boundary to those in 16 assessments of the environmental impacts of shale gas production. The findings illustrate significant variations in the scope of such studies, which complicate shale gas discussions.

Brasier et al. (2011). "Residents' perceptions of community and environmental impacts from development of natural gas in the Marcellus shale: a comparison of Pennsylvania and New York cases" Journal of Rural Social Sciences, **26**(1): 32–61

Communities experiencing rapid growth due to energy development ('boomtowns') have reported positive and negative impacts on community and individual well-being. The perceptions of impacts vary according to stage of energy development as well as experience with extractive industries. Development of the Marcellus Shale provides an opportunity to examine these impacts over time and across geographic and historical contexts. This paper describes case study research in Pennsylvania and New York to document preliminary impacts of development occurring there. Cases vary by level of development and previous extractive history. The study finds that, in areas with low population density, higher levels of development lead to a broader awareness of natural gas impacts, both positive and negative. Participants draw from the regional history of extraction to express environmental concern despite direct, local experience. Our findings suggest the need to track these perceptions during development, and as individuals and communities react and adapt to the impacts.

Branosky et al (2012). "Defining the shale gas life cycle: a framework for identifying and mitigating environmental impacts" World Resources Institute

Life cycle assessments of shale gas activities differ in their findings. Among the various studies, researchers estimate different greenhouse gas emissions, rates of water use, and rates of wastewater production. Some of the variation in findings is due to the parameters of each study, particularly the life cycle boundary. The life cycle boundary determines which life cycle stages and which processes attributable to those stages are included in the assessment. For example, a life cycle boundary for shale gas often includes stages for exploration, drilling, fracturing, well production, processing, and combustion. Attributable processes further define the activities in those stages. However, some assessments omit stages—such as exploration, processing, or combustion—or do not delineate between stages and processes at all. The variations make it difficult to compare assessments and begin a constructive dialogue on strategies that reduce impacts. This working paper proposes a life cycle boundary for shale gas spanning exploration to well closure/site remediation and from natural gas production to use. It follows the boundary setting guidance given in the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard, which builds and expands on the ISO 14044 standard for life cycle assessment. In addition, WRI compares its life cycle boundary to those in 16 assessments of the environmental impacts of shale gas production. The findings illustrate significant variations in the scope of such studies, which complicate shale gas discussions.

Brantley et al. (2014). "Water resource impacts during unconventional shale gas development: The Pennsylvania experience". International Journal of Coal Geology.. **126**:140–156

Improvements in horizontal drilling and hydrofracturing have revolutionized the energy landscape by allowing the development of so-called "unconventional" gas resources. The Marcellus play in the northeastern U.S.A. documents how fast this technology developed: the number of unconventional Marcellus wells in Pennsylvania (PA) increased from 8 in 2005 to ~7234 today. Publicly available databases in PA show only rare evidence of contamination of surface and groundwaters. This could document that incidents that impact PA waters have been relatively rare and that contaminants were quickly diluted. However, firm conclusions are hampered by i) the lack of information about location and timing of incidents; ii) the tendency to not release water quality data related to specific incidents due to liability or confidentiality agreements; iii) the sparseness of sample and sensor data for the analytes of interest; iv) the presence of pre-existing water impairments that make it difficult to determine potential impacts from shale-gas activity; and v) the fact that sensors can malfunction or drift. Although the monitoring data available to assess contamination events in PA are limited, the state manages an online database of violations. Overall, one fifth of gas wells drilled were given at least one non-administrative notice of violation (NOV) from the PA regulator. Through March 2013, 3.4% of gas wells were issued NOVs for well construction issues and 0.24% of gas wells received NOVs related to methane migration into groundwater. Between 2008 and 2012, 161 of the ~1000 complaints received by the state described contamination that implicated oil or gas activity: natural gas was reported for 56% and brine salt components for 14% of the properties. Six percent of the properties were impacted by sediments, turbidity, and/or drill cuttings. Most of the sites of groundwater contamination with methane and/or salt components were in previously glaciated northern PA where fracture flow sometimes allows long distance fluid transport. No cases of subsurface transport of fracking or flowback fluids into water supplies were documented. If Marcellus-related flowback/production waters did enter surface or groundwaters, the most likely contaminants to be detected would be Na, Ca, and Cl, but those elements are already common in natural waters. The most Marcellus-specific "fingerprint" elements are Sr, Ba, and Br. For example, variable Br concentrations measured in southwestern PA streams were attributed to permitted release of wastewaters from unconventional shale gas wells into PA streams through municipal or industrial wastewater treatment plants before 2011. Discharge has now been discontinued except for brines from a few plants still permitted to discharge conventional oil/gas brines after treatment. Overall, drinking water supply problems determined by the regulator to implicate oil/gas activities peaked in frequency in 2010 while spill rates increased through 2012. Although many minor violations and temporary problems have been reported, the picture that emerges from PA is that the fast shale-gas start may have led to relatively few environmental incidents of significant impact compared to wells drilled; however, the impacts remain difficult to assess due to the lack of transparent and accessible data.

Brooks (2013). "Frack to the Future". <u>New Scientist</u>. **219**(2929): 36-41

The article focuses on the environmental aspects of shale gas. It states that shale gas is methane trapped in shale rock formations that is extracted through hydraulic fracturing and mentions from 2005 to 2013 U.S. carbon emissions declined by nine percent due partly to the use of shale gas for energy production. It comments that the International Energy Agency estimates that 40 percent of the world's electricity is produced by coal which emits twice the carbon dioxide emissions of natural gas. The article also includes a brief overview of global shale gas exploitation and discusses environmental and economic considerations.

Brown (2014). "Radionuclides in Fracking Wastewater: Managing a Toxic Blend". <u>Environmental Health Perspectives</u>. **122**(2)

Naturally occurring radionuclides are widely distributed in the earth's crust, so it's no surprise that mineral and hydrocarbon extraction processes, conventional and unconventional alike, often produce some radioactive waste. Perhaps nowhere is the question of drilling waste more salient than in Pennsylvania, where gas extraction from the Marcellus Shale using hydraulic fracturing (fracking) made the state the fastest-growing U.S. producer between 2011 and 2012. The Marcellus is known to have high uranium content. To date the drilling industry and regulators have considered the risk posed to workers and the public by radioactive waste to be minor. In Pennsylvania, there is currently nothing to indicate the public or workers face any health risk from exposure to radiation from these materials. But given the wide gaps in the data, this is cold comfort to many in the public health community.

Campbell and Horne (2012). "Shale Gas in British Columbia Risks to B.C.'s water resources". The Pembina Institute and The Pembina Foundation

Jurisdictions with shale gas reserves are clearly attracted to the potential economic benefits that the resource offers, however, in some regions health and environmental concerns are beginning to dominate the debate, particularly because of potential contamination of ground and surface water resources. This report is split into 5 sections; Section 1 presents an introduction to shale gas in B.C. Section 2 explores the known and potential impacts to water resources from shale gas extraction in B.C. While this report attempts to draw on the most recent research available it is important to acknowledge that many knowledge gaps still exist and that there is considerable uncertainty and variability in the data. Section 3 discusses the current regulatory environment in B.C. for water use and disposal in the oil and gas industry. In many cases, B.C.'s approaches to resource management and environmental protection are not fully equipped to deal with the new pressures introduced by the anticipated pace of shale gas development. Section 4 provides an overview of regulatory developments in other jurisdictions attempting to manage shale gas development and respond to development proposals. Section 5 makes nine recommendations for ways in which B.C. can improve its planning and regulatory framework for shale gas development to provide better protection for the province's water resources.

CAPP (2011). "CAPP members establish new Guiding Principles for Hydraulic Fracturing"

Canadian natural gas producers today announced new guiding principles for hydraulic fracturing that guide water management and improved water and fluids reporting practices for shale gas development in Canada. The principles were created by members of the Canadian Association of Petroleum Producers (CAPP) and apply to all CAPP natural gas producing members, large and small, operating in Canada. These included including safeguarding groundwater, as well as more public disclosure on how much water is being used and what fracturing fluid additives are included in the process.

CAPP (2012). "CAPP Hydraulic Fracturing Operating Practice:Fracturing fluid additive disclosure"

Under this Operating Practice, companies will disclose, either on their own websites or on a third-party website, those chemical ingredients in their fracturing fluid additives which are identified on the MSDS. The ingredients which must be listed on the MSDS are identified by federal law. The well-by-well disclosure includes: The trade name of each additive and its general purpose in the fracturing process, the name and the Chemical Abstracts Service number of each chemical ingredient listed on the MSDS for each additive, and the concentration of each reportable chemical ingredient.

CAPP (2012). "CAPP Hydraulic Fracturing Operating Practice: Fracturing fluid additive risk assessment and management"

Under this Operating Practice, companies will assess the potential risks of fracturing fluid additives and create risk management plans to effectively manage the additives. This practice includes: Identifying chemical ingredients and characteristics of each additive, assessing potential health and environmental risks of each additive, defining operational procedures and controls for the identified risks, and incorporating risk management plans for each well fractured.

CAPP (2012) "CAPP Hydraulic Fracturing Operating Practice: Baseline groundwater testing"

Under this Operating Practice, companies will undertake domestic water well sampling programs and participate in regional groundwater monitoring programs. This practice includes: Testing water wells within 250 metres, or as specified by regulation, of a wellhead before drilling shale gas, tight gas or tight oil wells, establishing procedures to address and track stakeholder concerns that pertain to water well performance, including notifying the appropriate regulator, and collaborating with government and other industry operators in nearby regions to broadly understand regional groundwater quality and quantity through monitoring programs or studies that reflect good judgment and sound science.

CAPP (2012) "CAPP Hydraulic Fracturing Operating Practice: Wellbore construction and quality assurance”

Under this Operating Practice, companies will demonstrate that procedures are in place to ensure proper design and installation of the wellbore, and to ensure the integrity of the wellbore prior to initiation of hydraulic fracturing. This practice includes: Complying with applicable regulatory requirements and using good engineering practice for wellbore design, Installing and cementing surface casing to surface to create a continuous cement barrier, which is assessed to ensure integrity of the wellbore, designing the wellbore to withstand minimum and maximum loads anticipated during hydraulic fracturing, confirming wellbore integrity with a pressure test where possible, determining the cause and developing appropriate remedial plans to restore wellbore integrity in the unlikely event that it is compromised, such as surface casing vent flow or gas migration.

CAPP (2012) “Hydraulic Fracturing Operating Practice: Water Sourcing, Measurement and Reuse”

Under this Operating Practice, companies will safeguard water quantity through assessment and measurement of water sources (including recycled water). As with all industrial operations, the volume of water that can be withdrawn is approved by the provincial regulator to ensure sustainability of the resource. This practice includes: Complying with withdrawal limits and reporting requirements of water licences/permits. Also, collecting and reporting water use data through CAPP’s Responsible Canadian Energy™ Program, implementing a decision-making framework to evaluate and understand available water sources, monitoring surface water and groundwater quantity data, as required to demonstrate sustainability of the water source; and collaborating with other companies on best practices.

CAAP (2012). “Hydraulic Fracturing Operating Practice: Fluid Transport, Handling, Storage and Disposal”

Under this Operating Practice, companies will implement practices and procedures to identify, evaluate and mitigate potential risks related to fluid transport, handling, storage and disposal, and respond quickly and effectively to an accidental spill of fluids (including remediation of the spill site). This practice includes: Following applicable federal, provincial and municipal regulations for fluid transport, including Transportation of Dangerous Goods (TDG) regulations, ensure maintenance and safety protocols are in place to address the risks associated with fluid transport by road, rail or pipeline, reducing fluid transport by road in large-scale development projects where possible, constructing and operating pipelines that transport fluids in accordance with applicable regulations, removing natural gas from flowback prior to storage, following applicable regulatory requirements for fluid storage, restricting wildlife access to fluid storage sites, and safely disposing of fluids that are no longer needed at approved waste management facilities, including disposal wells.

Canadian Natural Gas (2013). “Report of the dialogues on Canada’s natural gas industry”

While many Canadians recognize the opportunity arising from the increasing abundance and affordability of natural gas, Canada’s natural gas industry also acknowledges that some in the public and many communities across the country have questions about the potential impacts of increased natural gas development and use. To gain a better perspective about the diversity of views, the Canadian Natural Gas Initiative (Canadian Association of Petroleum Producers, Canadian Gas Association, Canadian Energy Pipeline Association, Canadian Society for Unconventional Resources and the Canadian Natural

Gas Vehicle Alliance) undertook a series of eight Natural Gas Dialogues across the country in 2012. The primary objective of these Dialogues was to better understand Canadian perspectives on natural gas' challenges and opportunities and to identify actions that could be pursued to address issues and concerns, so as to better realize the potential of natural gas in the Canadian context.

There was widespread recognition that natural gas can contribute to improved environmental performance, particularly with respect to improved energy efficiency, air quality and greenhouse gas emissions performance. However, the Dialogues participants also identified real and substantive challenges to Canada realizing these opportunities. The key concerns raised by Dialogues participants involves impacts on the environment and communities where natural gas is developed. We heard that communities believe most of these issues can be addressed, but all of them pose challenges to industry and government that have to be addressed with priority and urgency.

Cardno Entrix (2012). "Hydraulic Fracturing Study PXP Inglewood Oil Field"

A lawsuit was filed in late 2008 against the County of Los Angeles and PXP challenging the validity of the Baldwin Hills community Standards District (CSD). The lawsuit was settled July 15, 2011. This Hydraulic Fracturing Study is the direct result of Term 13 of the Settlement, which states: PXP shall pay for an independent consultant to conduct a study of the feasibility and potential impacts of the types of fracturing operations PXP may conduct in the Oil Field. The report presents findings related to; Microseismic monitoring, groundwater, well integrity, methane, ground movement and subsidence, induced earthquakes, noise and vibration, air emissions and, community health.

Carpenter (2013). "Water and hydraulic fracturing"

This article provides an overview of the AWWA white paper "Water and Hydraulic Fracturing" that was requested by AWWA's Water Utility Council in response to increasing oil and natural gas development and the difficulty many utilities have experienced in seeking balanced and authoritative information on this issue. On Jan. 28, 2013, AWWA issued the white paper Water and Hydraulic Fracturing that provides an overview of hydraulic fracturing and the many related facets of oil and natural gas development that have the potential to affect drinking water utilities. It is intended to help utilities gain an understanding of the issues involved in fracking, learn how to separate tangible concerns from more speculative ones, and find ways to meaningfully address concerns that arise from staff and customers.

Cash et al (2006). "Scale and Cross-Scale Dynamics: Governance and Information in a Multilevel World" <u>Ecology and Society</u> **11**(2): 8

The empirical evidence in the papers in this special issue identifies pervasive and difficult cross-scale and cross-level interactions in managing the environment. The complexity of these interactions and the fact that both scholarship and management have only recently begun to address this complexity have provided the impetus for us to present one synthesis of scale and cross-scale dynamics. In doing so, we draw from multiple cases, multiple disciplines, and multiple perspectives. In this synthesis paper, and in the accompanying cases, we hypothesize that the dynamics of cross-scale and cross-level interactions are affected by the interplay between institutions at multiple levels and scales. We suggest that the advent of co-management structures and conscious boundary management that includes knowledge co-production, mediation, translation, and negotiation across scale-related boundaries may facilitate solutions to complex problems that decision makers have historically been unable to solve.

CCA (Council of Canadian Academies) (2014) "Environmental Impacts of Shale Gas Extraction in Canada" Ottawa (ON): The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction, Council of Canadian Academies.

To understand the risks associated with shale gas development in Canada, the Minister of Environment on behalf of Environment Canada asked the Council of Canadian Academies to assemble a panel of experts to address the following question: What is the state of knowledge of potential environmental impacts from the exploration, extraction, and development of Canada's shale gas resources, and what is the state of knowledge of associated mitigation options? The assessment of environmental impacts is hampered by a lack of information about many key issues 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.

Rather than aligning the report with the individual questions posed in the charge, the Panel chose to organize the report into three main sections: a) Background and context for the report are provided in Chapters 2 and 3; b) Environmental and health impacts of shale gas development, identified by the Panel, are explained in Chapters 4, 5, 6 and 7; and c) Managing and monitoring impacts are discussed in Chapter 8 and 9.

Centner (2013) "Evaluating the Oversight of Shale Gas Production for Ideas to Manage Risks" Athens: ATINER'S Conference Paper Series, No: ENV2013-0398

To encourage shale gas production in the United States, Congress enacted exceptions so that producers would not have to comply with established regulatory oversight designed to protect people and the environment. However, hydraulic fracturing in the Marcellus shale play is quite different from previous natural gas production. The presence of toxic substances in underlying rock strata and the need of a disposal option for flowback waters create additional risks. In response to these risks, governments may revise their regulatory controls to reconcile energy production with health and environmental protection.

Centner and O'Connell (2014). "Unfinished business in the regulation of shale gas production in the United States". **476–477**: 359–367

With increased drilling for natural gas, toxic chemicals used to fracture wells have been introduced into the environment accompanied by allegations of injuries. This article evaluates laws and regulations governing shale gas production to disclose ideas for offering further protection to people and the environment. The aim of the study is to offer state governments ideas for addressing contractual obligations of drilling operators, discerning health risks, disclosing toxic chemicals, and reporting sufficient information to detect problems and enforce regulations. The discussion suggests opportunities for state regulators to become more supportive of public health through greater oversight of shale gas extraction.

Chevron (2014) “Appalachia Shale Gas Water Management Best Practices”. SPE International Conference on Health, Safety, and Environment, 17-19 March, Long Beach, California, USA

Hydraulic fracturing for acquiring shale gas requires a significant amount of water be used. The sourcing, transport, storage, reuse, and disposal can each pose environmental and social challenges. The hydraulic fracturing industry has been targeted for consumption of fresh water and for the traffic the trucks on the road introduce to local communities. Pits used for storage of water pose an eyesore and require extensive reclamation. Chevron Appalachia has implemented a number of water management best practices and will share these. Best practices include storing water in above ground storage tanks, treating and reusing water rather than disposing of water, maximizing use of non-potable water, and installing fresh water pipelines rather than trucking fresh water. Above ground storage tanks built to a design standard allow for minimal impact to the environment during construction and also improve reclamation. The chemical treatment of water can be accomplished in a cost effective and environmentally friendly manner that can then enable its reuse, resulting in less disposal volumes and less draw upon other sources of water. All of these require a workforce dedicated to water management - these best practices require focus and acceptance of transition in order to cause change. A water driven approach must be taken from the start of an asset’s development in order to execute wells in a manner that minimizes the environmental impact of water consumption as well as allows for delivery of cost efficient wells. Many of these practices while not only diminishing impact on the environment have yielded significant cost savings for operators. The best practices shared in this meeting can be used by other operators not only in the Marcellus shale but also in many other shale plays. The most significant innovations that will be presented are the use of a patent-pending mobile above ground storage tanks, an environmentally friendly and efficient treatment methodology, and a model all inclusive water management lifecycle.

CIEH (Chartered Institute of Environmental Health) (2013) “Hydraulic Fracturing:Impacts on the Environment and Human Health”

The aim of this briefing paper is to summarise current best available evidence on any potential environment and health impacts of hydraulic fracturing (fracking). This includes an analysis of the scientific/technical process itself as well as actual cases and incidents. There is currently significant commercial interest in fracking operations within, and around, the Fermanagh area of Northern Ireland, in Wales and in Lancashire. At present, there are no shale gas operations within either Northern Ireland or Wales. Operations expected to start in the UK in January, 2012 are still suspended following two small-scale earthquakes in Lancashire that have been attributed to fracking. This briefing deliberately does not seek to take a position as to whether or not fracking should proceed. CIEH recognises the potential benefits associated with the process in terms of the economy, jobs and energy security. However benefits need to be balanced against potential risks and adverse impacts and it is hoped that this document will provide a summary of those from an environmental health perspective. We hope that this will in turn assist in informing future decision making.

CIWEM (2014). “Shale Gas and Water, An independent review of shale gas exploration and exploitation in the UK with a particular focus on the implications for the water environment”

The UK Government has expressed a commitment to facilitate exploration for shale gas and is putting in place a regulatory regime which it hopes will provide appropriate safeguards to communities, employees and the environment, whilst at the same time avoiding obstruction to the industry to a level that would discourage interest in this exploration. The volume of water used in hydraulic fracturing for shale gas when viewed in isolation appears large. However, when set in the context of national or regional water supply, it constitutes a very small fraction and compares with other industrial uses. Shale gas wells may be drilled in areas where there is also groundwater present. It is essential that these water resources are protected from contamination and the risk of this occurring will need to be thoroughly assessed during the planning and permitting stages. In order to establish the current condition of the water environment and successfully identify where contamination may have occurred, either as a result of shale gas-related activities or others, good baseline data is required. Experience from the US and Australia shows that without good baseline data, it is hard to scientifically establish a cause of contamination and this fosters conjecture, commonly leading to a polarised discussion lacking in robust evidence. It is important that before shale gas activities commence, baseline data for appropriate contaminants is obtained for potentially affected ground and surface waters.

Clark (2012) “Fracking politics: a case study of policy in New York and Pennsylvania from 2008-2011” Master of Arts thesis, Colorado State University

This paper focuses on the politics of regulating natural gas hydraulic fracturing (fracking) in New York and Pennsylvania from 2008 to 2011 and how policy has changed in each state during this time. By applying Kingdon's multiple streams model as a tool, this paper finds four major influences on the stringency of fracking in New York and Pennsylvania. First, is increased negative news reporting, which results in the problem being seen as more significant than previously believed and contributing to a change in policy stringency. Second, the presence of focusing events increases the likelihood of a change in policy stringency. Third, policy entrepreneurs exert influence over policy stringency. Fourth, when Republicans are in control, they seek less stringent fracking regulation while Democrats work for more stringent fracking regulation. Finally this paper observes that when the aforementioned streams converge and a window of opportunity opens there is significant policy stringency change in both New York and Pennsylvania.

Clark et al. (2012) “The Technology and Policy of Hydraulic Fracturing and Potential Environmental Impacts of Shale Gas Development” Environmental Practice **14**: 249–261

The development of large-scale shale gas production has been described as a game-changer for the US energy market and has generated interest in expanding the use of natural gas in sectors such as electricity generation and transportation. This development has been made possible by improvements in drilling technologies—specifically utilizing hydraulic fracturing in conjunction with horizontal drilling—that have enabled the production of natural gas from unconventional formations. However, the environmental implications of natural gas production and its use have been called into question. Environmental impacts associated with shale gas development can occur at the global and local levels and include impacts to climate, local air quality, water availability, water quality, seismic events, and the local community. A variety of technologies and practices are available to operators to reduce these impacts. Policies are currently under development at the federal, state, and local level to mitigate environmental impacts. In this document, we discuss the technologies involved in shale gas production, the potential abiotic impacts of shale gas production with an emphasis on air and water issues, and the practices and policies currently being developed and implemented to mitigate these impacts.

Clark et al. (2013). “Life Cycle Water Consumption for Shale Gas and Conventional Natural Gas” Environmental Science and Technology. **47**(20): 11829–11836

Shale gas production represents a large potential source of natural gas for the nation. The scale and rapid growth in shale gas development underscore the need to better understand its environmental implications, including water consumption. This study estimates the water consumed over the life cycle of conventional and shale gas production, accounting for the different stages of production and for flowback water reuse (in the case of shale gas). This study finds that shale gas consumes more water over its life cycle (13-37 L/GJ) than conventional natural gas consumes (9.3-9.6 L/GJ). However, when used as a transportation fuel, shale gas consumes significantly less water than other transportation fuels. When used for electricity generation, the combustion of shale gas adds incrementally to the overall water consumption compared to conventional natural gas. The impact of fuel production, however, is small relative to that of power plant operations. The type of power plant where the natural gas is utilized is far more important than the source of the natural gas.

Cluff et al. (2014) “Temporal Changes in Microbial Ecology and Geochemistry in Produced Water from Hydraulically Fractured Marcellus Shale Gas Wells”. Environmental Science and Technology. **48**(11): 6508–6517

Microorganisms play several important roles in unconventional gas recovery, from biodegradation of hydrocarbons to souring of wells and corrosion of equipment. During and after the hydraulic fracturing process, microorganisms are subjected to harsh physicochemical conditions within the kilometer-deep hydrocarbon-bearing shale, including high pressures, elevated temperatures, exposure to chemical additives and biocides, and brine-level salinities. A portion of the injected fluid returns to the surface and may be reused in other fracturing operations, a process that can enrich for certain taxa. This study tracked microbial community dynamics using pyrotag sequencing of 16S rRNA genes in water samples from three hydraulically fractured Marcellus shale wells in Pennsylvania, USA over a 328-day period. There was a reduction in microbial richness and diversity after fracturing, with the lowest diversity at 49 days. Thirty-one taxa dominated injected, flowback, and produced water communities, which took on distinct signatures as injected carbon and electron acceptors were attenuated within the shale. The majority (>90%) of the community in flowback and produced fluids was related to halotolerant bacteria associated with fermentation, hydrocarbon oxidation, and sulfur-cycling metabolisms, including heterotrophic genera *Halolactibacillus, Vibrio, Marinobacter, Halanaerobium,* and *Halomonas,* and autotrophs belonging to *Arcobacter*. Sequences related to halotolerant methanogenic genera *Methanohalophilus* and *Methanolobus* were detected at low abundance (<2%) in produced waters several months after hydraulic fracturing. Five taxa were strong indicators of later produced fluids. These results provide insight into the temporal trajectory of subsurface microbial communities after “fracking” and have important implications for the enrichment of microbes potentially detrimental to well infrastructure and natural gas fouling during this process

Cohen et al. (2013) “Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers”. Groundwater. **51**(3): 317–319

The Comment by Saiers and Barth (2012) on Myers’ (2012) paper “Potential Contaminant Pathways from

Hydraulically Fractured Shale to Aquifers" offers a useful overview of some of that paper's shortcomings. We believe, however, that there are additional fundamental issues to be addressed. This paper builds on a paper by Saiers and Barth (2012) presenting additional reasons for discounting the model used by Myers (2012) paper.

Colbourn (2011). "Natural Gas Operations from a Public Health Perspective". Human and Ecological Risk Assessment: An International Journal. **17**(5): 1039-1056

The technology to recover natural gas depends on undisclosed types and amounts of toxic chemicals. A list of 944 products containing 632 chemicals used during natural gas operations was compiled. Literature searches were conducted to determine potential health effects of the 353 chemicals identified by Chemical Abstract Service (CAS) numbers. More than 75% of the chemicals could affect the skin, eyes, and other sensory organs, and the respiratory and gastrointestinal systems. Approximately 40–50% could affect the brain/nervous system, immune and cardiovascular systems, and the kidneys; 37% could affect the endocrine system; and 25% could cause cancer and mutations. These results indicate that many chemicals used during the fracturing and drilling stages of gas operations may have long-term health effects that are not immediately expressed. In addition, an example was provided of waste evaporation pit residuals that contained numerous chemicals on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA) lists of hazardous substances. The discussion highlights the difficulty of developing effective water quality monitoring programs. To protect public health we recommend full disclosure of the contents of all products, extensive air and water monitoring, coordinated environmental/human health studies, and regulation of fracturing under the U.S. Safe Drinking Water Act.

Colorado Oil & Gas Association (COGA) (2011). "Voluntary Baseline Groundwater Quality Sampling Program"

The Colorado Oil & Gas Association (COGA) has developed a voluntary groundwater testing program (the COGA Program) to establish baseline groundwater quality conditions around new oil and gas well locations and to monitor water quality in the vicinity of the oil and gas wells before and after drilling and completion activities have concluded. This report includes an overview of the program, the data collection procedures plus data management and reporting requirements.

Colorado Oil & Gas Association (COGA) (2014). "Lessons learned in the front range flood of september 2013"

The Colorado Oil and Gas Conservation Commission ("COGCC" or the "Commission") estimates that more than 5,900 oil and gas wells lie within 500 feet of a Colorado waterway that is substantial enough to be named. When these streams flood, nearby oil and gas facilities are at risk of damage, spills, environmental injury and lost production. COGCC continues its work in the state's recovery from the September 2013 flood along the Front Range of Colorado. COGCC has completed more than 3400 firsthand inspections of the oil and gas facilities affected by the flood. The report presents recommendations to the Commissioners for future action by COGCC. These recommendations are built upon the observations and suggestions collected by COGCC during its flood response. COGCC staff suggests no statutory changes. It proposes for Commission consideration adopting additional "best management” approaches for oil and gas facilities located near Colorado waterways, including remote shut-in capability and certain construction requirements for wells and equipment. Finally, COGCC staff proposes several changes to COGCC policies and practices that would better prepare the agency for future emergencies.

Cooley and Donnelly (2012). “Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction”. Pacific Institute. ISBN: 1-893790-40-1

The report Hydraulic Fracturing and Water Resources: Separating the Frack from the Fiction is a detailed assessment and synthesis of existing research on fracking as well as the results of interviews with representatives from state and federal agencies, industry, academia, environmental groups, and community-based organizations from across the United States. Interviewees identified a broad set of social, economic, and environmental concerns, foremost among which are impacts of hydraulic fracturing on the availability and quality of water resources. Despite the diversity of viewpoints among the stakeholders interviewed, there was surprising agreement about the range of concerns associated with hydraulic fracturing. Among the most commonly cited were concerns about spills and leaks, wastewater management, and water withdrawals. In addition to concerns about impacts on water resources, social and economic concerns were identified as well, such as worker health and safety and community impacts associated with rapidly industrializing rural environments.

Council of Canadian Academies (2014). “Environmental Impacts of Shale Gas Extraction in Canada”.

This development of hydraulic fracturing is changing long-held expectations about oil and gas resource availability; several observers have characterized it as a game changer. Abundant, close to major markets, and relatively inexpensive to produce, shale gas represents a major new source of fossil energy. However, the rapid expansion of shale gas development in Canada over the past decade has occurred without a corresponding investment in monitoring and research addressing the impacts on the environment, public health, and communities. The primary concerns are the degradation of the quality of groundwater and surface water (including the safe disposal of large volumes of wastewater); the risk of increased greenhouse gas (GHG) emissions (including fugitive methane emissions during and after production), thus exacerbating anthropogenic climate change; disruptive effects on communities and land; and adverse effects on human health. Other concerns include the local release of air contaminants and the potential for triggering small- to moderate-sized earthquakes in seismically active areas. These concerns will vary by region. The shale gas regions of Canada can be found near urban areas in the south and in remote regions in the northwest, presenting a large diversity in their geology, hydrology, land uses, and population density. The phrase environmental impacts from shale gas development masks many regional differences that are essential to understanding these impacts. To understand the risks associated with shale gas development in Canada, the Minister of Environment on behalf of Environment Canada asked the Council of Canadian Academies (the Council) to assemble a panel of experts to address the following question: “What is the state of knowledge of potential environmental impacts from the exploration, extraction, and development of Canada’s shale gas resources, and what is the state of knowledge of associated mitigation options?”

Curtright & Giglio (2012). “Coal Mine Drainage for Marcellus Shale Natural Gas Extraction Proceedings and Recommendations from a Roundtable on Feasibility and Challenges"

On December 14, 2011, with funding from the Marcellus Shale Coalition, the RAND Corporation hosted a roundtable conference exploring the use of coal mine water for hydraulic fracturing in the Marcellus Shale formation. Speakers and audience members addressed concerns related to the technical, economic, and regulatory feasibility of using this coal mine water for drilling and hydraulic stimulation of shale gas wells. In summarizing these discussions, these conference proceedings describe many of the challenges and opportunities associated with this approach to extracting natural gas from shale. This document also highlights a number of research gaps, the resolutions for which may assist stakeholders with both short- and long-term decisionmaking.

The event, "Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction," was held in RAND's Pittsburgh office. RAND selected and invited the participants who were not officially affiliated with the Marcellus Shale Coalition, hosted and moderated the roundtable, and retained full editorial control of the writing and production of this proceedings document.

The speakers' prepared white papers and presentation slides are available as a series of online appendixes accompanying these proceedings at http://www.rand.org/pubs/conf_proceedings/CF300.html.

Dalton (2014). "Discussion Paper: Potential Socioeconomic Effects of Unconventional Oil and Gas Development in Nova Scotia Communities. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process"

Community impacts of energy development may be both positive and negative, and are described in four key areas: the local economy, social and physical infrastructure, the natural environment, and social relations within communities. The energy boomtown literature of the 1970s and 1980s focused on the negative impacts of the boom-bust-recovery cycle. Subsequent research has shown positive impacts in most categories.

This paper summarizes potential community effects of unconventional oil and gas development through hydraulic fracturing, and offers means by which monitoring and evaluation of effects can lead to adaptive management and improved control of outcomes within communities.

Dammel et al. (2011) "A Tale of Two Technologies: Hydraulic Fracturing and Geologic Carbon Sequestration" Environmental Science and Technology. **45**: 5075–5076

Two technologies, hydraulic fracturing and geologic carbon sequestration, may fundamentally change the United States' ability to use domestic energy sources while reducing greenhouse gas emissions.Despite similarities in their environmental risks, regulations for geologic carbon sequestration and hydraulic fracturing are drastically different; the result is that similar risks are managed quite differently. Ironically, nascent geologic sequestration technology has state-of-the art regulations that were crafted during a decade of federal notice-and-comment rulemaking.In contrast, the Energy Policy Act of 2005 officially exempted hydraulic fracturing from regulation under the UIC program. The environmental risks of shale gas production are managed through rules established by state oil and gas agencies. These rules reflect historical practices that emphasize production of hydrocarbons for maximum economic gain.A shift toward a 21st Century vision of regulation is required. Hydraulic fracturing and geologic sequestration are both technologies that could reduce greenhouse gas emissions, enhance domestic energy security, and fundamentally change trajectories of energy supply and use, not just in the United States but across the world. While both present risks to the environment, appropriate regulatory approaches that equitably and consistently balance risks and benefits can aid in public acceptance and responsible deployment.

Dammel (2011) “Notes from Underground: Hydraulic Fracturing in the Marcellus Shale”. Minnesota Journal of Law, Science & Technology. **12**(2): 773-810

Hydraulic fracturing for natural gas is fundamentally altering the subsurface and societal landscapes where it is practiced. Nowhere is this more apparent than within the Marcellus Shale formation, the richest shale gas resource in the world, which underlies large swaths of the densely populated Eastern United States. The subsurface has long been “carved up, conveyed, used, bought, sold, and developed.” Much of this activity has centered upon the extraction of the fossil fuels used to power our modern life. Recent developments have rocked this landscape, bringing increasing scrutiny and opposition to the extraction of natural gas via hydraulic fracturing.The previously untapped resources now accessible via fracking create a potentially tremendous impact on national energy security and local economic well-being, but the practice is not without environmental risks. Further, it may be difficult to balance these risks and interests under traditional oil and gas regulatory regimes. A new approach to subsurface law and regulation is necessary in order to strike the right balance between public and private interests.

This Note will focus on hydraulic fracturing in Pennsylvania, the epicenter of the Marcellus Shale controversy. The state provides a case study for the nexus of energy, climate, and water issues, as well as the role of state and federal regulation. Part II of this Note will give an overview of the context surrounding hydraulic fracturing, as well as a brief technical primer on the process. Next, a discussion on the legal principles governing subsurface disputes will lead into a summary of state and federal regulatory action regarding fracking, with a focus on Pennsylvania’s regulatory structure. Part III presents a summary of previously proposed changes to regulation of hydraulic fracturing and provides a collection of proposals that protect public concerns and bolster private interests. The great potential of this practice is bounded by significant public concern and scientific uncertainty. Moving forward, a clear and equitable legal and regulatory framework must buttress effective management of this important resource.

Davies (2011). “Methane contamination of drinking water caused by hydraulic fracturing remains unproven” Proceedings of the National Academy of Sciences. **108**(43): E871

Shale gas extraction involves the drilling of organic-rich, low permeability shale and then stimulation of hydraulic fractures that allows gas to be produced. Methane in aquifers located above the shale strata, for instance, in Pennsylvania, United States, has been attributed by some to be the result of contamination caused by the hydraulic fracturing process. The work by Osborn et al. (2011) described geochemical data from 68 drinking water wells in northeastern Pennsylvania and upstate New York and evaluated whether the aquifers that the water wells penetrated were contaminated with thermogenic methane sourced from the underlying Marcellus and Utica shale formations. The work by Osborn et al. (2011) concluded that contamination had occurred and that the contamination accompanied gas well drilling and hydraulic fracturing. Their data showed that contamination may have occurred, but the association with hydraulic fractures remains unproven. To test whether hydraulic fracturing could cause aquifer contamination requires baseline measurements of levels of CH_4 in aquifers before and after hydraulic fracturing, preferably elsewhere in the world where there has been less historical drilling and natural seepage.

Davies et al. (2012). “Hydraulic fractures: How far can they go?”. Marine and Petroleum Geology. **37**: 1-6

The maximum reported height of an upward propagating hydraulic fracture from several thousand fracturing operations in the Marcellus, Barnett,Woodford, Eagle Ford and Niobrara shale (USA) is ~ 588 m. Of the 1170 natural hydraulic fracture pipes imaged with three-dimensional seismic data offshore of West Africa and mid-Norway it is ~ 1106 m. Based on these empirical data, the probability of a stimulated and natural hydraulic fracture extending vertically >350 m is ~ 1% and ~ 33% respectively. Constraining the probability of stimulating unusually tall hydraulic fractures in sedimentary rocks is extremely important as an evidence base for decisions on the safe vertical separation between the depth of stimulation and rock strata not intended for penetration.

Davies et al. (2013). “Reply: Davies et al. (2012), Hydraulic fractures: How far can they go?”. Marine and Petroleum Geology. **43**: 519-521

Davies et al. (2012) measured the heights of stimulated and natural hydraulic fractures caused by high fluid pressure from eight sedimentary successions from around the world. They found the tallest natural hydraulic fractures to be w1133 m in height and the tallest upward propagating stimulated hydraulic fractures, generated by fracking operations for gas and oil exploitation to be 588 m in height. This provided a rationale for an initial, safe separation distance of 600 m between aquifers and the deeper shale gas and oil reservoirs where hydraulic fractures are being stimulated. Three months after the paper went online, Geiser et al. (2012) published a new method, tomographic fracture imaging, which potentially detects the movement of a fluid pressure pulse in pre-existing natural fracture systems located close to where stimulated hydraulic fractures are forming. These fracture systems are not necessarily natural hydraulic fractures, but could be joints and faults formed due to folding or faulting. They found the maximum vertical extent of these to be ~ 1000 m. Here we respond to the comment made by Lacazette and Geiser (2013) and consider the implications of the new findings of Geiser et al. (2012) for the conclusions we made (Davies et al., 2012). It has long been known that fracture systems of 1000 m extent occur in sedimentary rocks (Løseth et al., 2001) and Davies et al. (2012) showed that three-dimensional seismic data can image natural hydraulic fractures that extend this far. If we assume fractures (hydraulic or otherwise) are also being imaged by the tomographic fracture imaging approach then the key question is whether they remain open after the fracking operations to enable the ascent of fluid. Confining stresses would cause fractures to close-up when pumping stops and the pressure in the fluid drops so a system of open fractures to shallow levels is difficult conceive. It would require there to be sedimentary strata at the level of the reservoir that are permeable and natural ovepressure that keeps the conduits open and active. But we cannot be certain that there are no permeable routes through pre-existing fracture systems. It is important to state that after thousands of fracking operations, there are no proven examples of contamination of drinking water aquifers due to hydraulic fracturing.

Davies et al. (2014). “Oil and gas wells and their integrity: Implications for shale and unconventional resource exploitation”. Marine and Petroleum Geology. **56**: 239-254

Data from around the world (Australia, Austria, Bahrain, Brazil, Canada, the Netherlands, Poland, the UK and the USA) show that more than four million onshore hydrocarbon wells have been drilled globally. Here we assess all the reliable datasets (25) on well barrier and integrity failure in the published literature and online. These datasets include production, injection, idle and abandoned wells, both onshore and offshore, exploiting both conventional and unconventional reservoirs. The datasets vary considerably in terms of the number of wells examined, their age and their designs. Therefore the percentage of wells that have had some form of well barrier or integrity failure is highly variable (1.9%-75%). Of the 8030 wells targeting the Marcellus shale inspected in Pennsylvania between 2005 and 2013, 6.3% of these have been reported to the authorities for infringements related to well barrier or integrity failure. In a separate study of 3533 Pennsylvanian wells monitored between 2008 and 2011, there were 85 examples of cement or casing failures, 4 blowouts and 2 examples of gas venting. In the UK, 2152 hydrocarbon wells were drilled onshore between 1902 and 2013 mainly targeting conventional reservoirs. UK regulations,like those of other jurisdictions, include reclamation of the well site after well abandonment. As such, there is no visible evidence of 65.2% of these well sites on the land surface today and monitoring is not carried out. The ownership of up to 53% of wells in the UK is unclear; we estimate that between 50 and 100 are orphaned. Of 143 active UK wells that were producing at the end of 2000, one has evidence of a well integrity failure.

Davis and Robinson (2012). "A Geographic Model to Assess and Limit Cumulative Ecological Degradation from Marcellus Shale Exploitation in New York, USA" Ecology and Society. **17**(2): 25.

When natural resources are exploited, environmental costs and economic benefits are often asymmetric. An example is apparent in the environmental impacts from fossil fuel extraction by hydraulic fracturing. So far, most scrutiny has been focused on water quality in affected aquifers, with less attention paid to broader ecological impacts beyond individual drilling operations. Marcellus Shale methane exploitation in New York State, USA, has been delayed because of a regulatory moratorium, pending evaluation that has been directed primarily at localized impacts. We developed a GIS-based model, built on a hexagonal grid underlay nested within the U.S. Environmental Protection Agency's EMAP system, to examine potential cumulative ecological impacts.Results were computed as percent cumulative impact versus the number of sites committed and compared to a most-conservative selection process (ranked by statewide conservation vulnerability). Random selection with proportional distribution by town resulted in larger cumulative ecological impacts, but rank-ordered selection by town was in many ways comparable to selection by statewide conservation vulnerability ranking. These outcomes allow for a political solution for managing resource access fairly, based on a balanced geographic distribution of economic benefits, coupled with an underlying scientific basis for assessing the ecological costs that are publicly shared.

De Pater and Baisch (2011). "Geomechanical Study of Bowland Shale Seismicity"

Over the past decades, experience gained from mapping hundreds of hydraulic fracture treatments with downhole geophones has shown that seismic events induced by these fracture treatments normally have a magnitude much lower than 0 on the Richter scale. That is the reason for using downhole receivers, since these events are hard to detect at the surface. Stronger events occur when some of the fluid penetrates into faults and in rare cases, events with magnitude up to 0.8 ML have been detected. Another observation is that injection volume has an influence on micro-seismic magnitude: larger injected fluid volumes tend to yield stronger events. However, even mapping of many treatments in US shale plays has only shown events up to 0.8 ML for a treatment volume of 15,000 bbls (N.R. Warpinski, private communication). There are only two documented cases of a hydro-frac treatment causing events up to magnitude 1.9 ML and 2.8 MD, respectively (from massive hydro-frac treatments in Oklahoma; Luza and Lawson, 1990; Holland, 2011).

The seismic events observed after two treatments in the Preese Hall (United Kingdom) well are therefore quite exceptional. Two events reported by BGS (magnitudes 2.3 and 1.5) and 48 much weaker events have been detected, and it is therefore hard to dismiss them as an isolated incident. The observed events are already 2 orders of magnitude stronger than normally observed from hydraulic fracturing induced seismicity and if future stimulation treatments again induce seismicity, it is imperative that the maximum magnitude can be estimated. It only appears feasible to establish an upper bound on the seismic magnitude if the estimation of that bound can be based on a clear understanding of the mechanism behind the past events. In this report, the probable mechanism of the events is described based on a careful technical analysis of all available data. It will be shown that many factors coincided to induce these seismic events, which are unusual for stimulation treatments. Since the chance for any single factor to occur is small, the combined probability of a repeat occurrence of a fracture induced seismic event with similar magnitude is quite low.

de Rijke (2013). “Hydraulically fractured, Unconventional gas and anthropology”

In the context of global climate change, hydraulic fracturing has been heralded for its potential to provide a much cheaper and cleaner-burning energy source than coal and oil. However, the operation of this technology is accompanied by major environmental issues ranging from its potential to cause environmental pollution to triggering seismic events. The governments of industrialized countries have so far been ill-equipped to provide the stricter regulation that these sophisticated techniques are said to require, and their adoption – especially in countries with weaker regulatory regimes – could pose a particular threat to human populations. These factors make this technology particularly controversial today. In this paper, I begin by setting out some of the main aspects of global energy predictions, unconventional gas, and fracking. This provides context for discussion of disputes, anthropological research projects, and the limited published literature on the subject. Drawing on my ongoing research in the gas fields of Australia, in the third section of this paper I describe the conflicts surrounding the extraction of gas from coal seams in southern Queensland. This case material is presented thematically to illustrate the diversity of anthropological perspectives in the literature and the research currently underway.

Dobb (2013). “The New Oil Landscape. The fracking frenzy in North Dakota has boosted the U.S. fuel supply—but at what cost?” National Geographic

This is an article produced from interviews with various people involved with fracking in North Dakota. Several points raised in the article are summarised below. Local landowners now worry that the oil industry will deplete their aquifers. They argue that the Missouri River, not groundwater, should be the primary source of water used in fracking. Of every dollar the oil industry earns, the state takes 11.5 cents, which produced revenues of more than two billion dollars from July 2011 to October 2012. One-third of that has been deposited in a permanent fund, the interest on which cannot be touched until 2017. The rest is to be divided between the state and local jurisdictions. How the money will be spent remains uncertain. The state could use its oil bonanza to finally free itself from its boom-bust history by taking advantage of a natural resource both abundant and inexhaustible—the ever present wind.

Drewes (2011). “An Integrated Framework for Treatment and Management of Produced Water”. RPSEA

Report. 07122-12.FINAL

For proper gas well development in coal beds water must be pumped out of the formation (dewatering) in order to reduce reservoir pressure and allow the methane to desorb. The co-produced water generated during these operations is by far the largest volume byproduct or waste stream associated with gas production. In contrast to conventional oil and gas production, the produced water from a coal bed methane (CBM) well is pumped in large volumes in the early stages of production and is typically at full pump capacity for up to two years. The quantity of water produced during the life of a well can be 1 to 3 bbl/mcf of gas. If an operator cannot sufficiently minimize water management costs, the CBM resource cannot be developed. This project developed an integrated guidance framework that linked the composition of produced waters to beneficial use applications and identified the most cost-efficient, most environmentally sound, and most beneficial strategies for management and treatment of produced water from CBM and gas shale operations by taking into account the conditions in place in the field. This was accomplished by cost benefit analyses that considered both technical and non-technical factors. This site-specific approach identified potential combinations of treatment processes, which can potentially minimize the volume of residual concentrated brines by considering both well established and emerging desalination technologies.

Drilling and Completions Committee (DACC) (2014). “IRP 4: Well Testing and Fluid Handling, An Industry Recommended Practice (IRP) for the Canadian Oil and Gas Industry”

The environmental, safety and health risks associated with well testing and fluid handling can be minimized by ensuring workers are properly trained, implementing prudent procedures and using properly designed equipment. The purpose of this document is to ensure that guidelines for well testing and fluid handling operations are in place and readily available for all personnel. Industry Recommended Practice (IRP) 4 is intended to supplement existing standards and regulations. It is also intended to establish guidelines in areas where none existed previously.

Drohan et al (2012). “Early Trends in Landcover Change and Forest Fragmentation Due to Shale-Gas Development in Pennsylvania: A Potential Outcome for the Northcentral Appalachians” Environmental Management. **49**: 1061–1075

Worldwide shale-gas development has the potential to cause substantial landscape disturbance. The northeastern U.S., specifically the Allegheny Plateau in Pennsylvania, West Virginia, Ohio, and Kentucky, is experiencing rapid exploration. Using Pennsylvania as a proxy for regional development across the Plateau, we examine land cover change due to shale-gas exploration, with emphasis on forest fragmentation. Pennsylvania’s shale-gas development is greatest on private land, and is dominated by pads with 1–2 wells; less than 10 % of pads have five wells or more. Approximately 45–62 % of pads occur on agricultural land and 38–54 % in forest land (many in core forest on private land). Development of permits granted as of June 3, 2011, would convert at least 644–1072 ha of agricultural land and 536–894 ha of forest land. Agricultural land conversion suggests that drilling is somewhat competing with food production. Accounting for existing pads and development of all permits would result in at least 649 km of new road, which, along with pipelines, would fragment forest cover. The Susquehanna River basin (feeding the Chesapeake Bay), is most developed, with 885 pads (26 % in core forest); permit data suggests the basin will experience continued heavy development. The intensity of core forest disturbance, where many headwater streams occur, suggests that such streams should become a focus of aquatic monitoring. Given the intense development on private lands, we believe a regional strategy is needed to help guide infrastructure development, so that habitat loss, farmland conversion, and the risk to waterways are better managed.

Drohan and Brittingham (2012). “Topographic and Soil Constraints to Shale-Gas Development in the Northcentral Appalachians” Soil Science Society of America Journal. **76**(5): 1696-1706

Worldwide, shale-gas development is becoming a feasible extraction practice and the northern Allegheny Plateau, USA is a region experiencing such development. We used a GIS to investigate topographic and soil characteristics across existing and permitted shale-gas pads in Pennsylvania, which could affect infrastructure development and reclamation success. Results from this analysis, while regionally specific, can contribute knowledge for successful management of all shale-gas extraction. Approximately 60% of existing and permitted pads occur on slopes at risk to some excess surface water movement and local erosion. Pad development occurs >90% of the time on backslope landscape positions and 37% of the time on soils with a fragipan subsoil horizon, which can contribute to soil drainage problems. Most pads (73%) are developed on soils without drainage problems, but 21% are on potentially wet soils. Shale-gas development related to one pad typically disturbed a 0.1- to 20.5-ha area (mean of 2.7 ha). Aerial photography analysis from 2010 indicates a small proportion of pads have undergone restoration, and restored pads were recontoured and planted with grass. Agricultural lands restored after infrastructure development were found to return to some crop production. Assuming perfect site reclamation, grass, herbaceous, hardwood, and conifer establishment appears suitable across the range of existing and permitted pads; however revegetation success may be limited by poor soil reclamation.

Dusseault et al. (2014). “Towards a Road Map for Mitigating the Rates and Occurrences of Long-Term Wellbore Leakage”

Wellbore leakage, the seepage of natural gas through cement channels, casing annuli and behind the outermost casing string, is a problem reported across Canada. Wellbore leakage is a threat to the environment and public safety because of potential groundwater quality deterioration, contributions to greenhouse gas emissions and explosion risks if methane gas accumulates in inadequately ventilated areas. Leakage rates remain poorly quantified and remedial workovers are often challenging. Subsequent costs attributed to remedial workovers are often significant and present an economic strain on the industry as well as lost profit, reduced exploration and production and, therefore, foregone royalties. The purpose of this report has been to (1) identify persistent problems that result in wellbore leakage, (2) discuss potential approaches that appear to reduce the rates and occurrences of wellbore leakage, (3) describe methods for detecting and monitoring for wellbore leakage, and (4) discuss methods that have improved the efficiency of remedial workovers. Wellbore leakage will likely only become worse with time as new wells are completed and old wells are abandoned. We recommend that a Canadian working group be established to develop a Road Map for Wellbore Integrity R&D to improve long-term wellbore integrity. Hydraulic fracturing is perceived as a threat by many in the public, however, we believe that this concern is misplaced. Because of the real issues associated with greenhouse gas emissions and possible groundwater quality deterioration, we believe the more significant issue affecting the social license of the oil and gas industry is long-term wellbore integrity.

Earthworks OGAP (2005). “Our drinking water at risk, What EPA and the Oil and Gas Industry Don’t Want Us to Know About Hydraulic Fracturing”

Hydraulic fracturing is a common technique used to stimulate the production of oil and natural gas. Typically, fluids are injected underground at high pressures, the formations fracture, and the oil or gas flows more freely out of the formation. Some of the injected fluids remain trapped underground. A number of these fluids qualify as hazardous materials and carcinogens, and are toxic enough to contaminate groundwater resources. There are a number of cases in the U.S. where hydraulic fracturing is the prime suspect in incidences of impaired or polluted drinking water. In Alabama, Colorado, New Mexico, Virginia, West Virginia and Wyoming, incidents have been recorded in which residents have reported changes in water quality or quantity following fracturing operations of gas wells near their homes. Natural gas development is booming in the U.S., particularly coalbed methane (CBM) development; hundreds of companies are looking to drill for CBM wherever there are viable deposits of coal. In at least ten states (Alabama, Arkansas, Colorado, Kansas, Montana, New Mexico, Virginia, Washington, West Virginia and Wyoming), these coal formations contain drinking water aquifers. Despite the widespread use of the practice, and the risks hydraulic fracturing poses to human health and safe drinking water supplies, the U.S. Environmental Protection Agency (“EPA”) does not currently regulate the injection of fracturing fluids under the Safe Drinking Water Act. The oil and gas industry is the only industry in America that is allowed by EPA to inject hazardous materials –unchecked– directly into or adjacent to underground drinking water supplies. In 2000, in response to the 1997 court decision, the EPA initiated a study of the threats to water supplies associated with the fracturing of coal seams for methane production. The primary goal of the study was to assess the potential for fracturing to contaminate underground drinking water supplies. The EPA completed its study in 2004, finding that fracturing “poses little or no threat” to drinking water. The EPA also concluded that no further study of hydraulic fracturing was necessary. The 2004 EPA study has been called “scientifically unsound” by EPA whistleblower Weston Wilson. The Oil and Gas Accountability Project (OGAP) has conducted a review of the EPA study. We found that EPA removed information from earlier drafts that suggested unregulated fracturing poses a threat to human health, and that the Agency did not include information that suggests fracturing fluids may pose a threat to drinking water long after drilling operations are completed. OGAP’s review of relevant data on hydraulic fracturing suggests that there is insufficient information for EPA to have concluded that hydraulic fracturing does not pose a threat to drinking water.

Earthworks OGAP (2009). “Hydraulic fracturing, Myths and Facts”

This is an information sheet presenting some commonly believed ‘myths’ surrounding fracking and what earthworks claim are the ‘facts’. The article mainly looks at risks to drinking water and appeals for the following three points in a pledge to ‘Protect Our Drinking Water: Close the Halliburton Loophole in the Safe Drinking Water Act’ 1) Repeal the Safe Drinking Water Act exemption for hydraulic fracturing. 2) Require full chemical disclosure and monitoring of hydraulic fracturing products. 3) Require non-toxic hydraulic fracturing and drilling products.

Earthworks OGAP (2011). “Loopholes for polluters – The oil and gas industry’s exemptions to major environmental laws”.

The oil and gas industry is exempt from key provisions of seven major federal environmental laws allowing practices that would otherwise be illegal. Some exemptions date back decades. Others were adopted as recently as 2005. While states and tribes have tried to fill the gaps with their own rules and regulations, they vary widely in effectiveness and enforcement. Federal laws provide consistent standards that equally protect all Americans. That's why it's essential to reverse these federal loopholes. The document lists loopholes in the Safe Drinking Water Act (SDWA), The Clean Air Act (CAA), The Clean Water Act (CWA), The Resource Conservation and Recovery Act (RCRA), The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), The National Environmental Policy Act (NEPA) and The Toxic Release Inventory of EPCRA.

Earthworks OGAP (2012). "Gas Patch Roulette, Oil & gas accountability project how shale gas development risks public health in Pennsylvania"

The data gathered through this project point to three central conclusions: (1) contaminants that are associated with oil and gas development are present in air and water in areas where residents are experiencing health symptoms consistent with such exposures; (2) there is a strong likelihood that residents who are experiencing a range of health problems would not be if widespread gas development were not occurring; and (3) by permitting widespread gas development without fully understanding its impacts to public health—and using that lack of knowledge to justify regulatory inaction—Pennsylvania and other states are risking the public's health. More research is warranted to establish connections between reported health problems and particular events related to gas operations, such as chemical spills, leaking waste pits, and flaring and venting. This could include, for example, examination of case files compiled by regulatory agencies, interviews with residents near the facilities where problems occurred, and daily odor and symptom logs kept by residents.

Earthworks OGAP (2012). "Breaking All the Rules, The crisis in oil & gas regulatory enforcement"

The U.S. faces a crisis in the enforcement of rules governing the oil and gas industry. The shale gas and shale oil boom has brought an expansion of oil and gas activity unseen in many parts the country since the 19th century. Unfortunately, as this report shows, states are dangerously unprepared to oversee current levels of extraction, let alone increased drilling activity from the shale boom.

Among the findings are: 1) Every year hundreds of thousands of oil and gas wells – 53 to 91% of wells in the states studied (close to 350,000 active wells in the six states in 2010) – are operating with no inspections to determine whether they are in compliance with state rules. 2) When inspections do uncover rule violations, the violations often are not formally recorded – and the decision whether or not to record a violation is often left to the discretion of the individual inspector. 3) When violations are recorded, they result in few penalties. 4) When penalties are assessed, they provide little incentive for companies to not offend again.

Earthworks OGAP (2013). "Reckless Endangerment While Fracking the Eagle Ford"

Oil and gas operations in shale formations release chemicals to air, water and soil that are hazardous to human health. When operators act irresponsibly, these releases are exceptionally severe, and nearby communities are particularly at risk. Results from test investigations and several case studies are presented. The results indicate that air pollution from oil and gas development in the Eagle Ford Shale definitely threatens, and likely harms, the health or Karnes County Texas residents. Despite these

findings, no action has been taken by regulators to rein in irresponsible operations, or otherwise protect area residents.

Ecology Action Centre (Nova Scotia) (2014). “Keep it in the ground, the impacts of fracking in Nova Scotia”

Hydraulic fracturing (fracking) is a relatively new technology in the oil and gas industry, with directional drilling technologies and proprietary slickwater mixtures only having been incorporated into older techniques in the past 15 years. Experience from other jurisdictions shows that fracking can have a range of environmental and socio-economic impacts; Energy produced from shale is not a silver bullet for energy or jobs, fracking contaminates our drinking water, fracking traffic damages rural roads, fracking fragments landscapes and fracking isn’t good for farming. The Ecology Action Centre’s goal is to foster a society in Nova Scotia that respects and protects nature and provides environmentally and economically sustainable solutions for its citizens. Allowing fracking to proceed in Nova Scotia will not advance that goal. We urge the Panel and the Government to place a 10-year moratorium on fracking in Nova Scotia.

Ellsworth (2013). “Injection-induced earthquakes”. Science. **341**(6142): 142

Earthquakes in unusual locations have become an important topic of discussion in both North America and Europe, owing to the concern that industrial activity could cause damaging earthquakes. It has long been understood that earthquakes can be induced by impoundment of reservoirs, surface and underground mining, withdrawal of fluids and gas from the subsurface, and injection of fluids into underground formations. Injection-induced earthquakes have, in particular, become a focus of discussion as the application of hydraulic fracturing to tight shale formations is enabling the production of oil and gas from previously unproductive formations. Earthquakes can be induced as part of the process to stimulate the production from tight shale formations, or by disposal of wastewater associated with stimulation and production. Here, I review recent seismic activity that may be associated with industrial activity, with a focus on the disposal of wastewater by injection in deep wells; assess the scientific understanding of induced earthquakes; and discuss the key scientific challenges to be met for assessing this hazard.

Emmelin (1996). “Landscape impact analysis: a systematic approach to landscape impacts of policy” Landscape Research. **21**(1): 13-35

A method for analysis of landscape impacts and for presentation in visual terms was developed by the author and has been applied in Sweden and Norway to policy analysis. The method has successively been developed into a generalised method of landscape impact analysis (LIA). This deals with the interaction of human and natural systems and the resulting landscape. The method uses scenario techniques as a way of solving the problems of lack of specificity of policy, a problem which seems underestimated in the development of strategic environmental assessment. The paper describes the main steps of the method and shows examples of the application of the method to changes in Norwegian agricultural policy.

Energy and Mines Ministers’ Conference (2013). “Responsible Shale Development:Enhancing the

Knowledge Base on Shale Oil and Gas in Canada”. Cat. No. M34-14/2013E-PDF

The purpose of this report to Ministers and its accompanying Compendium is to compile and summarize in a single document all the major efforts and research that federal, provincial, and territorial governments have undertaken (or have underway) on shale resource innovation and development. To this end, this report serves as a 'resource' for all jurisdictions to better understand and benefit from the collective efforts across Canada. Another purpose of this report is to highlight how jurisdictions have in fact made important progress in addressing the most critical issues related to shale resource development and on-going efforts in strengthening Canada's overall knowledge base, as well as to help identify any gaps that may exist. Thus, this report also provides recommendations on areas for continued work and collaboration.

The Energy Institute UTA (2012). “Fact-Based Regulation for Environmental Protection in Shale Gas Development”

The findings of this exploration of shale gas regulation are summarized starting with an overview of shale gas followed by a description of media coverage and public perception of its development. The science of shale gas impacts is then reviewed, and the regulatory framework – and the enforcement of regulations – are described. Finally, the compiled results of the investigation are interpreted for future fact-based regulation of shale gas development.

A review of this report prepared by the University of Texas (2012) found that “Because of the inadequacy of project definition, management and review of the current project on shale gas fracturing and the damage to the credibility of the project caused by inadequate disclosure of potential conflict of interest on the part of the Principal Investigator, the publication resulting from Energy Institute’s project on shale gas fracturing should be withdrawn from the Institute’s website and the document “Separating Fact from Fiction in Shale Gas Development,” given its basis in the above, should not be further distributed at this time. Authors of the white papers should be allowed sufficient time and opportunity to finish their work, preparing their papers for submission for truly independent review by a broad panel of independent scientists and policy experts. The summary paper should be redrafted to accurately portray these revised white papers, with strong involvement from the Senior Contributors, and potential conflicts of those involved should be stated.”

Engle and Rowan (2014). “Geochemical evolution of produced waters from hydraulic fracturing of the Marcellus Shale, northern Appalachian Basin: A multivariate compositional data analysis approach”. International Journal of Coal Geology. **126**: 45–56

Multivariate compositional data analysis methods were used to investigate geochemical data for water injected during hydraulic fracturing and for water produced from 19 Marcellus Shale gas wells in the northern Appalachian Basin. The data were originally published as part of an industry report. The analysis was adapted to consider the compositional nature of the data and avoid potentially spurious correlations present in raw concentration data through the application of log-ratio transformations. Techniques such as robust variation arrays, robust principal component analysis, and relative variation plots were applied to log-ratio transformed data. Results from this battery of multivariate tools indicate that two primary processes affect the chemical evolution of the water returned to the surface during the first 90 days of production: mixing of injected water with formation brines of evaporated paleo-seawater origin and injection of sulfate-richwater during hydraulic fracturing may stimulate sulfate reduction at some sites. Spatial variability in sulfate/alkalinity ratios appears to influence variations in geochemical controls on strontium versus barium with elevated proportions of strontium being found in more bicarbonate-poor environments, while barium is a larger proportion in sulfate-poor areas. Comparison of results using a log-ratio approach versus the more common analysis of concentration data reveals both similarities and some marked differences in the resulting interpretations. Results from this work are important in terms of both demonstrating methods to avoid mathematical inconsistencies from using raw brine geochemical data and to further investigate the geochemical controls on produced waters generated from shale gas reservoirs.

Engelder et al. (2014). "The fate of residual treatment water in gas shale". Journal of Unconventional Oil and Gas Resources. **7**: 33–48

More than 2 x 10^4 m3 of water containing additives is commonly injected into a typical horizontal well in gas shale to open fractures and allow gas recovery. Less than half of this treatment water is recovered as flowback or later production brine, and in many cases recovery is <30%. While recovered treatment water is safely managed at the surface, the water left in place, called residual treatment water (RTW), slips beyond the control of engineers. Some have suggested that this RTW poses a long term and serious risk to shallow aquifers by virtue of being free water that can flow upward along natural pathways, mainly fractures and faults. These concerns are based on single phase Darcy Law physics which is not appropriate when gas and water are both present. In addition, the combined volume of the RTW and the initial brine in gas shale is too small to impact near surface aquifers even if it could escape. When capillary and osmotic forces are considered, there are no forces propelling the RTW upward from gas shale along natural pathways. The physics dominating these processes ensure that capillary and osmotic forces both propel the RTW into the matrix of the shale, thus permanently sequestering it. Furthermore, contrary to the suggestion that hydraulic fracturing could accelerate brine escape and make near surface aquifer contamination more likely, hydraulic fracturing and gas recovery will actually reduce this risk. We demonstrate this in a series of STP counter-current imbibition experiments on cuttings recovered from the Union Springs Member of the Marcellus gas shale in Pennsylvania and on core plugs of Haynesville gas shale from NW Louisiana.

Entrekin et al. (2011). "Rapid expansion of natural gas development poses a threat to surface waters" Frontiers in Ecology and the Environment. **9**(9): 503–511

Extraction of natural gas from hard-to-reach reservoirs has expanded around the world and poses multiple environmental threats to surface waters. Improved drilling and extraction technology used to access low permeability natural gas requires millions of liters of water and a suite of chemicals that may be toxic to aquatic biota. There is growing concern among the scientific community and the general public that rapid and extensive natural gas development in the US could lead to degradation of natural resources. Gas wells are often close to surface waters that could be impacted by elevated sediment runoff from pipelines and roads, alteration of streamflow as a result of water extraction, and contamination from introduced chemicals or the resulting wastewater. However, the data required to fully understand these potential threats are currently lacking. Scientists therefore need to study the changes in ecosystem structure and function caused by natural gas extraction and to use such data to inform sound environmental policy.

Environment New York, Research & Policy Center (2012). "The Costs of Fracking, The Price Tag of Dirty Drilling's Environmental Damage"

Over the past decade, the oil and gas industry has fused two technologies—hydraulic fracturing and horizontal drilling—to unlock new supplies of fossil fuels in underground rock formations across the United States. "Fracking" has spread rapidly, leaving a trail of contaminated water, polluted air, and marred landscapes in its wake. In fact, a growing body of data indicates that fracking is an environmental and public health disaster in the making. However, the true toll of fracking does not end there. Fracking's negative impacts on our environment and health come with heavy "dollars and cents" costs as well. In this report, we document those costs—ranging from cleaning up contaminated water to repairing ruined roads and beyond. Many of these costs are likely to be borne by the public, rather than the oil and gas industry. As with the damage done by previous extractive booms, the public may experience these costs for decades to come.

The case against fracking is compelling based on its damage to the environment and our health alone. To the extent that fracking does take place, the least the public can expect is for the oil and gas industry to be held accountable for the damage it causes. Such accountability must include up-front financial assurances sufficient to ensure that the harms caused by fracking are fully redressed. Fracking damages the environment, threatens public health, and affects communities in ways that can impose a multitude of costs: Drinking water contamination, health problems, natural resources impacts, impacts on public infrastructure and services, and broader economic impacts. As with previous fossil fuel booms that left long-term impacts on the environment, there is every reason to believe that the public will be stuck with the bill for many of the impacts of fracking.

EPA (Environmental Protection Agency) (2000). "A National Assessment of Landscape Change and Impacts to Aquatic Resources, A 10-year Research Strategy for the Landscape Sciences Program"

This 10-year strategic plan describes the rationale and approach for research activities proposed by the Landscape Ecology and Landscape Characterization Branches (Landscape Sciences Program) of the National Exposure Research Laboratory (NERL). The 10-year goal of the Landscape Sciences Program is to conduct a national assessment of landscape change between the early 1970s and the early 2000s at relatively fine spatial scales (60-meter resolution) and to evaluate the consequences of observed change on aquatic resources, including streams and estuaries. An emphasis on aquatic resource endpoints is based on legislative mandates and the important role that the EPA plays in monitoring and protecting these resources. However, the research strategy recognizes the importance of the terrestrial characteristics and processes in determining the condition of aquatic resources; therefore, many of the indicators being developed by the Landscape Sciences Program are terrestrial-based. Five priority research and development areas have been identified to achieve this 10-year goal: (1) acquisition and assembly of spatial databases on the environment that permit generation of landscape indicators, (2) development of new remote sensing methods to improve the quality of spatial databases and to measure landscape indicators of stress, (3) development of methods that permit an analysis of landscape change based on different satellite sensors, (4) development and selection of landscape indicators based on the degree to which they explain variability in aquatic resource conditions, and (5) development of landscape assessment approaches and watershed models that permit an analysis of multiple landscape indicators.

EPA (Environmental Protection Agency) (2004). “Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs Study”

The U.S. Environmental Protection Agency (EPA, or the Agency) conducted a study that assesses the potential for contamination of underground sources of drinking water (USDWs) from the injection of hydraulic fracturing fluids into coalbed methane (CBM) wells. To increase the effectiveness and efficiency of the study, EPA has taken a phased approach. Apart from using real world observations and gathering empirical data, EPA also evaluated the theoretical potential for hydraulic fracturing to affect USDWs. Based on the information collected and reviewed, EPA has concluded that the injection of hydraulic fracturing fluids into CBM wells poses little or no threat to USDWs and does not justify additional study at this time. EPA’s decision is consistent with the process outlined in the April, 2001 Final Study Design, which is described in Chapter 2 of this report.

EPA (Environmental Protection Agency) (2011). “Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources”

The overall purpose of this study is to elucidate the relationship, if any, between hydraulic fracturing and drinking water resources. More specifically, the study has been designed to assess the potential impacts of hydraulic fracturing on drinking water resources and to identify the driving factors that affect the severity and frequency of any impacts. Based on the increasing development of shale gas resources in the US, and the comments EPA received from stakeholders, this study emphasizes hydraulic fracturing in shale formations. Portions of the research, however, are also intended to provide information on hydraulic fracturing in coalbed methane and tight sand reservoirs. The scope of the research includes the hydraulic fracturing water use lifecycle, which is a subset of the greater hydrologic cycle. For the purposes of this study, the hydraulic fracturing water lifecycle begins with water acquisition from surface or ground water and ends with discharge into surface waters or injection into deep wells. The EPA study is designed to provide decision-makers and the public with answers to fundamental questions associated with the hydraulic fracturing water lifecycle relating to; Water Acquisition, Chemical Mixing, Well Injection, Flowback and Produced Water, Wastewater Treatment and Waste Disposal.

EPA (Environmental Protection Agency) (2012). “Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, Progress Report”

This report describes 18 research projects underway to answer the research questions posed in the EPA 2011 report (Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources) and presents the progress made as of September 2012 for each of the projects. Information presented as part of this report cannot be used to draw conclusions about potential impacts to drinking water resources from hydraulic fracturing. The research projects are organized according to five different types of research activities: analysis of existing data, scenario evaluations, laboratory studies, toxicity assessments, and case studies. As well as providing a summary of progress the report also provides information on the next steps of the project. Information presented as part of this report cannot be used to draw conclusions about potential impacts to drinking water resources from hydraulic fracturing.

EPA (Environmental Protection Agency) (2013). “Summary of the Technical Roundtable on EPA’s Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources”

At the request of Congress, the U.S. Environmental Protection Agency (EPA) is conducting a study to better understand the potential impacts of hydraulic fracturing on drinking water resources. The scope of the research includes the full cycle of water associated with hydraulic fracturing activities. In the study, each stage of the water cycle is associated with a primary research question: Water acquisition: What are the possible impacts of large volume water withdrawals from ground and surface waters on drinking water resources? Chemical mixing: What are the possible impacts of hydraulic fracturing fluid surface spills on or near well pads on drinking water resources? Well injection: What are the possible impacts of the injection and fracturing process on drinking water resources? Flowback and produced water: What are the possible impacts of surface spills on or near well pads of flowback and produced water on drinking water resources? Wastewater treatment and waste disposal: What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking water resources? On November 14–16, 2012, EPA conducted a series of five technical roundtables focused on each stage of the water cycle. EPA's goals for these roundtables were to discuss key aspects of this complex study with stakeholders and develop a list of potential topics for future technical workshops. Based on feedback from the roundtables, EPA hosted a series of technical workshops in 2013 to address specific topics in greater detail. On December 9, 2013, EPA reconvened the roundtable to review the work addressed in the technical workshop series. EPA presented a study update, an overview of the technical workshops and how they informed the study, plans for multiagency collaboration on unconventional oil and gas, an overview of EPA's study report, and a review of stakeholder engagement. Individual roundtable participants provided comments and input on technical issues related to the study and on suggested next steps for stakeholder engagement.

EPA (Environmental Protection Agency) (2014). "Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels: Underground Injection Control Program Guidance #84"

This guidance provides technical recommendations for protecting underground sources of drinking water (USDWs) from potential endangerment posed by hydraulic fracturing (HF) activities where diesel fuels are used. The U.S. Environmental Protection Agency (EPA) developed this guidance for EPA permit writers to ensure protection of USDWs in accordance with the Safe Drinking Water Act (SDWA) and Underground Injection Control (UIC) regulatory authority. This authority is limited to when diesel fuels are used in fluids or propping agents pursuant to oil, gas and geothermal activities. This document does not establish any new permitting requirements for HF activities using diesel fuels, but describes the EPA's interpretation of existing legal requirements as well as non-binding recommendations for EPA permit writers to consider in applying UIC Class II regulations to HF when diesel fuels are used in fracturing fluids or propping agents. This document does not address geothermal activities.

European Parliament. Directorate General for Internal Policies (2011). "Impacts of shale gas and shale oil extraction on the environment and on human health". IP/A/ENVI/ST/2011-07

This study discusses the possible impacts of hydraulic fracturing on the environment and on human health. Quantitative data and qualitative impacts are taken from US experience since shale gas extraction in Europe still is in its infancy, while the USA have more than 40 years of experience already having drilled more than 50,000 wells. Greenhouse gas emissions are also assessed based on a critical review of existing literature and own calculations. European legislation is reviewed with respect to hydraulic fracturing activities and recommendations for further work are given. The potential gas resources and future availability of shale gas is discussed in face of the present conventional gas supply and its probable future development.

Evensen et al. (2014). “A New York or Pennsylvania state of mind: social representations in newspaper coverage of gas development in the Marcellus Shale” Journal of Environmental Studies and Sciences. **4**: 65–77

What first comes to mind when you think of natural gas development in the Marcellus Shale region? The information and ideas we hold about shale gas development can strongly influence our discussion of this issue, the impacts we associate with it, and the types of regulation we view as appropriate. Our knowledge and beliefs are based in part on social representations—common sense understandings of complex, often scientific, phenomena, generated in the public sphere and reliant on the history, culture, and social structure of the context in which they emerge. In this article, we examine social representations of environmental, economic, and social impacts of natural gas development in the Marcellus Shale, as reported by major regional newspapers. We conducted a content analysis of newspaper coverage in two newspapers in the northern tier of Pennsylvania and two in the southern tier of New York from 2007 to 2011, with a total sample of 1,037 articles. Effects on water quality were by far the most prevalent environmental representation in each newspaper. Economic representations focused on jobs, leases, and royalties, but varied substantially across geographical contexts. Representations of social impacts were relatively rare in each media outlet. We also interviewed the journalists who wrote the most articles on shale gas development at each newspaper. Their perspectives provide some explanations for why certain impacts were mentioned more frequently than others, and for differences between newspapers. We conclude with implications for communicating about impacts associated with shale gas development, and for regulating development.

Ferrar et al. (2013). “Assessment of Effluent Contaminants from Three Facilities Discharging Marcellus Shale Wastewater to Surface Waters in Pennsylvania”. Environmental Science and Technology. **47**: 3472−3481

Unconventional natural gas development in Pennsylania has created a new wastewater stream. In an effort to stop the discharge of Marcellus Shale unconventional natural gas development wastewaters into surface waters, on May 19, 2011 the Pennsylvania Department of Environmental Protection (PADEP) requested drilling companies stop disposing their wastewater through wastewater treatment plants (WWTPs). This research includes a chemical analysis of effluents discharged from three WWTPs before and after the aforementioned request. The WWTPs sampled included two municipal, publicly owned treatment works and a commercially operated industrial wastewater treatment plant. Analyte concentrations were quanitified and then compared to water quality criteria, including U.S. Environmental Protection Agency MCLs and “human health criteria.” Certain analytes including barium, strontium, bromides, chlorides, total dissolved solids, and benzene were measured in the effluent at concentrations above criteria. Analyte concentrations measured in effluent samples before and after the PADEP’s request were compared for each facility. Analyte concentrations in the effluents decreased in the majority of samples after the PADEP’s request ($p < .05$). This research provides preliminary evidence that these and similar WWTPs may not be able to provide sufficient treatment for this wastewater stream, and more thorough monitoring is recommended.

Fisher (2010). “Data confirm safety of well fracturing”. The American Oil & Gas Reporter

The concerns around groundwater contamination raised by Congress are primarily centered on one fundamental question: Are the created fractures contained within the target formation so that they do not contact underground sources of drinking water? In response to that key concern, this article presents the first look at actual field data based on direct measurements acquired while fracture mapping more than 15,000 frac jobs during the past decade. Studies conducted by governmental agencies and respected authorities have unanimously concluded that hydraulic fracturing is safe. The Environmental Protection Agency, the Ground Water Protection Council and the Interstate Oil & Gas Compact Commission all have found hydraulic fracturing nonthreatening to the environment or public health.The results from our extensive fracture mapping database show that hydraulic fractures are better confined vertically (and are also longer and narrower) than conventional wisdom or models predict. Even in areas with the largest measured vertical fracture growth, such as the Marcellus, the tops of the hydraulic fractures are still thousands of feet below the deepest aquifers suitable for drinking water.

Fisher (2012). “Frackings Footprint, Scientists Study Impact of Shale Gas Development on Pennsylvania’s Forests”. CSA News. 4-11

Southeastern Pennsylvania is known for its lush, pastoral landscapes and prosperous farming communities. But the economy in the state’s north and west has historically depended on resource extraction and its inevitable cycles of boom and bust. Now the latest boom is on. Thousands of feet below the surface are the Marcellus and Utica shales and their largely untapped reserves of natural gas. Shale gas drilling likely won’t be as intense and damaging as strip-mining, nor will vast areas of land be affected, as during the lumbering era. Still, there is cause for concern. Major concerns relate to ecological disruption due to forest fragmentation and shifting patterns of soil infiltration, erosion and run off. This is why a team at Penn State University has embarked on an ambitious, interdisciplinary research project, which aims first to characterize the Pennsylvanian landscapes in which drilling is occurring: where the activity is concentrated, what the topography and soils are like, and whether the land cover is agriculture or forest. They hope their data can then inform the siting of future wells, pipelines, and roads so that this infrastructure causes the least disturbance in the short term and eases the way toward bringing back forests and farmland later on.

Fisher and Warpinski (2011). “Hydraulic Fracture-Height Growth: Real Data”. SPE Annual Technical Conference and Exhibition. SPE 145949

Much public discourse has taken place regarding hydraulic-fracture growth in unconventional reservoirs and whether fractures could potentially grow up to the surface and create communication pathways for frac fluids or produced hydrocarbons to pollute groundwater supplies. Real fracture-growth data mapped during thousands of fracturing treatments in unconventional reservoirs are presented along with the reported aquifer depths in the vicinity of the fractured wells. These data are supplemented with an in-depth discussion of fracture-growth limiting mechanisms augmented by mineback tests and other studies performed to visually examine hydraulic fractures. These height-growth limiting mechanisms, which are supported by the mapping data, provide insight into why hydraulic fractures are longer laterally and more constrained vertically. This information can be used to improve models, optimize fracturing, and provide definitive data for regulators and interest groups.

Field et al. (2014). “Air quality concerns of unconventional oil and natural gas production” Environmental science process and impacts. **16**: 954-969

Increased use of hydraulic fracturing (“fracking”) in unconventional oil and natural gas (O & NG) development from coal, sandstone, and shale deposits in the United States (US) has created environmental concerns over water and air quality impacts. In this perspective we focus on how the production of unconventional O & NG affects air quality. We pay particular attention to shale gas as this type of development has transformed natural gas production in the US and is set to become important in the rest of the world. A variety of potential emission sources can be spread over tens of thousands of acres of a production area and this complicates assessment of local and regional air quality impacts. We outline upstream activities including drilling, completion and production. After contrasting the context for development activities in the US and Europe we explore the use of inventories for determining air emissions. Location and scale of analysis is important, as O & NG production emissions in some US basins account for nearly 100% of the pollution burden, whereas in other basins these activities make up less than 10% of total air emissions. While emission inventories are beneficial to quantifying air emissions from a particular source category, they do have limitations when determining air quality impacts from a large area. Air monitoring is essential, not only to validate inventories, but also to measure impacts. We describe the use of measurements, including ground-based mobile monitoring, network stations, airborne, and satellite platforms for measuring air quality impacts. We identify nitrogen oxides, volatile organic compounds (VOC), ozone, hazardous air pollutants (HAP), and methane as pollutants of concern related to O & NG activities. These pollutants can contribute to air quality concerns and they may be regulated in ambient air, due to human health or climate forcing concerns. Close to well pads, emissions are concentrated and exposure to a wide range of pollutants is possible. Public health protection is improved when emissions are controlled and facilities are located away from where people live. Based on lessons learned in the US we outline an approach for future unconventional O & NG development that includes regulation, assessment and monitoring.

Flat and Payne (2014). “Curtailment first: why climate change and the energy industry suggest a new allocation paradigm is needed for water utilized in hydraulic fracturing”. University of Richmond law review. **48**: 101-128

Water, always necessary, is becoming less available. The Organization for Economic Cooperation and Development (“OECD”) predicts water use will increase by 55% between 2000 and 2050, and that by 2050, over 40% of the world’s population “will live in river basins under severe water stress.” Climate change is making this worse. Approximately 486 million people will be exposed to water scarcity or aggravated scarcity even if the average global temperature rise is limited to 2°C. If temperatures rise further, the numbers increase. Looking at food production globally, a quarter of croplands lack adequate water, and 56% of irrigated land is under high to extremely high water stress. The mechanisms put into place to manage scarcity in a water constrained world will have significant impacts on human populations, agriculture, energy, and the environment. This article addresses these issues specifically with regard to hydraulic fracturing activities, providing an overview of current water projections, a discussion of how water is utilized today, and an explanation of why hydraulic fracturing is different from other industrial uses. The article then provides an overview of how water allocation decisions are currently made in representative states and proposes a new paradigm for allocations associated with hydraulic fracturing.

Flavin and Kitasei (2010). “The Role of Natural Gas in a Low-Carbon Energy Economy”. Worldwatch

Institute

Growing estimates of natural gas resources, including a new category of ―unconventional‖ gas, suggest that accessible supplies of this least carbon-intensive of the fossil fuels may be far more abundant than previously assumed. This unexpected development creates opportunities for deploying natural gas in a variety of sectors—including power generation, industry, and transportation—to help displace oil and coal, thereby reducing greenhouse gas emissions and improving air quality. Beyond providing a cleaner, market-ready alternative to oil and coal, natural gas can facilitate the systemic changes that will underpin the development of a more energy-efficient and renewable energy-based economy. For example, smaller, distributed generators, many producing usable heat as well as electricity, could generate economical, low-emission replacements for a large fraction of currently operating conventional power plants, providing flexible back-up to the variable output of the solar and wind generators that will comprise a growing share of the electric power system. All of these gains are contingent on the development of sound public policy to incentivize and guide the transition. Critical policy decisions that are now pending include: electric power regulation at the local, state, and federal levels; effective federal and state oversight of the natural gas exploration and extraction process; future Environmental Protection Agency (EPA) regulatory decisions under the U.S. Clean Air Act; and putting a price on greenhouse gas emissions.

This first paper from the Worldwatch Institute's Natural Gas and Sustainable Energy Initiative provides an overview of the role that natural gas currently plays in the energy system and a roadmap for the role that gas could play in spurring the transition to a low-carbon economy in the decades ahead. Future papers will focus on a range of specific issues, from the local environmental problems caused by shale gas development to options for integrating natural gas generation with large wind farms.

Flewelling et al. (2013). "Hydraulic fracture height limits and fault interactions in tight oil and gas formations". Geophysical research letters. **40**: 3602–3606

The widespread use of hydraulic fracturing (HF) has raised concerns about potential upward migration of HF fluid and brine via induced fractures and faults. We developed a relationship that predicts maximum fracture height as a function of HF fluid volume. These predictions generally bound the vertical extent of microseismicity from over 12,000 HF stimulations across North America. All microseismic events were less than 600m above well perforations, although most were much closer. Areas of shear displacement (including faults) estimated from microseismic data were comparatively small (radii on the order of 10m or less). These findings suggest that fracture heights are limited by HF fluid volume regardless of whether the fluid interacts with faults. Direct hydraulic communication between tight formations and shallow groundwater via induced fractures and faults is not a realistic expectation based on the limitations on fracture height growth and potential fault slip.

Flewelling and Shama (2014). "Constraints on Upward Migration of Hydraulic Fracturing Fluid and Brine". Groundwater. **52**(1): 9–19

Recent increases in the use of hydraulic fracturing (HF) to aid extraction of oil and gas from black shales have raised concerns regarding potential environmental effects associated with predictions of upward migration of HF fluid and brine. Some recent studies have suggested that such upward migration can be large and that timescales for migration can be as short as a few years. In this article, we discuss the physical constraints on upward fluid migration from black shales (e.g., the Marcellus, Bakken, and Eagle

Ford) to shallow aquifers, taking into account the potential changes to the subsurface brought about by HF. Our review of the literature indicates that HF affects a very limited portion of the entire thickness of the overlying bedrock and therefore, is unable to create direct hydraulic communication between black shales and shallow aquifers via induced fractures. As a result, upward migration of HF fluid and brine is controlled by preexisting hydraulic gradients and bedrock permeability. We show that in cases where there is an upward gradient, permeability is low, upward flow rates are low, and mean travel times are long (often >106 years). Consequently, the recently proposed rapid upward migration of brine and HF fluid, predicted to occur as a result of increased HF activity, does not appear to be physically plausible. Unrealistically high estimates of upward flow are the result of invalid assumptions about HF and the hydrogeology of sedimentary basins.

Fontenot et al. (2013). "An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation". Environmental Science and Technology. **47**(17): 10032–10040

Natural gas has become a leading source of alternative energy with the advent of techniques to economically extract gas reserves from deep shale formations. Here, we present an assessment of private well water quality in aquifers overlying the Barnett Shale formation of North Texas. We evaluated samples from 100 private drinking water wells using analytical chemistry techniques. Analyses revealed that arsenic, selenium, strontium and total dissolved solids (TDS) exceeded the Environmental Protection Agency's Drinking Water Maximum Contaminant Limit (MCL) in some samples from private water wells located within 3 km of active natural gas wells. Lower levels of arsenic, selenium, strontium, and barium were detected at reference sites outside the Barnett Shale region as well as sites within the Barnett Shale region located more than 3 km from active natural gas wells. Methanol and ethanol were also detected in 29% of samples. Samples exceeding MCL levels were randomly distributed within areas of active natural gas extraction, and the spatial patterns in our data suggest that elevated constituent levels could be due to a variety of factors including mobilization of natural constituents, hydrogeochemical changes from lowering of the water table, or industrial accidents such as faulty gas well casings.

Fontenot et al. (2014). "Response to Comment on "An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation". Environmental Science and Technology. **48**(6): 3597–3599

Here we provide a response to McHugh et al. and provide additional clarification.

Food and Water Europe (2012). "Fracking: The new global water crisis"

Within the past decade, technological advances in horizontal drilling and hydraulic fracturing, or "fracking," have enabled the oil and gas industry to extract large quantities of oil and natural gas from shale formations in the United States. However, the practice has proven controversial. Pollution from modern drilling and fracking has caused widespread environmental and public health problems and created serious, long-term risks to underground water resources. In this report, Food & Water Europe reviews the risks and costs of shale development that have been demonstrated in the United States, including economic costs that run counter to industry-backed claims about the economic benefits of the practice. Food & Water Europe then summarizes the state of shale development in six selected countries:

France, Bulgaria, Poland, South Africa, China and Argentina.

Freyman (2014). “Hydraulic fracturing & water stress: Water Demand by the Numbers”. Ceres

This Ceres research paper analyzes escalating water demand in hydraulic fracturing operations across the United States and western Canada. It evaluates oil and gas company water use in eight regions with intense shale energy development and the most pronounced water stress challenges. The report also provides recommendations to investors, lenders and shale energy companies for mitigating their exposure to water sourcing risks, including improvement of on-the-ground practices. The research is based on well data available at FracFocus.org and water stress indicator maps developed by the World Resources Institute, where water stress denotes the level of competition for water in a given region.

Friends of the Earth Europe (2012). “Shale Gas, Unconventional and unwanted: the case against shale gas”

On the one hand, shale gas is promoted as a safe, clean energy source that can help Europe increase its energy security and provide an affordable transition to a low carbon economy. The hype accompanying the entry into Europe of shale gas as a possible energy ‘game changer’ derives from the rapid development of the sector in the US over the last 10 years. Industry sees it as a potential opportunity. But, as the US experience has shown, serious environmental and human health concerns continue to dog shale gas drilling. Chief among these are threats to groundwater quality, concerns about how much water is needed, worries over fracking’s impacts on air quality and its stimulation of earthquakes and its potential impact on climate change, which could be comparable to coal. According to the International Energy Agency (IEA), the development of the shale gas industry would put our CO2 emissions on a “trajectory consistent with a probable temperature rise of more than 3.5 degrees Celsius in the long term”. This briefing will examine some of the uncertainties around shale gas, including the gaps in existing EU legal and regulatory frameworks, the realities of enforcing an effective regulatory framework, the cost pressures, and the influence of the shale gas lobby. It will also examine the implications of European support for shale gas on the global energy picture, in particular on the impacts in developing countries. In that perspective, this briefing will argue shale gas cannot contribute to the achievement of the Millennium Development Goals, in particular the goal to achieve environmental sustainability.

Fry et al (2012). “Fracking vs Faucets: Balancing Energy Needs and Water Sustainability at Urban Frontiers”. Environmental Science and Technology. **46**: 7444−7445

Newly accessible shale deposits have dramatically increased global gas reserves and are touted as a bridge to a clean energy future. For example, in the U.S., where shale gas is projected to comprise 49% of national natural gas production by 2035, proponents argue that shale gas production can provide energy independence, create employment, and stimulate regional economies. Amidst this optimism, however, are growing concerns about the effects of shale gas extraction, and, in particular, hydraulic fracturing or “fracking”, on water resources−concerns that are magnified in urban areas where human populations and extractive operations overlap. We believe that water conflicts arising from expansion of the U.S. shale gas industry foreshadow developments in other countries with cities situated over large shale-gas deposits, including Diyarbakir, Turkey; Ahmedabad, India; and Chongqing, China. We use the Dallas-Fort Worth (DFW) Metroplex, Texas, to illustrate challenges associated with balancing energy

needs and water sustainability in cities with semiarid to arid climates.

GACE (2013). “Fracking for Shale Gas Production. A contribution to its appraisal in the context of energy and environment policy”. SRU Statement No. 18

Production of shale gas using the so-called fracking technology is currently the subject of a heated energy and environmental policy debate. Legal decisions on appropriate precautions against environmental risks arising from fracking will shortly have to be taken at both national and European level. There are however various other questions about the justifiability of fracking which need to be clarified before any commercial production of shale gas. The SRU regards fracking as a case for applying the precautionary principle). The precautionary principle justifies state action to avoid risks even if there is only abstract reason for concern about the possible occurrence of damage. Furthermore, risk assessment is also a process of weighing the potential benefits of a technology for society against its risks. In the case of shale gas production in Germany, the latter include risks for important legally protected goods in particular: water, human health, soil, biological diversity and climate. The conservation of drinking water and groundwater deserve special attention in this context. This report is based on existing studies but also raises further questions. In view of the great energy policy hopes attached to the production of shale gas, it is first important to establish whether and under what conditions shale gas can in fact make a positive contribution to the *German Energiewende* or may run counter to its objectives.

Gagnon (2014). “What are the interactions between unconventional gas resources and water resources? Input quality and quantity requirements and water treatment needs and impacts. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process”

Both quality and quantity of water are of great public concern and the government has an obligation to ensure water safety is upheld, regardless of the decision made regarding hydraulic fracturing. In the case that development of hydraulic fracturing is pursued, the following items will need to be addressed through a robust, responsive and transparent regulatory environment, and must be consistent with the Nova Scotia Environment Act: Transparency and understanding of operations and processing chemicals used, and identification of any potential adverse impacts on water quality (both ground and surface water) due to operations; Detailed analysis of water demands prior to and during operations on a case-by-case basis; and Transparency and upfront detailing of procedures and requirements for wastewater disposal and/or treatment.

GAO (2012). “Oil and Gas. Information on Shale Resources, Development, and Environmental and Public Health Risks”

This report describes what is known about the size of shale oil and gas resources in the United States and the amount produced from 2007 through 2011—the years for which data were available—and the environmental and public health risks associated with development of shale oil and gas. Estimates of the size of shale oil and gas resources in the United States by the Energy Information Administration (EIA), U.S. Geological Survey (USGS), and the Potential Gas Committee—three organizations that estimate the size of these resources—have increased over the last 5 years, which could mean an increase in the

nation's energy portfolio. Oil and gas development, whether conventional or shale oil and gas, pose inherent environmental and public health risks, but the extent of these risks associated with shale oil and gas development is unknown, in part, because the studies GAO reviewed do not generally take into account the potential long-term, cumulative effects.

Gardner (2014) "Discussion Paper: Petroleum Operations, Costs and Opportunities in Nova Scotia. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process"

This paper provides a basic overview of the process of exploring for and producing hydrocarbons, with a focus on economic costs and benefits, not technical matters. It describes generally what is involved in each phase of activity – exploration, field development, production and abandonment – setting out the costs and benefits including opportunities for involvement by the local workforce and contractors. Other papers cover technical matters in greater detail, including such topics as geology and resource potential, legal and regulatory considerations, and potential environmental and health impacts. The discussion assumes natural gas discoveries, although it is possible that oil may also be discovered.

The technical information in this paper is derived from published materials, with cost and local content estimates for conducting the various hydrocarbon activities based on information obtained directly from industry sources in Atlantic Canada and elsewhere in North America. Providing even a rough guide to what onshore petroleum exploration and development could mean for Nova Scotia requires a range of assumptions, given the limited onshore activity in the Province. Accordingly, the reader is cautioned that the activity and associated cost and content estimates are highly speculative and should at best be considered indicative, rather than definitive, of what could occur if this activity were ever to be pursued in Nova Scotia.

Gassait et al. (2013). "Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales". Water Resources Research. **49**: 8310–8327

Hydraulic fracturing, used to economically produce natural gas from shale formations, has raised environmental concerns. The objective of this study is to assess one of the largely unexamined issues, which is the potential for slow contamination of shallow groundwater due to hydraulic fracturing at depth via fluid migration along conductive faults. We compiled publically available data of shale gas basins and hydraulic fracturing operations to develop a two-dimensional, single-phase, multispecies, density-dependent, finite-element numerical groundwater flow and mass transport model. The model simulates hydraulic fracturing in the vicinity of a permeable fault zone in a generic, low-recharge, regional sedimentary basin in which shallow, active groundwater flow occurs above nearly stagnant brine. A sensitivity analysis of contaminant migration along the fault considered basin, fault and hydraulic fracturing parameters. Results show that specific conditions are needed for the slow contamination of a shallow aquifer: a high permeability fault, high overpressure in the shale unit, and hydrofracturing in the upper portion of the shale near the fault. Under such conditions, contaminants from the shale unit reach the shallow aquifer in less than 1000 years following hydraulic fracturing, at concentrations of solutes up to 90% of their initial concentration in the shale, indicating that the impact on groundwater quality could be significant. Important implications of this result are that hydraulic fracturing should not be carried out near potentially conductive faults, and that impacts should be monitored for long time spans. Further work is needed to assess the impact of multiphase flow on contaminant transport along natural preferential pathways.

Geiser et al. (2012). Beyond “dots in a box”: an Empirical View of Reservoir Permeability with Tomographic Fracture Imaging”. First Break. 63-69

Much of the research on reservoir permeability field has tended to focus on that of the rock matrix. While it has long been recognized that fractures are an important element of the total rock permeability due to imaging difficulties, the zones of high fracture density and permeability, sometimes referred to as fairways, have been less studied. Our technology, Tomographic Fracture Imaging (TFI) which uses Seismic Emission Tomography (SET) and surface based seismic networks now allows us to directly image and map the 4D behavior of fracture/fault systems which form the fairways that are the dominant paths for fluid flow. TFI hows that the reservoir permeability field consists of complex fracture networks formed from existing joint systems and typically have kilometer scale lateral and vertical dimensions.

Geng et al. (2013). “Migration of High-Pressure Air during Gas Well Drilling in the Appalachian Basin”. Journal of Environmental Engineering. **140**(5)

We present the details of a numerical model simulating the migration of pressurized air used for pneumatic drilling of a well in an aquifer. We used an incident that occurred in West Virginia during June 2012 as a basis for making the simulations realistic. We developed a 3D conceptual model using the multipurpose model TOUGH2 to simulate the events during this incident. Input parameters for the model were obtained from field measurements, and a number of reasonable assumptions were made for other parameters. Our results showed that compressed air from a drilling well is capable of creating a high pressure gradient in groundwater at hundreds of meters from the drill hole, even if the air leakage from the drilling well occurs in a confined aquifer, and even if the leakage duration is only 2 h. Therefore, one way to prevent the pressure buildup in the surrounding aquifers is through emplacement of observation wells before drilling, which would alert the drillers to any unusual pressure buildup inside the confined aquifer. However, air leakage in unconfined aquifers seems to have a much smaller spatial extent (less than tens of meters). Sensitivity analysis revealed that air pressure, fracture permeability, and injection time are critical parameters for the propagation of air.

Gilmore et al. (2014). ”Transport of Hydraulic Fracturing Water and Wastes in the Susquehanna River Basin, Pennsylvania”. Journal of Environmental Engineering. **140**(5)

The development of the Marcellus Shale gas play in Pennsylvania and the northeastern United States has resulted in significant amounts of water and wastes transported by truck over roadways. This study used geographic information systems (GIS) to quantify truck travel distances via both the preferred routes (minimum distance while also favoring higher-order roads) as well as, where available, the likely actual distances for freshwater and waste transport between pertinent locations (e.g., gas wells, treatment facilities, freshwater sources). Results show that truck travel distances in the Susquehanna River Basin are greater than those used in prior life-cycle assessments of tight shale gas. When compared to likely actual transport distances, if policies were instituted to constrain truck travel to the closest destination and higher-order roads, transport mileage reductions of 40–80% could be realized. Using reasonable assumptions of current practices, greenhouse gas (GHG) emissions associated with water and waste hauling were calculated to be 70–157 MT CO2eq per gas well. Furthermore, empty so-called backhaul trips, such as to freshwater withdrawal sites or returning from deep well injection sites, were found to increase emissions by an additional 30%, underscoring the importance of including return trips in the analysis. The results should inform future life-cycle assessments of tight shale gases in managed watersheds and help local and regional governments plan for impacts of transportation on local infrastructure.

Glazer et al. (2014) “Potential for Using Energy from Flared Gas for On-Site Hydraulic Fracturing Wastewater Treatment in Texas”. Environmental Science and Technology Letters. **1**(7): 300–304

Hydraulic fracturing faces several environmental challenges: the process is highly water-intensive, generates significant volumes of wastewater, and is associated with widespread flaring of coproduced natural gas. One possible solution to simultaneously mitigate these challenges is to use energy from flared natural gas for on-site wastewater treatment, thereby reducing flared gas, volumes of wastewater, and volumes of freshwater necessary for subsequent shale production as treated wastewater could be reused. This study builds an analytical framework for understanding the feasibility of this approach. We concluded that the thermal energy required to treat wastewater from the first 10 days after well completion is 148000−865000 MJ (140−820 MMBTU) and would generate 750−6800 m3 of treated water. Additionally, using the volume of flared natural gas in Texas in 2012, the theoretical maximal volume of treated water that could be generated was calculated to be 180−540 million m3, representing approximately 3−9% of the state’s annual water demand for municipal purposes or 1−2.4% of total statewide water demand for all purposes (Water for Texas: 2012 State Water Plan; Texas Water Development Board: Austin, TX, 2012).

Goodwin et al. (2014). “Water Intensity Assessment of Shale Gas Resources in the Wattenberg Field in Northeastern Colorado”. Environmental Science and Technology. **48**(10): 5991–5995

Efficient use of water, particularly in the western U.S., is an increasingly important aspect of many activities including agriculture,urban, and industry. As the population increases and agriculture and energy needs continue to rise, the pressure on water and other natural resources is expected to intensify. Recent advances in technology have stimulated growth in oil and gas development, as well as increasing the industry’s need for water resources. This study provides an analysis of how efficiently water resources are used for unconventional shale development in Northeastern Colorado. The study is focused on the Wattenberg Field in the Denver−Julesberg Basin. The 2000 square mile field located in a semiarid climate with competing agriculture, municipal, and industrial water demands was one of the first fields where widespread use of hydraulic fracturing was implemented. The consumptive water intensity is measured using a ratio of the net water consumption and the net energy recovery and is used to measure how efficiently water is used for energy extraction. The water and energy use as well as energy recovery data were collected from 200 Noble Energy Inc. wells to estimate the consumptive water intensity. The consumptive water intensity of unconventional shale in the Wattenberg is compared with the consumptive water intensity for extraction of other fuels for other energy sources including coal, natural gas, oil, nuclear, and renewables. 1.4 to 7.5 million gallons is required to drill and hydraulically fracture horizontal wells before energy is extracted in the Wattenberg Field. However, when the large short-term total freshwater−water use is normalized to the amount of energy produced over the lifespan of a well, the consumptive water intensity is estimated to be between 1.8 and 2.7 gal/MMBtu and is similar to surface coal mining.

Goldstein et al. (2014). “The Role of Toxicological Science in Meeting the Challenges and Opportunities of Hydraulic Fracturing”. Toxicological Sciences. **139**(2): 271–283

We briefly describe how toxicology can inform the discussion and debate of the merits of hydraulic fracturing by providing information on the potential toxicity of the chemical and physical agents associated with this process, individually and in combination. We consider upstream activities related to bringing chemical and physical agents to the site, on-site activities including drilling of wells and containment of agents injected into or produced from the well, and downstream activities including the flow/removal of hydrocarbon products and of produced water from the site. A broad variety of chemical and physical agents are involved. As the industry expands this has raised concern about the potential for toxicological effects on ecosystems, workers, and the general public. Response to these concerns requires a concerted and collaborative toxicological assessment. This assessment should take into account the different geology in areas newly subjected to hydraulic fracturing as well as evolving industrial practices that can alter the chemical and physical agents of toxicological interest. The potential for ecosystem or human exposure to mixtures of these agents presents a particular toxicological and public health challenge. These data are essential for developing a reliable assessment of the potential risks to the environment and to human health of the rapidly increasing use of hydraulic fracturing and deep underground horizontal drilling techniques for tightly bound shale gas and other fossil fuels. Input from toxicologists will be most effective when employed early in the process, before there are unwanted consequences to the environment and human health, or economic losses due to the need to abandon or rework costly initiatives.

Gorody (2012). “Factors affecting the variability of stray gas concentration and composition in groundwater”. Environmental Geosciences. **19**(1): 17-31.

Identifying the source of stray gas in drinking water supplies principally relies on comparing the gas composition in affected water supplies with gas samples collected in shows while drilling, produced gases, casing head gases, pipeline gases, and other potential point sources. However, transport dynamics of free and dissolved gas migration in groundwater aquifers can modify both the concentration and the composition of point source stray gases flowing to aquifers and occurring in the groundwater environment. Accordingly, baseline and forensic investigations related to stray gas sources need to address the effects of mixing, dilution, and oxidation reactions in the context of regional and local hydrology. Understanding and interpreting such effects are best addressed by collecting and analyzing multiple samples from baseline groundwater investigations, potential point sources, and impacted water resources.

Several case studies presented here illustrate examples of the natural variability in gas composition and concentration data evident when multiple samples are collected from produced gases, casing head gases, and baseline groundwater investigations. Results show that analyses of single samples from either potential contaminant point sources or groundwater and surface water resources may not always be sufficient to document site-specific baseline conditions. Results also demonstrate the need to consistently sample and analyze a variety of baseline groundwater and gas composition screening parameters. A multidisciplinary approach is the best practice for differentiating among the effects of fluid and gas mixing, dilution, and natural attenuation.

Goss (2007). “Evaluating the historical impacts of landscape transformation on hydrologic fluxes for

environmental assessment and modeling” PhD Thesis, Purdue University.

Land use/cover change can have a profound impact on the hydrologic cycle, with significant consequences for both water resources management and ecosystem services. However, a lack of concurrent land use/cover and water flux data for large watersheds over historical time scales has largely prevented scientists and water resource managers from being able to perform detailed hydrologic analyses spanning 50 or more years. To overcome the limitations provided by a lack of historical land use/cover data, a “backcast” method was developed to estimate historical land cover using proxies from U.S. Census data and agricultural statistics. This backcasting method was applied to the Muskegon River Watershed in southwestern Michigan. Land cover backcasts from 1910 to 1978 were then used as inputs into a macroscale water and energy balance model, the Variable Infiltration Capacity (VIC) model. Model results for simulations run using identical climate records but different land cover data suggest that widespread agricultural abandonment and afforestation have dramatically altered the seasonal water balance of the basin. Also, urbanization over the last century has changed the ratio of stream flow provided by overland flow versus near surface baseflow. However, despite strong patterns of change at sub-watershed scales, the model predicted no significant overall change in mean monthly or annual stream flow for the watershed as a whole. Thus water resources managers focusing solely on watershed-scale stream flow for impact assessment would not detect fundamental alterations in the water balance of the region. Future refinements of the method developed here to analyze the hydrologic dynamics of large watersheds will include modification of proxy datasets used to backcast land cover change and enhancement of the parameterization of vegetation and urban areas within the hydrologic model. Overall, this approach allows water resource managers to develop large-scale assessments of hydrologic changes resulting from land cover variations, using data that are available for most large watersheds in the U.S.

Gradient Corp (2013) “National Human Health Risk Evaluation for Hydraulic Fracturing Fluid Additives”. Prepared for Halliburton Energy Services, Inc.

The purpose of this report is to addressed whether adverse human health impacts relating to drinking water could be associated with HF as a result of their intended use (to aid in fracturing deeply buried hydrocarbon deposits) or in the event that there were unintended surface releases (spills) and to assess the potential impacts on drinking water in a broad range of shale plays and other tight formations across the contiguous United States.

Based on the foregoing analysis, we conclude that when used in their intended manner in tight oil and gas formations, i.e., pumped into a subsurface formation to induce fractures in the target formation, HF fluids are not expected to pose adverse risk to human health because wells are designed and constructed to prevent HF fluids in the well from coming in contact with shallow aquifers and it is implausible that the fluids pumped into the target formation would migrate from the target formation through overlying bedrock to reach shallow aquifers. Even in the event of surface spills, inherent environmental dilution mechanisms would, with a high degree of confidence (based on our probabilistic analysis covering wide ranging conditions), reduce concentrations of HF chemical constituents in either groundwater or surface water below levels of human health concern (RBCs), such that adverse human health impacts are not expected to be significant. Our conclusions are based on examining a broad spectrum of conditions spanning HF operations in tight oil and gas formations across the country. By extension, these conclusions would apply more broadly under environmental conditions (including geologic formations) in other parts of the world that are similar to those we have examined in the US.

Gregory et al. (2011). “Global Water Sustainability: Water Management Challenges Associated with the Production of Shale Gas by Hydraulic Fracturing” Elements. **7**(3): 181-186

Development of unconventional, onshore natural gas resources in deep shales is rapidly expanding to meet global energy needs. Water management has emerged as a critical issue in the development of these inland gas reservoirs, where hydraulic fracturing is used to liberate the gas. Following hydraulic fracturing, large volumes of water containing very high concentrations of total dissolved solids (TDS) return to the surface. The TDS concentration in this wastewater, also known as “flowback,” can reach 5 times that of sea water. Wastewaters that contain high TDS levels are challenging and costly to treat. Economical production of shale gas resources will require creative management of flowback to ensure protection of groundwater and surface water resources. Currently, deep-well injection is the primary means of management. However, in many areas where shale gas production will be abundant, deep-well injection sites are not available. With global concerns over the quality and quantity of fresh water, novel water management strategies and treatment technologies that will enable environmentally sustainable and economically feasible natural gas extraction will be critical for the development of this vast energy source.

Groundwater Protection Council (2011). “State Oil and Gas Agency Groundwater Investigations and Their Role in Advancing Regulatory Reforms. A Two-State Review: Ohio and Texas”

State agencies are responsible for investigating and addressing complaints about groundwater contamination that may be caused by oilfield activities. State agency directors generally have the authority to suspend oilfield operations, order corrective action, and order remediation or replacement of disrupted groundwater supplies when the responsible parties have been identified. State agencies identify the activities that cause groundwater contamination incidents and evaluate contributory patterns over time. These investigations can be an important diagnostic tool for supporting regulatory reform and prioritizing inspections of specifically identified higher-risk oilfield activities. States evaluate the overall effectiveness of their current regulatory schemes by monitoring groundwater incident trends over a given time period. This report evaluates agency groundwater investigation findings in two states, Ohio and Texas.During the 25 year study period (1983-2007),

Ohio documented 185 groundwater contamination incidents caused by historic or regulated oilfield activities. Of those, 144 groundwater contamination incidents were caused by regulated activities, and 41 incidents resulted from orphaned well leakage. Seventy-six of the incidents caused by regulated activities (52.7 percent) occurred during the first five years of the study (1983-1987). When viewed in five year increments, the number of incidents caused by regulated activities declined significantly (90.1 percent) during the study period. Seventy-eight percent (113) of all documented regulated activity incidents were caused by drilling or production phase activities. Improper construction or maintenance of reserve pits was the primary source of groundwater contamination, which accounted for 43.8 percent of all regulated activity incidents (63) in Ohio. During the 16 year study period (1993-2008), Texas documented 211 groundwater contamination incidents. More than 35 percent of these incidents (75) resulted from waste management and disposal activities including 57 legacy incidents caused by produced water disposal pits that were banned in 1969 and closed no later than 1984. Releases that occurred during production phase activities including storage tank or flow line leaks resulted in 26.5 percent of all regulated activity incidents (56) in Texas.

Griffiths (2007). “Protecting Water, Producing Gas. Minimizing the Impact of Coalbed Methane and Other Natural Gas Production on Alberta’s Groundwater”

As the supply of conventional gas declines, shallow gas and unconventional sources of gas, especially coalbed methane (CBM), are being developed. Landowners are worried that these new wells may impact fresh groundwater, which supplies the water for over 90% of rural Albertans. Water resources are already stressed in parts of central and southern Alberta due to high population density and agricultural use, and climate change is likely to cause major water shortages in the future. The report; gives an overview of natural gas production in Alberta, examines why Albertans and especially rural landowners are concerned about the protection of water, describes the main types of gas production in Alberta, and identifies some measures that landowners would like energy companies to adopt to reduce the risk to water of contamination. Finally recommendations in the last chapter are addressed to government. Additional measures are proposed to fully protect fresh water aquifers and ensure there is no dewatering or contamination.

GWPC and ALL consulting (2009). “Modern shale gas development in the United States A primer”

Natural gas production from hydrocarbon-rich shale formations, known as “shale gas”, is one of the most rapidly expanding trends in onshore domestic oil and gas exploration and production today. In some areas, this has included bringing drilling and production to regions of the country that have seen little or no activity in the past. New oil and gas developments bring changes to the environmental and socio-economic landscape, particularly in those areas where gas development is a new activity. With these changes have come questions about the nature of shale gas development, the potential environmental impacts, and the ability of the current regulatory structure to deal with this development. Regulators, policy makers, and the public need an objective source of information on which to base answers to these questions and decisions about how to manage the challenges that may accompany shale gas development. This Primer endeavors to provide much of that information. It describes the importance of shale gas in meeting the future energy needs of the United States (U.S.), including its role in alternative energy strategies and reducing greenhouse gas (GHG) emissions. The Primer provides an overview of modern shale gas development, as well as a summary of federal, state, and local regulations applicable to the natural gas production industry, and describes environmental considerations related to shale gas development. The Primer is intended to serve as a technical summary document, including geologic information on the shale gas basins in the U.S. and the methods of shale gas development. By providing an overview of the regulatory framework and the environmental considerations associated with shale gas development, it will also help facilitate the minimization and mitigation of adverse environmental impacts. By so doing, the Primer can serve as an instrument to facilitate informed public discussions and to support sound policy-making decisions by government.

Hall (2013). “Hydraulic Fracturing Contamination Claims: Problems of Proof”. Ohio State Law Journal Furthermore. **74**: 71-85

Hydraulic fracturing is controversial. Many people believe that hydraulic fracturing has caused contamination of groundwater and that the process should be prohibited because it is likely to cause additional contamination if it continues to be used. Many other people believe that hydraulic fracturing has not caused contamination and that little additional regulation is needed because fracturing is a useful process that poses little risk. Notably, this disagreement is not merely a difference of opinion regarding how society should balance economic development and environmental protection. Instead, the disagreement concerns facts— whether fracturing already has caused contamination and how much risk the process entails. This Essay contains five Parts. Parts II and III discuss what hydraulic fracturing is and the reasons why proving contamination claims is often difficult. The remaining Parts discuss ways to deal with two "problems of proof." Specifically, Part IV examines new state regulations that require or encourage baseline testing of groundwater before oil or gas drilling takes place. In the past, the lack of such testing has often been a problem when evaluating contamination claims. The fifth Part of this Essay discusses Lone Pine orders, a procedure that courts can use in an effort to quickly resolve cases in which plaintiffs lack evidence to support an essential element of their claim.

Haluszczak et al. (2013). "Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA". Applied Geochemistry. **28**: 55–61

Large quantities of highly saline brine flow from gas wells in the Marcellus Formation after hydraulic stimulation (''fracking''). This study assesses the composition of these flowback waters from the Marcellus shale in Pennsylvania, USA. Concentrations of most inorganic components of flowback water (Cl, Br, Na, K, Ca, Mg, Sr, Ba, Ra, Fe, Mn, total dissolved solids, and others) increase with time from a well after hydraulic stimulation. Based on results in several datasets reported here, the greatest concentration of Cl in flowback water is 151,000 mg/L. For total Ra (combined 226Ra and 228Ra) in flowback, the highest level reported is 6540 pCi/L. Flowback waters from hydraulic fracturing of Marcellus wells resemble brines produced from conventional gas wells that tap into other Paleozoic formations in the region. The Br/Cl ratio and other parameters indicate that both types of brine formed by the evaporation of seawater followed by dolomitization, sulfate reduction and subsurface mixing with seawater and/or freshwater. Trends and relationships in brine composition indicate that (1) increased salt concentration in flowback is not mainly caused by dissolution of salt or other minerals in rock units, (2) the flowback waters represent a mixture of injection waters with highly concentrated in situ brines similar to those in the other formations, and (3) these waters contain concentrations of Ra and Ba that are commonly hundreds of times the US drinking water standards.

Hansen et al. (2013). "Water Resource Reporting and Water Footprint from Marcellus Shale Development in West Virginia and Pennsylvania".

The findings of this report suggest that the volumes of water used to fracture Marcellus Shale gas wells are substantial and the quantities of waste generated are significant. While West Virginia and Pennsylvania have recently taken steps to improve data collection and reporting related to gas development, critical gaps persist that prevent researchers, policymakers, and the public from attaining a full picture of trends. Given this, it is highly likely that much more water is being withdrawn and more waste is being generated than is known.

While a considerable amount of flowback fluid is now being reused and recycled, the data suggest that it still displaces only a small percentage of freshwater withdrawals, which will limit its benefits except in times of drought where small percentages could be important. While West Virginia and Pennsylvania are generally water-rich states, these findings indicate that horizontal drilling and hydraulic fracturing operations could have significant impacts on water resources in more arid areas of the country. However, if existing techniques are applied to the much deeper and thicker Utica Shale that lies below the Marcellus, than even water-rich regions could find that shale gas operations make water supplies vulnerable.

In short, the true scale of water impacts can still only be estimated, and considerable improvements in industry reporting, data collection and sharing, and regulatory enforcement are needed. The challenge of appropriately handling a growing volume of waste to avoid environmental harm will continue to loom large unless such steps are taken.

Hayes and Ritcey (2014). "Discussion Paper: The Potential Oil and Gas Resource Base in Nova Scotia Accessible by Hydraulic Fracturing. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process"

This paper looks at the resource and infrastructure potential for onshore oil and gas extraction in Nova Scotia including the use of hydraulic fracturing techniques. The physical geology does recognize resource potential for conventional and unconventional oil and gas in specific areas (sedimentary basins) in the Province, mostly in rural areas. Limited on-shore petroleum development has occurred to date, but no commercial oil and gas production has been established. Local and export markets exist for both oil and natural gas with demand growing.

As knowledge of the subsurface, including sedimentary rocks and hydrocarbons, is extremely limited, it is very difficult to quantify the potential or even rank the various basins in terms of overall prospectivity. The shales in basins closest to New Brunswick are of most interest to developers to date because New Brunswick basins have demonstrated commercial production of both gas and oil, and pipeline infrastructure is in place. Using published information, potential gas volumes have been estimated at 17-69 TCF in the Windsor- Kennetcook Basin and coal bed methane volumes at .28-1.18 TCF in the Sydney, Stellarton and Cumberland Basins. Other basins may or may not have potential but very limited data or information exists. Exploration activity is likely to be limited, at least for the next several years, until such time as the moratorium on hydraulic fracturing is reviewed, additional seismic and well data are acquired, and the complexities of developing frontier basins are addressed.

Heisig and Scott (2013). "Occurrence of methane in groundwater of south-central New York State, 2012—Systematic evaluation of a glaciated region by hydrogeologic setting". U.S. Geological Survey Scientific Investigations Report 2013–5190. 32

A survey of methane in groundwater was undertaken to document methane occurrence on the basis hydrogeologic setting within a glaciated 1,810-square-mile area of south-central New York along the Pennsylvania border. Sixty-six wells were sampled during the summer of 2012. All wells were at least 1 mile from any known gas well (active, exploratory, or abandoned). Results indicate strong positive and negative associations between hydrogeologic settings and methane occurrence. The hydrogeologic setting classes are based on topographic position (valley and upland), confinement or non-confinement of groundwater by glacial deposits, well completion in fractured bedrock or sand and gravel, and hydrogeologic subcategories. Only domestic wells and similar purposed supply wells with well-construction and log information were selected for classification. Field water-quality characteristics (pH, specific conductance, dissolved oxygen, and temperature) were measured at each well, and samples were collected and analyzed for dissolved gases, including methane and short-chain hydrocarbons.

Carbon and hydrogen isotopic ratios of methane were measured in 21 samples that had at least 0.3 milligram per litre (mg/L) of methane.

Henderson and Duggan-Haas (2014). “Drilling into controversy: the educational complexity of shale gas development” Journal of Environmental Studies and Sciences. **4**: 87–96

Potential development of shale gas presents a complicated and controversial education problem. Research on human learning and our own experiences as educators support the conclusion that traditional, disciplinary-focused educational experiences are insufficient due to the nature of the concepts necessary for understanding the development of shale gas within the energy system as a complex, contextualized phenomenon. Educators engaging in communicating complex phenomena such as shale gas development can also increase sophistication of learner understanding by taking into account the sociocultural and psychological mechanisms that shape one’s understanding of the change processes at work. We therefore review an emerging body of research showing that nurturing environmental literacy requires more than the clear explication of evidence, and instead requires interrogating one’s existing worldview and comparing alternative options for action, as opposed to analyzing energy options in isolation. We then apply the results of this research to the challenging task of creating meaningful learning experiences and engagement with complex issues such as emerging energy systems and shale gas development in particular.

Hladik et al. (2013). “Discharges of produced waters from oil and gas extraction via wastewater treatment plants are sources of disinfection by-products to receiving streams”. Science of the Total Environment. **466-467**: 1085–1093.

Fluids co-produced with oil and gas production (produced waters) are often brines that contain elevated concentrations of bromide. Bromide is an important precursor of several toxic disinfection by-products (DBPs) and the treatment of produced water may lead to more brominated DBPs. To determine if wastewater treatment plants that accept produced waters discharge greater amounts of brominated DBPs, water samples were collected in Pennsylvania from four sites along a large river including an upstream site, a site below a publicly owned wastewater treatment plant (POTW) outfall (does not accept produced water), a site below an oil and gas commercial wastewater treatment plant (CWT) outfall, and downstream of the POTW and CWT. Of 29 DBPs analyzed, the site at the POTW outfall had the highest number detected (six) ranging in concentration from 0.01 to 0.09 μg L^{-1} with a similar mixture of DBPs that have been detected at POTW outfalls elsewhere in the United States. The DBP profile at the CWT outfall was much different, although only two DBPs, dibromochloronitromethane (DBCNM) and chloroform, were detected, DBCNM was found at relatively high concentrations (up to 8.5 μg L^{-1}). The water at the CWT outfall also had a mixture of inorganic and organic precursors including elevated concentrations of bromide (75 mg L^{-1}) and other organic DBP precursors (phenol at 15 μg L^{-1}). To corroborate these DBP results, samples were collected in Pennsylvania from additional POTW and CWT outfalls that accept produced waters. The additional CWT also had high concentrations of DBCNM (3.1 μg L^{-1}) while the POTWs that accept produced waters had elevated numbers (up to 15) and concentrations of DBPs, especially brominated and Iodinated THMs (up to 12 μg L^{-1} total THM concentration). Therefore, produced water brines that have been disinfected are potential sources of DBPs along with DBP precursors to streams wherever these wastewaters are discharged.

Holahan and Arnold (2013). “An institutional theory of hydraulic fracturing policy” Ecological Economics. **94**: 127–134

The use of high-volume horizontal hydraulic fracturing (fracking) has increased substantially over the past five years in the United States. Use of this drilling technology to extract natural gas from hitherto impermeable shale is expected to increase even more in coming decades. Two institutions, integration contracts and well spacing requirements, evolved to mitigate the common-pool economic wastes associated with conventional oil and gas drilling. U.S. regulators have applied these institutions to fracking. However, shale plays differ geologically from conventional plays and are subject to different extractive technologies. We theorize that the point-source pollution characteristics of conventional drilling allowed integration contracts and well space requirements to minimize local negative environmental externalities as an unintended byproduct of minimizing common-pool economic wastes. The non-point source pollution characteristics of fracking, however, make these institutions insufficient to minimize negative environmental externalities associated with drilling in shale plays, because the economic waste problem is different. If policymakers understand the crucial differences between conventional oil and gas plays and shale plays and the drilling technologies applied to them, they should be better equipped to craft fracking regulatory policies that internalize problematic externalities.

Holroyd and Retzer (2005). “A Peak into the Future: Potential Landscape Impacts of Gas Development in Northern Canada”. The Pembina Institute

This paper illustrates the potential physical footprint of gas development in three fields within northern Canada’s sedimentary basins: the Mackenzie Delta, Colville Hills and Peel Plateau. In this study ALCES®, a landscape-scale simulation model, was used to estimate the footprint in the three fields of typical gas development over the next 30 years. The model was also used to explore alternative management scenarios that apply several “best practices” currently used in the gas industry. Based on current oil and gas reserve estimates and development proposals, this study aims to provide Northern communities with a ‘picture’ of potential cumulative gas development in three regions of the North. This information is intended to serve as a useful tool for communicating the scope and scale of potential gas development to Northerners. The study results will be used to: Provide decision makers with information about the potential nature and extent of the footprint associated with gas development in the event that the Mackenzie Valley pipeline is built. Raise public awareness about the footprint and environmental impacts associated with gas development. Encourage discussion on industry “best practices” that may be used to reduce the footprint of development.

Holzman (2011). “Methane Found in Well Water Near Fracking Sites”

In a study of 68 private drinking water wells in northeastern Pennsylvania and New York, methane contamination rose sharply with proximity to natural gas drilling and hydraulic fracturing (“fracking”) sites. The average methane concentration in shallow groundwater in active drilling areas fell within the defined action level (> 10 mg/L but < 28 mg/L) for hazard mitigation recommended by the U.S. Department of the Interior, and the maximum (64 mg/L) was well beyond that threshold, according to a recent report. However, the researchers found no evidence of fracturing fluids. Principal investigator Robert B. Jackson of Duke University says fracking has been conducted in the sampled region since about 2008. The team sampled the water supplies in 2010. The researchers measured concentrations of gases and certain isotopes of carbon in methane and other hydrocarbons to distinguish the ancient thermogenic gas stores sought in drilling operations from methane generated by microbial degradation of organic matter. The closer the well was to an active drilling site, the more likely it was the methane detected was thermogenic.

Hopkinson et al. (2013). “Assessing the Surface Water Quality Impacts of Marcellus Shale Development in Whiteday Creek Watershed, West Virginia”. World Environmental and Water Resources Congress 2013. 2833-2842

The Marcellus shale can likely support the drilling of thousands of wells, potentially increasing economic activity and helping meet energy needs. Concerns remain of possible environmental impacts to water resources. This research assessed impacts of drilling for gas in the Marcellus shale in Whiteday Creek watershed in northern West Virginia by monitoring water quality. Four stream sites, located upstream and downstream of an active drilling operation, were monitored. Conductivity, pH, turbidity, and temperature were measured biweekly at each sampling site. Water grab samples were also collected biweekly and analyzed for alkalinity, acidity, bromide, calcium, chloride, magnesium, sulfate, and strontium. Differences between upstream and downstream field sites were observed in conductivity, pH, and total dissolved solids.

Horwitt (2011). “Cracks in the Façade 25 Years Ago, EPA Linked “Fracking” to Water Contamination”

In 2006, a Dallas-based company riding a nationwide natural gas boom drilled and hydraulically fractured a gas well in a sandstone and shale formation in Jackson County, W. Va. Just after EXCO Resources fractured the well, area residents said that two nearby water wells became polluted. The landowners whose water wells were involved in the incident have declined to comment, saying they signed confidentiality agreements with EXCO. The Strohls’ account bears striking similarities to a report issued almost 25 years ago by the Environmental Protection Agency, which concluded that hydraulic fracturing (colloquially known as “fracking”) could – and did – contaminate underground drinking water sources. That all-but-forgotten report from December 1987, uncovered by Environmental Working Group and Earthjustice, contradicts the drilling industry’s insistence that there has never been a documented case of groundwater contamination caused by hydraulic fracturing. EPA’s long-ignored 1987 report found that fracturing fluid from a shale gas well more than 4,000 feet deep had contaminated well water just across the road from the Strohls’ home, that the contamination was “illustrative” of the types of pollution associated with natural gas and oil drilling, and that EPA’s investigation had been hampered by confidentiality agreements between industry and affected landowners.

Howarth et al. (2011). “Natural Gas: Should fracking stop?” Nature. **477**. 271-275

This article contains two viewpoints on whether fracking should stop: Yes, its too high risk - Natural gas from shale is widely promoted as clean compared with oil and coal, a ‘win–win’ fuel that can lessen emissions while still supplying abundant fossil energy over coming decades until a switch to renewable energy sources is made. But shale gas isn’t clean, and shouldn’t be used as a bridge fuel. No, it’s too valuable - After a career in geological research on one of the world’s largest gas supplies, I am a born-again ‘cornucopian’. I believe that there is enough domestic gas to meet our needs for the foreseeable future thanks to technological advances in hydraulic fracturing. According to IHS, a business-information company in Douglas County, Colorado, the estimated recoverable gas from US shale source rocks using fracking is about 42 trillion cubic metres, almost equal to the total conventional gas discovered in the

United States over the past 150 years, and equivalent to about 65 times the current US annual consumption. During the past three years, about 50 billion barrels of additional recoverable oil have been found in shale oil deposits — more than 20% of the total conventional recoverable US oil resource.

Howarth et al (2011). “Methane and the greenhouse-gas footprint of natural gas from shale formations”. Climate Change. **106**: 679–690

We evaluate the greenhouse gas footprint of natural gas obtained by high-volume hydraulic fracturing from shale formations, focusing on methane emissions. Natural gas is composed largely of methane, and 3.6% to 7.9% of the methane from shale-gas production escapes to the atmosphere in venting and leaks over the lifetime of a well. These methane emissions are at least 30% more than and perhaps more than twice as great as those from conventional gas. The higher emissions from shale gas occur at the time wells are hydraulically fractured—as methane escapes from flow-back return fluids—and during drill out following the fracturing. Methane is a powerful greenhouse gas, with a global warming potential that is far greater than that of carbon dioxide, particularly over the time horizon of the first few decades following emission. Methane contributes substantially to the greenhouse gas footprint of shale gas on shorter time scales, dominating it on a 20-year time horizon. The footprint for shale gas is greater than that for conventional gas or oil when viewed on any time horizon, but particularly so over 20 years. Compared to coal, the footprint of shale gas is at least 20% greater and perhaps more than twice as great on the 20-year horizon and is comparable when compared over 100 years.

Hughes (2013). “Drill, Baby, Drill: Can Unconventional Fuels Usher in a New Era of Energy Abundance?”. Post Carbon Institute

The U.S. is a mature exploration and development province for oil and gas. New technologies of large scale, multistage, hydraulic fracturing of horizontal wells have allowed previously inaccessible shale gas and tight oil to reverse the long-standing decline of U.S. oil and gas production. This production growth is important and has provided some breathing room. Nevertheless, the projections by pundits and some government agencies that these technologies can provide endless growth heralding a new era of “energy independence,” in which the U.S. will become a substantial net exporter of energy, are entirely unwarranted based on the fundamentals. At the end of the day, fossil fuels are finite and these exuberant forecasts will prove to be extremely difficult or impossible to achieve. A new energy dialogue is needed in the U.S. with an understanding of the true potential, limitations, and costs—both financial and environmental—of the various fossil fuel energy panaceas being touted by industry and government proponents. The U.S. cannot drill and frack its way to “energy independence.” At best, shale gas, tight oil, tar sands, and other unconventional resources provide a temporary reprieve from having to deal with the real problems: fossil fuels are finite, and production of new fossil fuel resources tends to be increasingly expensive and environmentally damaging. Fossil fuels are the foundation of our modern global economy, but continued reliance on them creates increasing risks for society that transcend our economic, environmental, and geopolitical challenges. The best responses to this conundrum will entail a rethink of our current energy trajectory. Unfortunately, the “drill, baby, drill” rhetoric in recent U.S. elections belies any understanding of the real energy problems facing society. The risks of ignoring these energy challenges are immense. Developed nations like the United States consume (on a per capita basis) four times as much energy as China and seventeen times as much as India. Most of the future growth in energy consumption is projected to occur in the developing world. Constraints in energy supply are certain to strain future international relations in unpredictable ways and threaten U.S. and global economic and political stability. The sooner the real problems are recognized by political leaders, the sooner real solutions to our long term energy problem can be implemented.

Humphries (2013). “U.S. Crude Oil and Natural Gas Production in Federal and Non-Federal Areas”. CRS Report for Congress

In 2012, oil prices ranged from $80 to $110 per barrel (West Texas Intermediate spot price) and remain high in early 2013. Congress is faced with proposals designed to increase domestic energy supply, enhance security, and/or amend the requirements of environmental statutes. A key question in this discussion is how much oil and gas is produced each year and how much of that comes from federal and non-federal areas.On non-federal lands, there were modest fluctuations in oil production from fiscal years (FY) 2008-2010, then a significant increase from FY2010 to FY2012 increasing total U.S. oil production by about 1.1 million barrels per day over FY2007 production levels. All of the increase from FY2007 to FY2012 took place on non-federal lands, and the federal share of total U.S. crude oil production fell by about seven percentage points. Natural gas prices, on the other hand, have remained low for the past several years, allowing gas to become much more competitive with coal for power generation. The shale gas boom has resulted in rising supplies of natural gas. Overall, U.S. natural gas production rose by four trillion cubic feet (tcf) or 20% since 2007, while production on federal lands (onshore and offshore) fell by about 23% and production on non-federal lands grew by 40%. The big shale gas plays are primarily on non-federal lands and are attracting a significant portion of investment for natural gas development.

IALE (2013). “Land system change impacts on European landscapes”

This is information on a symposium to explore the extent and spatial distribution of land system changes.

IHS Global Insight (2009). “Measuring the Economic and Energy Impacts of Proposals to Regulate Hydraulic Fracturing”.

The American Petroleum Institute (API) has engaged IHS Global Insight to perform an independent study to determine the potential impact on future hydrocarbon production and on U.S. economic performance of proposed policy changes pertaining to hydraulic stimulation or fracturing of oil and gas wells. The study investigated three scenarios: 1) Implementation of regulations similar to those used by EPA to regulate the UIC program. 2) Restrictions on the use of certain fluids that are being highlighted by policymakers as having the potential to impact underground aquifers, and 3) Elimination of hydraulic fracturing. This report highlights and summarizes key observations and conclusions and also documents the methodologies and assumptions used to produce the forecast scenarios.

Ingraffea et al. (2014). “Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012”. Proceedings of the National Academy of Sciences. **Early edition**.

Casing and cement impairment in oil and gas wells can lead to methane migration into the atmosphere and/or into underground sources of drinking water. An analysis of 75,505 compliance reports for 41,381 conventional and unconventional oil and gas wells in Pennsylvania drilled from January 1, 2000–

December 31, 2012, was performed with the objective of determining complete and accurate statistics of casing and cement impairment. Statewide data show a sixfold higher incidence of cement and/or casing issues for shale gas wells relative to conventional wells. The Cox proportional hazards model was used to estimate risk of impairment based on existing data. The model identified both temporal and geographic differences in risk. For post-2009 drilled wells, risk of a cement/casing impairment is 1.57-fold (95% confidence interval (CI) (1.45, 1.67); $P < 0.0001$) higher in an unconventional gas well relative to a conventional well drilled within the same time period. Temporal differences between well types were also observed and may reflect more thorough inspections and greater emphasis on finding well leaks, more detailed note taking in the available inspection reports, or real changes in rates of structural integrity loss due to rushed development or other unknown factors. Unconventional gas wells in northeastern (NE) Pennsylvania are at a 2.7-fold higher risk relative to the conventional wells in the same area. The predicted cumulative risk for all wells (unconventional and conventional) in the NE region is 8.5-fold (95% CI (7.16, 10.18); $P < 0.0001$) greater than that of wells drilled in the rest of the state.

International Security Advisory Board (ISAB) (2014). "Report on Energy Geopolitics: Challenges and Opportunities"

The crisis in Ukraine is the latest reminder of how energy permeates the geopolitical landscape and is a fundamental element of national power. It can be a source of political leverage or vulnerability for individual countries, and can promote economic prosperity or instability. U.S. energy independence is a myth. Since the 1970s, successive administrations have described energy independence as a desirable policy goal, or a plausible market reality. It is neither. Rising U.S. oil production does not alone justify a change in the country's relationship with the Middle East. The United States continues to import oil from the Middle East, even if in smaller amounts than other major countries, and the United States has an enduring interest in the free flow of energy to its allies and trading partners. The U.S. oil and gas revolution is remarkable. But the rise of emerging market demand for fossil fuels, especially in Asia, is arguably the more geopolitically significant energy development. On the one hand, U.S. oil and gas production growth has important economic benefits and contributes to stable, well-supplied energy markets as the United States now imports less and exports more. Over the long-term, the greatest national security challenge posed by energy is climate change. Expected fossil-fuel consumption trends would make it impossible to meet stated climate change mitigation goals. A growing body of scientific literature asserts in increasingly clear terms that climate change, the primary causes of which are inextricably tied to energy, is poised to threaten every nation on the planet.

Jackson et al. (2013). "Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction". Proceedings of the National Academy of Sciences. **110** (28): 11250-11255

Horizontal drilling and hydraulic fracturing are transforming energy production, but their potential environmental effects remain controversial. We analyzed 141 drinking water wells across the Appalachian Plateaus physiographic province of northeastern Pennsylvania, examining natural gas concentrations and isotopic signatures with proximity to shale gas wells. Methane was detected in 82% of drinking water samples, with average concentrations six times higher for homes <1 km from natural gas wells ($P = 0.0006$). Ethane was 23 times higher in homes <1 km from gas wells ($P = 0.0013$); propane was detected in 10 water wells, all within approximately 1 km distance ($P = 0.01$). Of three factors previously proposed to influence gas concentrations in shallow groundwater (distances to gas wells, valley bottoms, and the Appalachian Structural Front, a proxy for tectonic deformation), distance to gas wells was highly significant for methane concentrations ($P = 0.007$; multiple regression), whereas distances to valley bottoms and the Appalachian Structural Front were not significant ($P = 0.27$ and $P = 0.11$, respectively). Distance to gas wells was also the most significant factor for Pearson and Spearman correlation analyses ($P < 0.01$). For ethane concentrations, distance to gas wells was the only statistically significant factor ($P < 0.005$). Isotopic signatures (δ13C-CH4, δ13C-C2H6, and δ2H-CH4), hydrocarbon ratios (methane to ethane and propane), and the ratio of the noble gas 4He to CH4 in groundwater were characteristic of a thermally postmature Marcellus-like source in some cases. Overall, our data suggest that some homeowners living <1 km from gas wells have drinking water contaminated with stray gases.

Jackson et al. (2011). "Reply to Davies: Hydraulic fracturing remains a possible mechanism for observed methane contamination of drinking water". Proceedings of the National Academy of Sciences. **108**(43): E872

Davies (2011) agrees that methane contamination of drinking water has occurred in aquifers overlying the Marcellus formation but asserts that we prematurely ascribed its cause to hydraulic fracturing. We respond briefly, noting that we carefully avoided ascribing any mechanism and suggested some additional research for the important need that Davies identifies to understand the mechanism of contamination better. Comments about sampling procedures and methane seeps are in refs. 3 (Osborn et al. 2011) and 4 (Jackson et al. 2011). Our paper discussed three mechanisms for stray gas migration. One was physical displacement of gas-rich water up from the shale formation, which we dismissed as "unlikely". The other two mechanisms were leaky gas well casings and the possibility that hydraulic fracturing might generate new or enlarge existing fractures above the target formation, increasing connectivity. Of these two mechanisms, we wrote that "methane migration through the 1- to 2-km-thick geological formations that overlie the Marcellus and Utica shales is less likely as a mechanism for methane contamination than leaky well casings".

Jackson et al. (2011). "Research and policy recommendations for hydraulic fracturing and shale-gas extraction"

Natural gas has been used as a domestic and industrial fuel source for over a century. It contains more energy per pound than coal. When burned, it produces almost none of the mercury, sulfur dioxide, and particulates that burning coal produces, nor does it require destructive mountain-top mining and other approaches inherent in coal production. As a cleaner source of energy, and as a bridge to a carbon constrained future, natural gas has many desirable qualities. Despite these benefits, more research is needed to assess the mechanisms of water contamination and possible methane losses to the atmosphere. Moreover, some additional oversight may be needed to protect communities and the environment from water contamination near extraction and disposal sites. The research and policy recommendations presented here are provided in the spirit of making natural-gas extraction safer and more consistent across companies, locations, and time. Decisions regarding the extent to which natural gas extraction should be regulated must balance public health and safety, energy needs, and the inevitable bureaucracy that regulation brings. Based on the results of Osborn and colleagues and the additional background provided here, we believe that horizontal drilling, hydraulic fracturing, and shale-gas extraction in general would benefit from 1) better-coordinated, and sustained scientific study; 2) a review of the potential health consequences of methane and other hydrocarbons in drinking water; 3) industry-driven approaches to develop safer and more consistent extraction technologies, and 4) consideration of stronger state or federal regulation. Other topics not discussed here but that would benefit from increased study include the treatment and disposal of waste waters; current practices include wastewater treatment with subsequent release into surface streams and rivers, or disposal through injection into deep geological formations. As the United States and other countries continue to develop new methods for accessing unconventional sources of energy, and as hydraulic fracturing becomes increasingly common for extracting conventional oil and gas reserves, the questions that we have raised are likely to become more common. Developing a comprehensive approach to industry oversight and regulation, based on scientific data and on appropriate state and federal oversight, will provide a positive path forward for future energy extraction technologies.

Jacquet (2014). “Review of Risks to Communities from Shale Energy Development”. Environmental Science and Technology. **48**: 8321−8333

Although shale energy development can bring infusions of money and jobs to local communities, an array of risks to community level assets and institutions is also possible. Sociological research dating back to the 1970s links rapid oil and gas development with overburdened municipal services, upended social and cultural patterns, and volatile economic growth. Research on technological risk has demonstrated communities can come to be associated with pollution and contamination, resulting in out-migration, declining amenity-led development, and decreased financial investment. Emerging shale energy case studies in Wyoming, Pennsylvania, North Dakota, and Texas show a similar, although nuanced, picture of these concerns. Yet, little data exists on the prevalence or magnitude of these risks in the current context of shale gas development. The existing research has largely remained case-based in nature, has not been synthesized across various disciplines, and has not been updated to account for various social and technological trends that have occurred since its publication. This paper offers a critical review of major research endeavors that inform our knowledge of risk to communities from shale energy development, while identifying gaps in our understanding of these risks and areas of research need.

Jalbert et al. (2014). “Civil society research and Marcellus Shale natural gas development: results of a survey of volunteer water monitoring organizations”. Journal of Environmental Studies and Sciences. **4**: 78–86

This paper reports the results of a survey of civil society organizations that are monitoring surface water for impacts of Marcellus Shale development in Pennsylvania and New York. We argue that enlisting volunteers to conduct independent monitoring is one way that civil society organizations are addressing knowledge gaps and the “undone science” of surface water quality impacts related to gas extraction. The survey, part of an ongoing 2-year study, examines these organizations' objectives, monitoring practices, and financial, technical, and institutional support networks. We find that water monitoring organizations typically operate in networks of two main types: centralized networks, with one main “hub” organization connecting many chapter groups or teams, and decentralized networks, consisting primarily of independent watershed associations and capacity building organizations. We also find that there are two main orientations among water monitoring groups. Roughly, half are advocacy-oriented, gathering data in order to improve regulation, support litigation, and change industry behavior. We characterize the other half as knowledge-oriented, gathering data in order to protect natural resources through education and awareness. Our analysis finds that many monitoring programs function relatively independently of government and university oversight supported instead by a number of capacity building organizations in the field. We argue that this reflects neoliberal tendencies toward increased public responsibility for environmental science. We also find that new participants in the field of water monitoring, mainly large environmental NGOs integral to the operations of centralized networks, are shifting monitoring programs towards more advocacy-oriented objectives. We believe this shift may impact how civil society water monitoring efforts interact with regulatory bodies, such as by taking normative positions and using volunteer-collected data to advocate for policy change.

Jaspal and Nerlich (2014).”Fracking in the UK press: Threat dynamics in an unfolding debate”. Public Understanding of Science. **23**(3): 348–363

Shale gas is a novel source of fossil fuel which is extracted by induced hydraulic fracturing, or “fracking”. This article examines the socio-political dimension of fracking as manifested in the UK press at three key temporal points in the debate on the practice. Three newspaper corpora were analysed qualitatively using Thematic Analysis and Social Representations Theory. Three overarching themes are discussed: “April–May 2011: From Optimism to Scepticism”; “November 2011: (De-)Constructing and Re-Constructing Risk and Danger”; “April 2012: Consolidating Social Representations of Fracking”. In this article, we examine the emergence of and inter-relations between competing social representations, discuss the dynamics of threat positioning and show how threat can be re-construed in order to serve particular socio-political ends in the debate on fracking.

Jiang et al. (2014). “Life Cycle Water Consumption and Wastewater Generation Impacts of a Marcellus Shale Gas Well”. Environmental Science and Technology. **48**: 1911−1920

This study estimates the life cycle water consumption and wastewater generation impacts of a Marcellus shale gas well from its construction to end of life. Direct water consumption at the well site was assessed by analysis of data from approximately 500 individual well completion reports collected in 2010 by the Pennsylvania Department of Conservation and Natural Resources. Indirect water consumption for supply chain production at each life cycle stage of the well was estimated using the economic input−output life cycle assessment (EIO-LCA) method. Life cycle direct and indirect water quality pollution impacts were assessed and compared using the tool for the reduction and assessment of chemical and other environmental impacts (TRACI). Wastewater treatment cost was proposed as an additional indicator for water quality pollution impacts from shale gas well wastewater. Four water management scenarios for Marcellus shale well wastewater were assessed: current conditions in Pennsylvania; complete discharge; direct reuse and desalination; and complete desalination. The results show that under the current conditions, an average Marcellus shale gas well consumes 20 000 m3 (with a range from 6700 to 33 000 m3) of freshwater per well over its life cycle excluding final gas utilization, with 65% direct water consumption at the well site and 35% indirect water consumption across the supply chain production. If all flowback and produced water is released into the environment without treatment, direct wastewater from a Marcellus shale gas well is estimated to have 300−3000 kg N-eq eutrophication potential, 900−23 000 kg 2,4D-eq freshwater ecotoxicity potential, 0−370 kg benzene-eq carcinogenic potential, and 2800−71 000 MT toluene-eq non-carcinogenic potential. The potential toxicity of the chemicals in the wastewater from the well site exceeds those associated with supply chain production, except for carcinogenic effects. If all the Marcellus shale well wastewater is treated to surface discharge standards by desalination, $59 000−270 000 per well would be required. The life cycle study results indicate that when gas end use is not considered hydraulic fracturing is the largest contributor to the life cycle water impacts of a Marcellus shale gas well.

Johnson and Johnson (2012). “Hydraulic fracture water usage in northeast British Columbia: locations, volumes and trends”. Geoscience reports 2012, BC Ministry of Energy and Mines. 41-63

Water demand for gas development in northeast British Columbia is dictated by certain aspects of multistage hydraulic fracturing. Approximately 500 wells, dating from 2005 to 2010, each with more than three fracture stages, were analyzed in terms of water use and gas production. Special focus was placed on fracture type, stimulation volume, well location and number of fractures per well. The water volume per fracture stage can vary by an order of magnitude depending on the completion method used. Water use is amplified by the number of completions per well. Slickwater completions are a preferred method because of their low cost and their ability to generate high stimulated reservoir volumes. The completion method and (to a lesser extent) the number of completions per well, is dictated by the geology of the basin. Gas production in the Montney Trend is very economical in terms of water use compared to the Horn River Basin. Water demand is expected to be high in the Cordova Embayment and the Montney North Trend. As water use is increasing rapidly, ongoing monitoring and improved database access are recommended for the Horn River Basin, the Montney North Trend, the Cordova Embayment and the Liard Basin.

Jones and Pejchar (2013). “Comparing the Ecological Impacts of Wind and Oil & Gas Development: A Landscape Scale Assessment”. PLoS ONE. **8**(11): e81391

Energy production in the United States is in transition as the demand for clean and domestic power increases. Wind energy offers the benefit of reduced emissions, yet, like oil and natural gas, it also contributes to energy sprawl. We used a diverse set of indicators to quantify the ecological impacts of oil, natural gas, and wind energy development in Colorado and Wyoming. Aerial imagery was supplemented with empirical data to estimate habitat loss, fragmentation, potential for wildlife mortality, susceptibility to invasion, biomass carbon lost, and water resources. To quantify these impacts we digitized the land-use footprint within 375 plots, stratified by energy type. We quantified the change in impacts per unit area and per unit energy produced, compared wind energy to oil and gas, and compared landscapes with and without energy development. We found substantial differences in impacts between energy types for most indicators, although the magnitude and direction of the differences varied. Oil and gas generally resulted in greater impacts per unit area but fewer impacts per unit energy compared with wind. Biologically important and policy-relevant outcomes of this study include: 1) regardless of energy type, underlying land-use matters and development in already disturbed areas resulted in fewer total impacts; 2) the number and source of potential mortality varied between energy types, however, the lack of robust mortality data limits our ability to use this information to estimate and mitigate impacts; and 3) per unit energy produced, oil and gas extraction was less impactful on an annual basis but is likely to have a much larger cumulative footprint than wind energy over time. This rapid evaluation of landscape-scale energy development impacts could be replicated in other regions, and our specific findings can help meet the challenge of balancing land conservation with society’s demand for energy.

Jones (2012). “The impact of energy sprawl on biodiversity and ecosystem services”. MSc thesis, Colorado State University.

The future of energy production is uncertain as society demands clean and abundant energy to meet the needs of a growing and increasingly developed population. Wind energy offers the benefit of reduced greenhouse gas emissions; however, like conventional power sources such as oil and natural gas, wind energy results in an environmental footprint that contributes to energy sprawl, or the use and degradation of land due to energy production. In order to better understand these potential affects I summarized and evaluated the impacts on a diverse set of indicators including habitat loss, fragmentation, wildlife mortality, noise and light pollution, invasive species, and changes in carbon stock and water resources. I quantified these indicators by digitizing the land-use footprint within 375 randomly selected one kilometer diameter plots, stratified across each energy type, within Colorado and Wyoming, USA. I found substantial differences in impacts between energy types for most indicators, although the magnitude and direction of the differences varied. Wind energy resulted in greater impacts to noise and light pollution whereas oil and natural gas development resulted in greater habitat fragmentation and impacts to biomass carbon stock and water resources. Underlying land-use and location of production activities were a critical factor in describing the impacts. This novel technique and my specific findings can be used by developers, planners and policy-makers to design energy development that retains biodiversity while meeting society's demand for energy.

Jowell (2012). "Geo-spatial modeling of potential oil and gas structures in mineral leases within the Attoyac watershed of East Texas and their impact on landscape fragmentation". MSc thesis, Austin State University

The Haynesville Shale in Western Louisiana and East Texas saw increased lease development from 2000 to 2010 with the increased popularity of hydrologic fracking. Natural gas prices fell later in that span and development slowed down. A Python model was developed using ESRI's ArcPy Library suite to simulate what future expansion of the oil and gas industry would look like in the Attoyac Watershed in East Texas if prices were to rise again. This model included parameters in regards to spacing laws set up by the Texas Rail Road Commission of having 467 feet (142.3 m) between each well and neighboring mineral leases. Simulated new wells were generated and converted to raster cells in proportion with a 30m resolution classified image that was created from Landsat 5 imagery of the area. The two were mosaicked together to simulate a landscape disturbance within the East Texas region. Spatial metrics were calculated for the image using FRAGSTATS and Spatial Analyst tools in ESRI's ArcMap program. Habitat fragmentation and landscape ecology concepts were postulated from the results. Tests of normality were run on model iterations to determine variance in the model's output. Inferring from FRAGSTATS results the forest matrix in the model output had comparable dumpiness to other studies. Localized effects for single patch clusters for each cover type were present and will have short term and long term effects for the Attoyac region as a whole. It is expected that vegetation dominance and fauna species will shift in local patches from changes in patch structure and impacts of climate and weather.

Kassen et al. (2012). "Water Under Pressure: What Oil Shale Could Mean for Western Water, Fish and Wildlife". A report for Sportsmen for Responsible Energy Development.

This report explores how large-scale commercial oil shale development in Utah, Wyoming and Colorado could affect the region's water supply and quality and what that might mean for fish, wildlife and communities. After more than 100 years of trying, we are still several years away from an economically viable oil shale industry. The technology is unproven and the potential environmental impacts are unknown. Even conservative estimates indicate the volume of water needed to transform kerogen – a precursor to oil – into a usable fuel could be huge. For a resource that lies in the midst of the semi-arid West, with sparse precipitation and few large rivers, it is not clear where the water would come from, or how it would affect the fish that live in the local streams. With the region already straining its water supply and facing continued population growth, finding another increment of water for oil shale, while protecting native and sport fisheries, may be an insurmountable challenge.

The U.S. Bureau of Land Management (BLM) is currently proposing a cautious approach to oil shale development. The BLM has proposed keeping development off sensitive wildlife habitat, limiting new public leases to research and demonstration projects and moving ahead with commercial leases only after the pilot projects produce results. This approach is a prudent way to test oil shale potential and limit the risk to the region's water supplies..

Kassotis et al. (2014). “Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region”. Endocrinology. **155**: 897–907

The rapid rise in natural gas extraction using hydraulic fracturing increases the potential for contamination of surface and ground water from chemicals used throughout the process. Hundreds of products containing more than 750 chemicals and components are potentially used throughout the extraction process, including more than 100 known or suspected endocrine-disrupting chemicals. We hypothesized thataselected subset of chemicalsusedin natural gas drilling operationsandalso surface and ground water samples collected in a drilling-dense region of Garfield County, Colorado, would exhibit estrogen and androgen receptor activities. Water samples were collected, solid-phase extracted, and measured for estrogen and androgen receptor activities using reporter gene assays in human cell lines. Of the 39 unique water samples, 89%, 41%, 12%, and 46% exhibited estrogenic, antiestrogenic, androgenic, and antiandrogenic activities, respectively. Testing of a subset of natural gas drilling chemicals revealed novel antiestrogenic, novel antiandrogenic, and limited estrogenic activities. The Colorado River, the drainage basin for this region, exhibited moderate levels of estrogenic, antiestrogenic, and antiandrogenic activities, suggesting that higher localized activity at sites with known natural gas–related spills surrounding the river might be contributing to the multiple receptor activities observed in this water source. The majority of water samples collected from sites in a drilling-dense region of Colorado exhibited more estrogenic, antiestrogenic, or antiandrogenic activities than reference sites with limited nearby drilling operations. Our data suggest that natural gas drilling operations may result in elevated endocrine-disrupting chemical activity in surface and ground water.

King (2012). “Hydraulic Fracturing 101: What every representative, environmentalist, regulator, reporter, investor, University researcher, neighbour and engineer should know about estimating frac risk and improving frac performance in unconventional gas and oil wells. SPE Hydraulic Fracturing Technology Conference, The Woodlands, Texas USA.

Identification of risk, the potential for occurrence of an event and impact of that event, is the first step in improving a process by ranking risk elements and controlling potential harm from occurrence of a detrimental event. Hydraulic Fracturing has become a hot environmental discussion topic and a target of media articles and University studies during development of gas shales near populated areas. The furore over fracturing and frac waste disposal was largely driven by lack of chemical disclosure and the pre-2008 laws of some states. The spectacular increase in North American natural gas reserves created by shale gas development makes shale gas a disruptive technology, threatening profitability and continued development of other energy sources. Introduction of such a disruptive force as shale gas will invariably draw resistance, both monetary and political, to attack the disruptive source, or its enabler; hydraulic fracturing. Some “anti-frack” charges in media articles and university studies are based in fact and require a state-by-state focussed improvement of well design specific for geology of the area and oversight of overall well development. Other articles have demonstrated either a severe misunderstanding or an international misstatement of well development processes, apparently to attack the disruptive source. Transparency requires cooperation from all sides in the debate. To enable more transparency on the oil and gas side, both to assist in the understanding of oil and gas activities and to set a foundation for rational discussion of fracturing risks, a detailed explanation of well development activities is offered in this paper, from well construction to production, written at a level of general public understanding, along with an initial estimation of the frac risk and alternatives to reduce the risk, documented by literature and case histories. This discussion is a starting point for the well development descriptions and risk evaluation discussions, not an ending point.

Kinne et al. (2014). “Making critical connections through interdisciplinary analysis:exploring the impacts of Marcellus shale development”. Journal of Environmental Studies and Sciences. **4**:1–6

The term “fracking” simultaneously conjures up images of extractive technologies, community tensions, and stories of overnight wealth and environmental nightmares. The introduction and rapid expansion of hydraulic fracturing technology to develop oil and gas resources in shale plays across the USA has created complex and interrelated socioeconomic, biophysical, and geopolitical challenges. In the Marcellus shale region, distinct but interrelated issues of water security, health, energy, and community overlap in the broader socio-ecological system and further illuminate the daunting character of drilling for natural gas and other hydrocarbons. This special issue of the Journal of Environmental Studies and Sciences intentionally focuses on hydrocarbon development in the Marcellus shale, but situates this dialogue in the context of a broader, transdisciplinary approach to realizing a sustainable energy system. The interdisciplinary research published here examines the far-reaching complexities and consequences of the impacts of rapid, intensive natural resource development, including the role that access to information and inclusion in decision making have in connecting the global to the local facilitating critical evaluation of the long-term sustainability of development decisions at multiple scales.

Kiviat (2013). “Risks to biodiversity from hydraulic fracturing for natural gas in the Marcellus and Utica shales”. Annals of the New York academy of sciences. **1286**: 1-14

High-volume horizontal hydraulic fracturing (HVHHF) for mining natural gas from the Marcellus and Utica shales is widespread in Pennsylvania and potentially throughout approximately 280,000 km2 of the Appalachian Basin. Physical and chemical impacts of HVHHF include pollution by toxic synthetic chemicals, salt, and radionuclides, landscape fragmentation by well pads, pipelines, and roads, alteration of stream and wetland hydrology, and increased truck traffic. Despite concerns about human health, there has been little study of the impacts on habitats and biota. Taxa and guilds potentially sensitive to HVHHF impacts include freshwater organisms (e.g., brook trout, freshwater mussels), fragmentation-sensitive biota (e.g., forest-interior breeding birds, forest orchids), and species with restricted geographic ranges (e.g., Wehrle’s salamander, tongue-tied minnow). Impacts are potentially serious due to the rapid development of HVHHF over a large region.

Kondash et al. (2014). “Radium and Barium Removal through Blending Hydraulic Fracturing Fluids with Acid Mine Drainage”. Environmental Science and Technology. **48**: 1334−1342

Wastewaters generated during hydraulic fracturing of the Marcellus Shale typically contain high concentrations of salts, naturally occurring radioactive material (NORM), and metals, such as barium, that pose environmental and public health risks upon inadequate treatment and disposal. In addition, fresh water scarcity in dry regions or during periods of drought could limit shale gas development. This paper explores the possibility of using alternative water sources and their impact on NORM levels through blending acid mine drainage (AMD) effluent with recycled hydraulic fracturing flowback fluids (HFFFs). We conducted a series of laboratory experiments in which the chemistry and NORM of different mix proportions of AMD and HFFF were examined after reacting for 48 h. The experimental data combined with geochemical modeling and X-ray diffraction analysis suggest that several ions, including sulfate, iron, barium, strontium, and a large portion of radium (60−100%), precipitated into newly formed solids composed mainly of Sr barite within the first ∼10 h of mixing. The results imply that blending AMD and HFFF could be an effective management practice for both remediation of the high NORM in the Marcellus HFFF wastewater and beneficial utilization of AMD that is currently contaminating waterways in northeastern U.S.A.

Kovats et al. (2014). "The health implications of fracking". The Lancet. **383**. 757-758.

What is known about the health effects of gas extraction by induced hydraulic fracturing of gas-bearing rock ie, fracking? A workshop held on Nov 15, 2013, at the London School of Hygiene and Tropical Medicine and attended by scientists, public health professionals, and decision makers addressed this question. Fracking is at a very early stage in the UK, with only one shale gas well tested so far. This situation provides an important opportunity to gather information and to conduct studies of health and environmental effects before any large-scale development. Scientific study of the health effects of fracking is in its infancy, but findings suggest that this form of extraction might increase health risks compared with conventional oil and gas wells because of the larger surface footprints of fracking sites; their close proximity to locations where people live, work, and play; and the need to transport and store large volumes of materials. In the USA, where more than 52 000 shale gas wells have been drilled, data suggest that risks of environmental contamination occur at all stages in the development of shale gas extraction. Failure of the structural integrity of the well cement and casing, surface spills and leakage from above-ground storage, emissions from gas processing equipment, and the large numbers of heavy transport vehicles involved are the most important factors that contribute to environmental contamination and exposures in the USA.

Krueger (2011). "The Public Policy Implications of Shale Gas Extraction in Canada".

With recent developments in horizontal drilling and hydraulic fracturing of gas bearing sediments, previously marginal shale gas resources are being considered for development throughout Canada. The techniques and technologies used in extracting gas from shale formations are more aggressive than previously employed in conventional gas wells.

The goal of the paper is to look at the potential areas for shale gas extraction and analyze the impact that further development would have on water resources. A review of policy options available to control the shale gas extraction business will be considered as well as recommendations for regulating the industry to minimize its environmental impacts on water resources in Canada.

Krupnick et al. (2012). “Pathways to Dialogue What the Experts Say about the Environmental Risks of Shale Gas Development”. Resources for the Future (RFF) Report.

The national debate over shale gas development in the United States is characterized by a seeming lack of consensus over its environmental, economic, and social implications. On the one hand, shale gas offers great promise as a low-cost source of electricity, industrial feedstocks, residential and commercial energy, and even transportation fuel. On the other hand, public fears about the environmental effects of shale gas development threaten to dim or eliminate these prospects.This report is the first survey-based, statistical analysis of experts in government, industry, universities, and nongovernmental organizations (NGOs) to identify the priority environmental risks related to shale gas development—those for which the experts believe government regulation and/or voluntary industry practices are currently inadequate to protect the public or the environment. The results stand in sharp contrast to the rhetoric of much of the public debate. For example, a key finding is the high degree of consensus among experts about the specific risks to mitigate. These “consensus risks” are those that survey respondents from all four expert groups most frequently identified as needing further regulatory or voluntary action. Several of the consensus risks pertain to impacts that have received less attention in the popular debate than others. For example, the experts frequently identified the potential impacts on lakes, rivers, and streams (surface water) as a priority, and less frequently identified potential risks to underground aquifers (groundwater). In fact, only 2 of the 12 consensus risks identified by the experts are unique to the shale gas development process, and both have potential impacts on surface water. The remaining 10 consensus risks relate to practices common to gas and oil development in general, such as the construction of roads, well pads, and pipelines and concerns about leaky casing and cementing.

Lacazette & Geiser (2013) “Comment on Davies et al 2012 - Hydraulic fractures: how far can they go?”. Marine and Petroleum Geology. **43**: 516-518.

In the paper “Hydraulic Fractures: How far can they go?” Davies et al. (2012) make an important contribution to addressing the problem of hydraulic fracture propagation distance. They analyze the mass of published data on both natural and induced fractures and demonstrate that the probability of induced fractures growing more than 350 m vertically is <1%. The purpose of this comment is to discuss an additional layer of complexity of hydraulic fracture fluid movement revealed by a new passive seismic imaging method. The additional complexity is interaction between the hydraulic fracture treatment and the preexisting natural fracture system. Davies et al. (2012) recognize that natural fracture systems can extend vertically and laterally for distances over 1 km. However, at the time of their writing they were unaware of a new method of surface-based microseismic imaging that detects subtle seismic activation of natural fractures during hydraulic fracture treatments. The method, Tomographic Fracture Imaging (TFI), is described in Geiser et al. (2012). In conclusion, although we agree with Davies et al. (2012) regarding propagation of artificial hydraulic fractures, hydraulic fracture fluid and fluid pressure pulses can move greater distances in preexisting natural fracture systems. Fluid pressure pulses can be transmitted without significant flow, i.e. without changing the original fluid composition in the fracture network.

Lavoie et al. (2014). “The Utica Shale and gas play in southern Quebec: Geological and hydrogeological syntheses and methodological approaches to groundwater risk evaluation”. International Journal of Coal Geology. **126**: 77–91

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 well bore. 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.

Li & Carlson (2014). "Distribution and Origin of Groundwater Methane in the Wattenberg Oil and Gas Field of Northern Colorado". Environmental Science and Technology. **48**: 1484−1491

Public concerns over potential environmental contamination associated with oil and gas well drilling and fracturing in the Wattenberg field in northeast Colorado are increasing. One of the issues of concern is the migration of oil, gas, or produced water to a groundwater aquifer resulting in contamination of drinking water. Since methane is the major component of natural gas and it can be dissolved and transported with groundwater, stray gas in aquifers has elicited attention. The initial step toward understanding the environmental impacts of oil and gas activities, such as well drilling and fracturing, is to determine the occurrence, where it is and where it came from. In this study, groundwater methane data that has been collected in response to a relatively new regulation in Colorado is analyzed. Dissolved methane was detected in 78% of groundwater wells with an average concentration of 4.0 mg/L and a range of 0−37.1 mg/L. Greater than 95% of the methane found in groundwater wells was classified as having a microbial origin, and there was minimal overlap between the C and H isotopic characterization of the produced gas and dissolved methane measured in the aquifer. Neither density of oil/gas wells nor distance to oil/gas wells had a significant impact on methane concentration suggesting other important factors were influencing methane generation and distribution. Thermogenic methane was detected in two aquifer wells indicating a potential contamination pathway from the producing formation, but microbial-origin gas was by far the predominant source of dissolved methane in the Wattenberg field.

Linley (2011). "Fracking under pressure. The Environmental and Social Impacts and Risks of Shale Gas Development". Sustainalytics

Despite mounting evidence of climate change and the resulting need to shift toward a lower-carbon economy, the demand for fossil fuel continues to rise. Natural gas production and consumption are projected to continue to increase in both absolute terms and as a proportion of the fossil fuel mix. Meanwhile, reserves of conventional sources of oil and gas are dwindling and producers are increasingly focusing on unconventional sources, the development of which usually generates higher environmental and social risks. Shale gas is one such unconventional source. Shale gas reserves are vast, with especially large deposits in China, the U.S., and Russia. However, the environmental and social impacts of shale gas extraction have generated a significant amount of controversy. Impacts such as high levels of fugitive emissions are causing concerns about local air quality and contributions to climate change. Many of these impacts are directly related to the process of hydraulic fracturing, which has generated the majority of the controversy surrounding the shale gas industry. It is important to note, however, that hydraulic fracturing is just one step in the shale gas extraction process. Responsible investors have an important role to play in decreasing impacts and mitigating risks associated with natural gas development, they should view shale gas development in the context of the broader need to shift our economy away from its dependence on fossil fuels. Shale gas development, even with best practices in place, does nothing to contribute to this shift. Therefore, while pushing for best practices, responsible investors should push even harder for investment in renewable, sustainable forms of energy and for regulatory environments that incentivize such investment.

Liroff (2011). "Extracting the Facts: An investor guide to disclosing risks from hydraulic fracturing operations"

Natural gas production from shale formations in the United States has grown dramatically since the early 2000s, amidst expanding controversy over the horizontal drilling and hydraulic fracturing used to access the gas. The supplies of newly accessible gas are an energy "game changer", and companies are now assessing shales on nearly every continent.Investors supporting this document recommend that companies adopt the following 12 core management goals (CMGs) for natural gas operations, implement best management practices (BMPs) to achieve them, and report on key performance indicators (KPIs) to communicate outcomes. Some BMPs also function as KPIs.

Llewellyn (2014). "Evidence and mechanisms for Appalachian Basin brine migration into shallow aquifers in NE Pennsylvania, USA". Hydrogeology Journal. **22**(5): 1055-1066

Multiple geographic information system (GIS) datasets, including joint orientations from nine bedrock outcrops, inferred faults, topographic lineaments, geophysical data (e.g. regional gravity, magnetic and stress field), 290 pre-gas-drilling groundwater samples (Cl–Br data) and Appalachian Basin brine (ABB) Cl–Br data, have been integrated to assess pre-gas-drilling salinization sources throughout Susquehanna County, Pennsylvania (USA), a focus area of Marcellus Shale gas development. ABB has migrated naturally and preferentially to shallow aquifers along an inferred normal fault and certain topographic lineaments generally trending NNE–SSW, sub-parallel with the maximum regional horizontal compressive stress field (orientated NE–SW). Gravity and magnetic data provide supporting evidence for the inferred faults and for structural control of the topographic lineaments with dominant ABB shallow groundwater signatures. Significant permeability at depth, imparted by the geologic structures and their orientation to the regional stress field, likely facilitates vertical migration of ABB fluids from depth. ABB is known to currently exist within Ordovician through Devonian stratigraphic units, but likely originates from Upper Silurian strata, suggesting significant migration through geologic time, both vertically and laterally. The natural presence of ABB-impacted shallow groundwater has important implications for differentiating gas-drilling-derived brine contamination, in addition to exposing potential vertical migration pathways for gas-drilling impacts.

Lovejoy (2012). “The rise of shale gas: Implications of the shale gas boom for natural gas markets, environmental protection and U.S. energy policy”. M.A. Thesis Georgetown University.

Through the processes of hydraulic fracturing and horizontal drilling, once overlooked deposits of natural gas in shale formations have become economically viable to extract. In the past decade, energy companies have rushed to produce this newly available resource. Energy economists believe that this influx of shale gas will lead to lower, more stable natural gas prices, reduce our country’s dependence on foreign oil, and reduce the use of coal for electricity generation. However, environmental advocates are concerned that shale gas production comes at too high an environmental price through groundwater contamination and methane emissions. This paper analyzed the relationship between shale gas production and natural gas prices through a fixed effects regression model. Results of the model indicated that state-level variations in natural gas supply were not sufficient to affect prices set at the national level. In terms of policy implications, the United States must be deliberate in deciding the role of shale gas in U.S. energy policy. Full blown investment in shale resources should be delayed until the environmental impacts of hydraulic fracturing are more fully understood and appropriate precautions are put in place. In addition, if natural gas is to be used as a “bridge fuel,” care must be taken to ensure the expansion of natural gas does not undermine investments in alternative energy sources.

Lutz et al. (2013). “Generation, transport, and disposal of wastewater associated with Marcellus Shale gas development”. Water Resources Research. **49**: 647–656

Hydraulic fracturing has made vast quantities of natural gas from shale available, reshaping the energy landscape of the United States. Extracting shale gas, however, generates large, unavoidable volumes of wastewater, which to date lacks accurate quantification. For the Marcellus shale, by far the largest shale gas resource in the United States, we quantify gas and wastewater production using data from 2189 wells located throughout Pennsylvania. Contrary to current perceptions, Marcellus wells produce significantly less wastewater per unit gas recovered (approximately 35%) compared to conventional natural gas wells. Further, well operators classified only 32.3% of wastewater from Marcellus wells as flowback from hydraulic fracturing; most wastewater was classified as brine, generated over multiple years. Despite producing less wastewater per unit gas, developing the Marcellus shale has increased the total wastewater generated in the region by approximately 570% since 2004, overwhelming current wastewater disposal infrastructure capacity.

Lyons (2014). “Produced Water: Asset or Waste?”. Atlantic Council. ISBN: 978-1-61977-054-6

This report is one of several in the Council’s Energy and Water Nexus Initiative series. The three major goals of this initiative are to promote sustainable policies with common sense recommendations, clarify the terms of the debate with fact-based information, and provide a gateway for the public and policy makers to experts and additional information. Over the past five years, the Council has addressed several areas of the nexus, including electricity production, fuels extraction, and the municipal water sector. Today, the Council is focusing on an intersecting issue that both the energy and water industries can work on together: how to promote sustainable strategies for recycling and finding beneficial uses for produced water from oil and gas production. The Council convened its “Produced Water: Asset or

Waste?" workshop on June 24-25, 2013, to provide the energy and water industries with an opportunity to identify sustainable water use plans and technologies to meet the needs for treating produced water. Both industries were asked to discuss policy and regulatory recommendations that would encourage best practices. Other key stakeholders and experts discussed market opportunities and the investment outlook. The audience heard many different perspectives from Capitol Hill to organizations working on unique produced water projects. By holding forums with experts and stakeholder groups, the Council aims to both educate and encourage dialogues that can lead to solutions.

Lyster (2013). "Quantification of Uncertainty in Shale Gas Resources". Alberta Energy Regulator, Alberta Geological Survey. AER/AGS Open File Report 2013-13.

Recent advances in fracturing and horizontal drilling technology have made unconventional petroleum resources increasingly important to the oil and gas industry in Alberta. The term 'shale gas' has largely become a catchall phrase to describe any unconventional plays that require fracturing, including shale gas, shale oil, tight gas, tight oil, and hybrid laminated reservoirs. With the emergence of these new sources of oil and gas, quantification of the resources has become a topic of major interest. The scarcity of historical data, sparse sampling of shale formations, and relatively poor understanding of unconventional reservoirs lead to large uncertainty in shale gas resource estimates. The Energy Resource Appraisal group of the Energy Resources Conservation Board has developed a methodology for quantifying the uncertainty in shale gas resource estimates in a geostatistical, data-driven framework that accounts for as many sources of uncertainty as possible. The uncertainty in individual variables can be quantified by maps, bivariate scatterplots, or histograms. However, when taken together, the distribution of all variables simultaneously is too complex to summarize in any simplified way. The methodology presented in this report is to calculate shale and other continuous unconventional resources for which few wells are available for data collection and little or no production history is established. The methodology has proven to be robust regarding data availability to determine resource endowment for a formation and also to identify areas where land sales and drilling may first occur. The latter is useful for planning by local and provincial governments and agencies.

MacIntosh (2014). "Discussion Paper: Hydraulic Fracturing - Understanding the General Regulatory Issues. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process".

Regulations are a key method by which governments protect and promote the interests of their citizens. Ideally, they serve to prevent harm from occurring, and include measures to mitigate the impact or consequences of harms which may nonetheless take place. Nova Scotians have expressed concerns about whether regulations can provide a satisfactory level of protection from the known and suspected risks associated with hydraulic fracturing. These concerns must be addressed. This discussion paper does not project a regulatory regime for Nova Scotia. Rather, it explains the limits of regulating, and identifies some of the factors which make it more or less likely that a regulatory regime will serve its purpose.

The paper identifies the roles of different levels of government in the decision-making process around hydraulic fracturing activities, and provides an overview of some of the approaches to regulating hydraulic fracturing in various provinces, including Nova Scotia. It then turns to exploring the relationship between regulations and risk-management, and in particular identifies how the efficacy of regulations for protecting health and the environment turns on (i) the adequacy of the knowledge base,(ii) political will and responsiveness of the regulations to the knowledge base, and (iii) whether and how regulations are implemented, resourced and enforced. The paper provides examples of these elements in action, drawn from hydraulic fracturing experiences in Canada and the United States. The paper observes that since the adequacy of protection from risks is a matter of degree, resting both on the actions of industry and of the state, and since hydraulic fracturing is publicly contentious, that decisions about the terms under which hydraulic fracturing may or may not take place in Nova Scotia ought to be regionally-specific and community driven. At the end of the paper is an appendix, which describes some of the lawsuits that have been launched around hydraulic fracturing in Canada and the United States. It includes a brief discussion of legal actions which have been brought against companies as well as provinces.

MacIntosh (2014). "Hydraulic Fracturing and the Aboriginal, Treaty and Statutory Rights of the Mi'kmaq Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process".

The Mi'kmaq people possess robust Treaty rights as well as Aboriginal rights in Nova Scotia. These rights have considerable consequences for provincial deliberations over hydraulic fracturing, as the province is constitutionally obliged to honour these rights. The province does not have lawful authority to take actions which infringe upon the Mi'kmaq's treaty rights without consent. As a result the province must engage in a consultation process so that it can understand how treaty rights could be affected by activities associated with hydraulic fracturing. The province is also constitutionally required to respect the Mi'kmaq's Aboriginal rights, and to consult with the Mi'kmaq so as to understand what those inherent rights. In some circumstances, the province may be able to infringe upon the Mi'kmaq's Aboriginal rights, but only if a strict justification test is met. If the Mi'kmaq people possess Aboriginal title rights over portions of Nova Scotia where there is subsurface shale gas, they have the right to decide whether that gas will be exploited and to receive the economic benefits. Similarly, if there is shale gas located below reserve land, hydraulic fracturing can likely only take place on their reserves with their full consent.

Maguire-Boyle et al. (2014). "Automated method for determining the flow of surface functionalized nanoparticles through a hydraulically fractured mineral formation using plasmonic silver nanoparticles". <u>Environmental Science Processes & Impacts</u>.**16**: 220–231

Quantifying nanoparticle (NP) transport within porous geological media is imperative in the design of tracers and sensors to monitor the environmental impact of hydraulic fracturing that has seen increasing concern over recent years, in particular the potential pollution and contamination of aquifers. The surface chemistry of a NP defining many of its solubility and transport properties means that there is a wide range of functionality that it is desirable to screen for optimum transport. Most prior transport methods are limited in determining if significant adsorption occurs of a NP over a limited column distance, however, translating this to effects over large distances is difficult. Herein we report an automated method that allows for the simulation of adsorption effects of a dilute nanoparticle solution over large distances under a range of solution parameters. Using plasmonic silver NPs and UV-visible spectroscopic detection allows for low concentrations to be used while offering greater consistency in peak absorbance leading to a higher degree of data reliability and statistics. As an example, breakthrough curves were determined for mercaptosuccinic acid (MSA) and cysteamine (CYS) functionalized Ag NPs passing through Ottawa sand (typical proppant material) immobile phase (C) or bypassing the immobile phase (C0). Automation allows for multiple sequences such that the absorption plateau after each breakthrough and the rate of breakthrough can be compared for multiple runs to provide statistical analysis. The mobility of the NPs as a function of pH is readily determined. The stickiness (a) of the NP to the immobile phase calculated from the C/C0 ratio shows that MSA-Ag NPs show good mobility, with a slight decrease around neutral pH, while CYS-Ag NPs shows an almost sinusoidal variation. The automated process described herein allows for rapid screening of NP functionality, as a function of immobile phase (proppant versus reservoir material), hydraulic fracturing fluid additives (guar, surfactant) and conditions (pH, temperature).

Manda et al. (2014). "Evolution of multi-well pad development and influence of well pads on environmental violations and wastewater volumes in the Marcellus shale (USA)". Journal of Environmental Management. **142**: 36-45

A majority of well pads for unconventional gas wells that are drilled into the Marcellus shale (northeastern USA) consist of multiple wells (in some cases as many as 12 wells per pad), yet the influence of the evolution of well pad development on the extent of environmental violations and wastewater production is unknown. Although the development of multi-well pads (MWP) at the expense of single well pads (SWP) has been mostly driven by economic factors, the concentrated nature of drilling activities from hydraulic fracturing and horizontal drilling operations on MWP suggests that MWP may create less surface disturbance, produce more volumes of wastewater, and generate more environmental violations than SWP. To explore these hypotheses, we use geospatial techniques and statistical analyses (i.e., regression and ManneWhitney tests) to assess development of unconventional shale gas wells, and quantify environmental violations and wastewater volumes on SWP and MWP in Pennsylvania. The analyses include assessments of the influence of different types of well pads on potential, minor and major environmental events. Results reveal that (a) in recent years, a majority of pads on which new wells for unconventional gas were drilled are MWP, (b) on average, MWP have about five wells located on each pad and thus, had the transition to MWP not occurred, between two and four times as much land surface disturbance would have occurred per year if drilling was relegated to SWP, (c) there were more environmental violations on MWP than SWP, but when the number of wells were taken into account, fewer environmental violations per well were observed on MWP than on SWP, (d) there were more wastewater and recycled wastewater volumes per pad and per well produced on MWP than on SWP, and (e) the proportion of wastewater that was recycled was higher on MWP than SWP. This study sheds light on how the evolution from SWP to MWP has influenced environmental violations and wastewater production in a field that has undergone rapid development in recent years.

Mangmeechai et al. (2014). "Life cycle consumptive water use for oil shale development and implications for water supply in the Colorado River Basin". The International Journal of Life Cycle Assessment. **19**(3): 677-687

Oil shale is an unconventional petroleum source that can be produced domestically in the USA. Oil shale resources are primarily located in Utah, Wyoming, and Colorado, within the Colorado River Basin. In this paper, we analyze the life cycle consumptive water use for oil shale production and its impacts on water resources of the Colorado River Basin. The study is focused on life cycle consumptive water use for oil shale development. Consumptive water use is defined as "water that is evaporated, transpired, incorporated into products, or otherwise removed from the immediate water environment." The analysis includes direct consumptive water requirements to extract, process, and refine shale oil, as well as indirect consumptive water use for generating the electricity associated with the extraction and processing. From the results, strategies for water supply certainty are discussed, and strategies for implementation are suggested. In addition, refining the shale oil outside of the oil shale region (removing the need for local water), using dry cooling systems for electricity generation, and building desalination plants in California (to replace water) are evaluated. Life cycle consumptive water use for oil shale is significant and could impact water availability for consumers in the lower Colorado River Basin. At a level of oil production of 2 million barrels per day, the life cycle consumptive water use would be significant: between 140 and 305 billion gallons (0.4 and 0.9 million acre-ft.) of water per year if surface mining and retorting is done, or between 150 and 340 billion gallons (0.5 and 1 million acre-ft.) of water per year if the Shell in situ process is used. Strategies could be implemented to provide water supply certainty including refining the shale oil outside of the region (removing some need for local water), using dry cooling systems for electricity generation, and building desalination plants in California (to replace water). Water supply in the Colorado River Basin could be a primary constraint to the development of oil shale. At a level of oil production of 2 million barrels per day, the life cycle consumptive water use would be significant. Energy companies or governments may want to invest in water management and supply strategies that would eliminate the uncertainty associated with the water availability in the Colorado River Basin for oil shale development.

Maryland Department of the Environment Maryland & Department of Natural Resources (2014). “Marcellus shale safe drilling initiative study part II, interim final best practices”. Prepared pursuant to Executive Order 01.01.2011.11.

An Advisory Commission was established to assist State policymakers and regulators in determining whether and how gas production from the Marcellus Shale in Maryland can be accomplished without unacceptable risks of adverse impacts to public health, safety, the environment, and natural resources. The State has not yet determined whether gas production can be accomplished without unacceptable risk and nothing in this report should be interpreted to imply otherwise. Whereas the CGDP establishes the locations for well pads, roads, pipelines and other ancillary equipment, the application for an individual well permit will require detailed plans for all activities, from construction of the access road through closure and restoration of the site. The elements of the plan must meet or exceed standards for engineering, design and environmental controls that are recommended in this report. These standards address activities from the initial construction of the access road and pad through closure and restoration of the site. They address sediment and erosion control, stormwater management, transportation planning, water acquisition, storage and reuse, disclosure of chemicals, drilling, casing and cement, blowout prevention, hydraulic fracturing, flowback and produced water, air emissions, wastewater treatment and disposal, leak detection, light, noise, invasive species, spill prevention control and emergency response, site security and closure and reclamation. These standards do not preclude the use of new and innovative technologies that provide greater protection of public health, the environmental and natural resources. The report also makes recommendations relating to monitoring, recordkeeping and reporting. Appendices provide additional information on specific subjects and include comments of the Advisory Commission and a summary of and response to public comments.

Mauter et al. (2014) “Regional Variation in Water-Related Impacts of Shale Gas Development and Implications for Emerging International Plays”. Environmental Science and Technology. **48**: 8298−8306

The unconventional fossil fuel industry is expected to expand dramatically in coming decades as conventional reserves wane.Minimizing the environmental impacts of this energy transition requires a contextualized understanding of the unique regional issues that shale gas development poses. This manuscript highlights the variation in regional water issues associated with shale gas development in the U.S. and the approaches of various states in mitigating these impacts. The manuscript also explores opportunities for emerging international shale plays to leverage the diverse experiences of U.S. states in formulating development strategies that minimize water-related impacts within their environmental, cultural, and political ecosystem.

Mauro (2014). “Discussion Paper: The Environmental Impacts of Hydraulic Fracturing in Nova Scotia – A public participatory risk assessment”

This paper takes a participatory risk assessment approach to understanding the environmental impacts associated with hydraulic fracturing in Nova Scotia. Analyzing 238 unique public submissions to the Expert Panel, it was found that a significant majority of these stakeholders oppose hydraulic fracturing and want to see a continued moratorium or ban in the province. The main perceived risks by those submitting comments on hydraulic fracturing in order of significance were related to: water, community and infrastructure, economy, waste and clean-up, human health, climate change and other environmental issues like increased potential for earthquakes and habitat fragmentation. These citizens’ perspectives were compared to and supported by available scientific literature suggesting that hydraulic fracturing poses credible threats to human and environmental systems. Uncertainty exists regarding the manageability of environmental risks and externalities and a precautionary approach to developing hydraulic fracturing in Nova Scotia is recommended. Given the multi-faceted nature of this type of development, hydraulic fracturing may be considered a complex or ‘wicked problem’ that is difficult to resolve in purely scientific terms. Ongoing public consultation, interdisciplinary research and careful consideration of policies and regulations moving forward is required to ensure the balance between sustainability and economic renewal in Nova Scotia.

McGarial et al. (date unknown). “Landscape dynamics, Overview of landscape dynamic concepts”

This is a series of slides listing the objective of: To provide an overview of important concepts underpinning the study of landscape dynamics and alternative concepts of landscape equilibrium. Highlight the spatial and temporal scaling of disturbance regimes and the influence on equilibrium/nonequilibrium dynamics.

Topics covered include: 1) Landscape dynamics concepts – stability, persistence, resistance, resilience and recovery. 2) Landscape equilibrium concepts – absolute constancy, shifting mosaic-steady state, stationary processes, bounded equilibrium. 3) Nonequilibrium landscapes – role of legacies, landscape uniqueness, importance of scale. 4) Disturbance and landscape equilibrium – scaling of disturbance regimes. 5) Anthropogenic influences on landscape dynamics. 6) Management implications.

McHugh et al. (2014) “Comment on “An Evaluation of Water Quality in Private Drinking Water Wells Near Natural Gas Extraction Sites in the Barnett Shale Formation”. Environmental Science and Technology. **48**(6): 3595–3596

This is a response to Fontenot et al. 2013 which found that the authors' data do not support their conclusions because: a) the comparison between the active area and the non-active/reference data sets is flawed; b) the comparison against the historic data sets does not suggest current impacts; c) the water quality patterns observed in these datasets are not likely related to natural gas extraction activities.

McNutt (2011). “Natural Gas Hydraulic Fracturing, Issues USGS is Tracking”. US Geological Survey

This is a series of slides, the topics covered include: 1) Water quality, domestic water supply and impact on aquatic species. 2) Induced seismicity with evidence of cause/effect. 3) Landscape modification, degree of fragmentation and impacts on wildlife migration. 4) Science of fluid flow at depths of injection, long-term fate of 10's of millions of gallons of fluids and stress-strain-time history. The slides conclude stating that; Direct and indirect impacts result from hydraulic fracturing, monitoring data and science can inform decision making and coordination through federal –state –industry partnerships are important.

Meng (2014). “Modeling and prediction of natural gas fracking pad landscapes in the Marcellus Shale region, USA”. Landscape and Urban Planning **121**: 109–116

Natural gas fracking pad sites, as a type of industrial landscape, have been blooming up in Marcellus Shale region especially within the State of Pennsylvania in the last few years. However, no study has explored the driving landscape and environmental variables of fracking pad sites, and how gas fracking pads as a specific landscape spread out in the Marcellus Shale region. Using the Washington County, Pennsylvania, USA as the study area, this paper proposes a novel GIS landscape modeling approach to model the relationships between landscape variables and natural gas fracking pad sites. The impacts of significant landscape variables on natural gas fracking pad sites are assessed. Statistic diagnostics of spatial logistic regression modeling find significant landscape variables of elevation, slope, and land use land cover. Higher elevation will result in higher probability to be fracking pad sites, while deeper slopes will result in a lower probability to be fracking pad sites. Natural gas fracking pad sites do not randomly intrude the initial landscapes, while land use land cover experiences different invasive risks of natural gas fracking, and in the order of open water, developed land, barren land, forest land, shrubland, grassland, agriculture land, and wetland, the probability of being intruded by natural gas fracking sites increases at 3.76%. This landscape model finally is used to predict natural gas fracking pad sites. The predicted spatial distribution provides significant insight for landscape and natural resources regulation, land use administration, transportation and urban planning, and ecosystem and environment conservations.

Michaels et al. (2010). “Fractured communities, Case studies of the environmental impacts of industrial gas drilling”. Riverkeeper

This report describes hundreds of case studies demonstrating that industrial gas drilling, including horizontal drilling using high-volume hydraulic fracturing, results in significant adverse environmental impacts. These impacts result from changes in land use, road building, water withdrawals, improper cementing and casing of wells, over-pressurized wells, gas migration from new and abandoned wells, the inability of wastewater treatment plants to treat flowback and produced water, underground injection of brine wastewater, improper erosion and sediment controls, truck traffic, compressor stations, as well as accidents and spills. The studies in this report rely exclusively on investigations, findings, and statements of state and federal regulators in the Marcellus Shale region (Pennsylvania, Ohio, and West Virginia), the Barnett Shale (Texas), the Fayetteville Shale (Louisiana and Arkansas), as well as regulators in the western states of Wyoming and Colorado. After analyzing reports from state and federal regulators, this report concludes with recommendations that, if fully realized, may help to alleviate some of the problems documented across the country. These recommendations include legislative and regulatory actions that would be necessary in order to prevent and control further environmental contamination.

Mohan et al. (2013). “Microbial Community Changes in Hydraulic Fracturing Fluids and Produced Water from Shale Gas Extraction”. Environmental Science and Technology. **47**: 13141−13150

Microbial communities associated with produced water from hydraulic fracturing are not well understood, and their deleterious activity can lead to significant increases in production costs and adverse environmental impacts. In this study, we compared the microbial ecology in prefracturing fluids (fracturing source water and fracturing fluid) and produced water at multiple time points from a natural gas well in southwestern Pennsylvania using 16S rRNA gene-based clone libraries, pyrosequencing, and quantitative PCR. The majority of the bacterial community in prefracturing fluids constituted aerobic species affiliated with the class Alphaproteobacteria. However, their relative abundance decreased in produced water with an increase in halotolerant, anaerobic/facultative anaerobic species affiliated with the classes Clostridia, Bacilli, Gammaproteobacteria, Epsilonproteobacteria, Bacteroidia, and Fusobacteria. Produced water collected at the last time point (day 187) consisted almost entirely of sequences similar to Clostridia and showed a decrease in bacterial abundance by 3 orders of magnitude compared to the prefracturing fluids and produced water samples from earlier time points. Geochemical analysis showed that produced water contained higher concentrations of salts and total radioactivity compared to prefracturing fluids. This study provides evidence of long-term subsurface selection of the microbial community introduced through hydraulic fracturing, which may include significant implications for disinfection as well as reuse of produced water in future fracturing operations.

Molofsky et al. (2013). “Evaluation of Methane Sources in Groundwater in Northeastern Pennsylvania”. Groundwater. **51**(3): 333–349

Testing of 1701 water wells in northeastern Pennsylvania shows that methane is ubiquitous in groundwater, with higher concentrations observed in valleys vs. upland areas and in association with calcium-sodiumbicarbonate, sodium-bicarbonate, and sodium-chloride rich waters—indicating that, on a regional scale, methane concentrations are best correlated to topographic and hydrogeologic features, rather than shale-gas extraction. In addition, our assessment of isotopic and molecular analyses of hydrocarbon gases in the Dimock Township suggest that gases present in local water wells are most consistent with Middle and Upper Devonian gases sampled in the annular spaces of local gas wells, as opposed to Marcellus Production gas. Combined, these findings suggest that the methane concentrations in Susquehanna County water wells can be explained without the migration of Marcellus shale gas through fractures, an observation that has important implications for understanding the nature of risks associated with shale-gas extraction.

Moore et al. (2014). “Hydraulic fracturing for shale gas in the UK: Examining the evidence for potential environmental impacts”. The Royal Society for the Protection of Birds

High-volume hydraulic fracturing in combination with horizontal drilling are key techniques that have enabled the economic production of unconventional, onshore natural gas resources from shale gas plays. While the rapid expansion of shale gas production has dramatically changed the energy landscape in the United States, recent scientific findings show evidence for contamination of water resources and point to a range of environmental challenges arising from the process. It is, therefore, vital that the emerging shale gas industry in the UK benefits from the lessons learned from the US experience. The objectives of this evidence report are to examine and review available evidence on: The potential environmental impacts of hydraulic fracturing and shale gas extraction, in general, and the adequacy of practices and policies currently being developed and implemented in the UK to mitigate these impacts. In addition, the report involves a high-level vulnerability assessment of the water-related and ecological threats by considering how the industry is likely to evolve and how it will interact with the natural environment given what we know about both the nature of the industry, and the ecological and water body receptors likely to be affected.

Muehlenbachs et al. (2014). "The Housing Market Impacts of Shale Gas Development." Resources for the Future (RFF) Report. RFF DP 13-39-REV

Using data from Pennsylvania and New York and an array of empirical techniques to control for confounding factors, we recover hedonic estimates of property value impacts from shale gas development that vary with geographic scale, water source, well productivity, and visibility. Results indicate large negative impacts on nearby groundwater-dependent homes, while piped-water-dependent homes exhibit smaller positive impacts, suggesting benefits from lease payments. At a broader geographic scale, we find that new wellbores increase property values, but these effects diminish over time. Undrilled permits cause property values to decrease. Results have implications for the debate over regulation of shale gas development.

Myers (2013). "Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers". Groundwater. **50**(6): 872–882 ***this paper has since been debunked by several sources***

Hydraulic fracturing of deep shale beds to develop natural gas has caused concern regarding the potential for various forms of water pollution. Two potential pathways—advective transport through bulk media and preferential flow through fractures—could allow the transport of contaminants from the fractured shale to aquifers. There is substantial geologic evidence that natural vertical flow drives contaminants, mostly brine, to near the surface from deep evaporite sources. Interpretative modeling shows that advective transport could require up to tens of thousands of years to move contaminants to the surface, but also that fracking the shale could reduce that transport time to tens or hundreds of years. Conductive faults or fracture zones, as found throughout the Marcellus shale region, could reduce the travel time further. Injection of up to 15,000,000 L of fluid into the shale generates high pressure at the well, which decreases with distance from the well and with time after injection as the fluid advects through the shale. The advection displaces native fluids, mostly brine, and fractures the bulk media widening existing fractures. Simulated pressure returns to pre-injection levels in about 300 d. The overall system requires from 3 to 6 years to reach a new equilibrium reflecting the significant changes caused by fracking the shale, which could allow advective transport to aquifers in less than 10 years. The rapid expansion of hydraulic fracturing requires that monitoring systems be employed to track the movement of contaminants and that gas wells have a reasonable offset from faults.

National Resource Defence Council (NRDC) (2012). "Hydraulic Fracturing Can Potentially Contaminate Drinking Water Sources"

Communities across the country are concerned about the risks that oil and gas production using fracking poses to drinking water sources. Hydraulic fracturing, or fracking, is the practice of injecting water, chemicals, and proppant at high pressure into a gas or oil well. The high-pressure injection fractures or re-fractures the rock, stimulating oil and gas production. But scientists and environmentalists are increasingly concerned about groundwater and surface water contamination that may be associated directly or indirectly with fracking. NRDC opposes expanded fracking until effective safeguards are in place. To protect drinking water sources from contamination, NRDC urges the use of key management practices to minimize the risks associated with fracking activities. This includes; federal regulation of all hydraulic fracturing under the Safe Drinking Water Act, regulation of toxic oil and gas waste under federal and state hazardous waste laws, and stronger standards and enforcement under the federal Clean Water Act and state laws.

National Resource Defence Council (NRDC) (2012). "In Fracking's Wake: New Rules are Needed to Protect Our Health and Environment from Contaminated Wastewater". NRDC Issue Brief. ib:12-05-A

This report combines an evaluation of federal and state laws regulating fracking wastewater with a thorough review, compiled for NRDC by an independent scientist, of the health and environmental risks posed by this high-volume waste stream and the currently available treatment and disposal methods. It finds that the currently available options are inadequate to protect human health and the environment, but that stronger safeguards at the state and federal levels could better protect against the risks associated with this waste. The most significant of the policy changes needed now are (a) closing the loophole in federal law that exempts hazardous oil and gas waste from treatment, storage, and disposal requirements applicable to other hazardous waste, and (b) improving regulatory standards for wastewater treatment facilities and the level of treatment required before discharge to water bodies. In examining a number of different fracking wastewater disposal methods that are being used in the Marcellus Shale region, the report finds that although all are problematic, with better regulation some could be preferable while others should not be allowed at all. NRDC opposes expanded fracking without effective safeguards. States such as New York that are considering fracking should not move forward until the available wastewater disposal options are fully evaluated and safeguards are in place to address the risks and impacts identified in this report. Where fracking is already taking place, the federal government and states must move forward swiftly to adopt the policy recommendations in this report to better protect people and the environment.

National Resource Defence Council (NRDC) (2012). "State Hydraulic Fracturing Disclosure Rules and Enforcement: A Comparison". NRDC Issue Brief. ib:12-06-A

This analysis compares state hydraulic fracturing disclosure rules that: require some identification of the substances used in hydraulic fracturing for oil and gas; and make records available to the public online without a public records request. Fourteen states require some level of public hydraulic fracturing disclosure as of the date of publication. However, there is hydraulic fracturing activity in at least twenty-nine states. More than half of the states with hydraulic fracturing activity currently have no disclosure requirements at all. Of the existing state rules, none provide comprehensive disclosure. Enforcement of state rules is also found to be uneven.

National Energy Laboratory (2013). "Waste Water Metrology Challenges Related to Unconventional Gas

Production”. Project No: FHRE05, Report No: 2013 310

This report covers the current state of play of unconventional gas production and measurement practices in the UK, Europe and USA; Regulatory requirements and water quality standard development for waste water discharges and Waste water management, measurement and handling options.

Nature Climate Change (2013). “Fracking fracus”. Nature climate change. **3**: 429

Natural gas from organic-rich shale deposits is widely touted as a bridge to a cleaner future. According to supporters, shale-gas use will deliver energy security and reduce energy costs. They also claim that burning shale gas rather than coal for energy will reduce greenhouse gas emissions from power plants. Opponents, on the other hand, see shale gas as a bridge to nowhere. These detractors point to methane emissions and other environmental and safety concerns associated with shale-gas extraction through hydraulic fracturing, or ‘fracking’. They also fear that in the long term, shale gas will be fully exploited in addition to, rather than instead of, oil and coal. Many peopled concerned about the environment nevertheless see a place for shale gas as a cleaner alternative to oil and coal. Others would prefer shale gas to be left in the ground, arguing that policymakers should focus instead on energy efficiency and renewables. For nations such as the United States, that simply is not going to happen. The powers that be seem convinced that shale-gas exploitation will have significant economic benefits.

Navi et al. (2014). “Coal seam gas water: potential hazards and exposure pathways in Queensland”. International Journal of Environmental Health Research. **DOI:10.1080/09603123.2014.915018**

The extraction of coal seam gas (CSG) produces large volumes of potentially contaminated water. It has raised concerns about the environmental health impacts of the co-produced CSG water. In this paper, we review CSG water contaminants and their potential health effects in the context of exposure pathways in Queensland’s CSG basins. The hazardous substances associated with CSG water in Queensland include fluoride, boron, lead and benzene. The exposure pathways for CSG water are (1) water used for municipal purposes; (2) recreational water activities in rivers; (3) occupational exposures; (4) water extracted from contaminated aquifers; and (5) indirect exposure through the food chain. We recommend mapping of exposure pathways into communities in CSG regions to determine the potentially exposed populations in Queensland. Future efforts to monitor chemicals of concern and consolidate them into a central database will build the necessary capability to undertake a much needed environmental health impact assessment.

New York Marine Sciences Consortium (NYMSC) (2011). “An Assessment of Some of the Environmental and Public Health Issues Surrounding Hydraulic Fracturing in New York State”

The New York Marine Sciences Consortium (NYMSC) is an association of colleges, universities, and degree-granting institutions (28 members, 5 affiliates) with expertise and interest in marine and/or coastal sciences. NYMSC is the voice of New York State’s marine science academic community, which strives to influence public policy, communicate science, and increase funding for the marine sciences within New York. Through research and education, NYMSC seeks to find solutions to the challenges that New York’s coastal communities face. In response to the New York State Department of Environmental Conservation’s Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas, and Solution Mining Regulatory Program (SGEIS) and the impending decision of the Governor, the Consortium is writing to offer several recommendations regarding the proposed use of hydraulic fracturing for the production of natural gas in New York State. Foremost among these is that the moratorium be extended at least until 2014 when a more comprehensive study of potential impacts on water resources will have been completed by the federal government.The following is an outline of the primary research questions regarding the environmental impact of hydraulic fracturing of the Marcellus Shale and for New York State. In the absence of clear federal regulations and the exemptions from the Federal Safe Drinking Water Act, Clean Water Act, and the Clean Air Act, we believe that it is imperative for New York State to move cautiously in embracing this industry. Now is definitely a time when the Precautionary Principle should be adopted.

New York State Department of Health (2014). “A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development”

As with most complex human activities in modern societies, absolute scientific certainty regarding the relative contributions of positive and negative impacts of high volume hydraulic fracturing (HVHF) on public health is unlikely to ever be attained. In this instance, however, the overall weight of the evidence from the cumulative body of information contained in this Public Health Review demonstrates that there are significant uncertainties about the kinds of adverse health outcomes that may be associated with HVHF, the likelihood of the occurrence of adverse health outcomes, and the effectiveness of some of the mitigation measures in reducing or preventing environmental impacts which could adversely affect public health. Until the science provides sufficient information to determine the level of risk to public health from HVHF to all New Yorkers and whether the risks can be adequately managed, DOH recommends that HVHF should not proceed in NYS

NGWA (National Groundwater Association) (2011). “Hydraulic Fracturing: Meeting the Nation’s Energy Needs While Protecting Groundwater Resources”

NGWA recognizes that hydraulic fracturing of oil and gas wells is a mature technology and has been employed for many decades. While no widespread water quality or quantity issues have been definitively documented that are attributable to hydraulic fracturing and related activities at oil and gas well sites, there have been isolated cases where faulty casing installations (including poor cement bonds) or poor management of materials/chemicals at the surface are suspected as having negatively impacted groundwater, surface water, or water wells. Therefore, NGWA believes that additional studies, research, and monitoring related to the potential for groundwater contamination from the installation, hydraulic fracturing, operation, and maintenance of oil and gas wells are needed, given the growing use of horizontal wells and hydraulic fracturing. U.S. EPA’s hydraulic fracturing study, if adequately funded, implemented, and peer reviewed, will result in valuable data upon which to build. In the interim, the nation’s groundwater resource can best be protected by ensuring that policies are in place and enforced at the appropriate level of government that promote proper well construction and maintenance, both water well and oil and gas; the filling and sealing of abandoned wells; water supply planning and minimization of freshwater use in oil and gas operations; careful chemical handling and waste disposal by the oil and gas industry; disclosure of chemicals used in oil and gas hydraulic fracturing; baseline testing of drinking water wells in proximity to future oil and gas operations; an integrated groundwater quality and level monitoring program tailored to these operations; as well as recognition of the timeframe of groundwater movement.

Nicot et al. (2012). “Oil & Gas Water Use in Texas: Update to the 2011 Mining Water Use Report”. Prepared for Texas Oil & Gas Association, Austin, Texas.

This report provides and update to the previous 2011 report where the authors undertook a study of water use in the mining and oils and gas industry in Texas, from 2008 and projected until 2060. The study also includes the upstream segment of the oil and gas industry (that is, water used to extract the commodity until it leaves the wellhead). The report predicts an increase in brackish water use which when combined with improvements in water recycling will result in lower fresh water consumption. The predictions show that oil and gas will account for approximately 50% of water use in the mining industry, but that this only represents <1% of the total water use in Texas.

Nicot et al. (2014). “Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective” Environmental Science and Technology. **48**(4): 2464–2471

Considerable controversy continues about water availability for and potential impacts of hydraulic fracturing (HF) of hydrocarbon assets on water resources. Our objective was to quantify HF water volume in terms of source, reuse, and disposal, using the Barnett Shale in Texas as a case study. Data were obtained from commercial and state databases, river authorities, groundwater conservation districts, and operators. Cumulative water use from ~18 000 (mostly horizontal) wells since 1981 through 2012 totaled ~170 000 AF (210 Mm^3); ~26 000 AF (32 Mm^3) in 2011, representing 32% of Texas HF water use and ~0.2% of 2011 state water consumption. Increase in water use per well by 60% (from 3 to 5 Mgal/well; 0.011–0.019 Mm^3) since the mid-2000s reflects the near-doubling of horizontal-well lengths (2000–3800 ft), offset by a reduction in water-use intensity by 40% (2000–1200 gal/ft; 2.5–1.5 m^3/m). Water sources include fresh surface water and groundwater in approximately equal amounts. Produced water amount is inversely related to gas production, exceeds HF water volume, and is mostly disposed in injection wells. Understanding the historical evolution of water use in the longest-producing shale play is invaluable for assessing its water footprint for energy production.

Nikiforuk (2013) “Shale gas: how hard on the landscape?” The Tyee

The shale gas industry claims that it is doing everything it can to minimize its impact on forests and farms, but therein lies the resource's second major myth. Industry lobbyists such as Canadian Association of Petroleum Producers (CAPP), for example, claim that a natural gas well site is about the size of a two car garage and that "the use of multi-well drilling pads have greatly reduced the area of land disturbed in drilling operations."EnCana, a big shale gas player, adds its own twist to the claim: "One 250-by-250-metre-square multi-well pad produces some 15 square kilometres of resource, essentially replacing several hundred vertical wells and well sites, along with their associated roads and pipelines. The result is enhanced environmental performance through minimized land disturbance." But Anthony Ingraffea, the Cornell University professor of engineering who has long studied the science of rock fracturing and consulted to industry, says that frackers aren't telling the whole story about their impact on landscapes.

North Carolina Department of Environment and Natural Resources (NCDENR) (2012). “North Carolina Oil and Gas Study under Session Law 2011---276”

In Session Law 2011-276, the North Carolina General Assembly directed the North Carolina Department of Environment and Natural Resources (DENR), the Department of Commerce (Commerce), and the Department of Justice, in conjunction with the nonprofit Rural Advancement Foundation International (RAFI), to study the issue of oil and gas exploration in the state and specifically the use of directional and horizontal drilling and hydraulic fracturing for natural gas production.

DENR researched oil and gas resources present in the Triassic Basins (Section 1 of this report), methods of exploration and extraction of oil and gas (Section 2), potential impacts on infrastructure, including roads, pipelines and water and wastewater services (Section 3), potential environmental and health impacts (Section 4), potential social impacts (Section 6), and potential oversight and administrative issues associated with an oil and gas regulatory program (Section 7).

NSHF (2014). "Primer on the Process of Hydraulic Fracturing" Nova Scotia Hydraulic Fracturing Independent Review and Public Consultation

This document is not a position paper. It is intended solely as a descriptive 'primer' on the process of Hydraulic Fracturing for use in the Hydraulic Fracturing Independent Review and Public Consultation in Nova Scotia. Hydraulic fracturing is sometimes referred to as 'fracking' or 'fracing'. The paper does not draw any conclusions but invites feedback – from stakeholders and from the Nova Scotia public - so that we can start from a common set of understandings about the technology. The document will be further developed based on feedback received as the Review unfolds. This Primer focuses primarily on the technical aspects of fracturing. In this paper we do not address the oil and gas resource potential in Nova Scotia or the associated geological, economic, social, community, environmental, health or legal issues – including Aboriginal treaty questions - which will be the subject of future papers. The Primer is set out as a list of frequently asked questions; What is hydraulic fracturing? What industries use this technology? Which industrial use are we dealing with in this review? What is 'shale gas'? Is the exploitation of unconventional gas something new? Why is unconventional gas exploitation done? How are wells drilled to access unconventional gas reservoirs? Why is fracturing done and how is it accomplished? What is the fracturing fluid composed of? What is brought back to the surface after fracturing? What is done with the flow back water?

NSHF (2014). "What are the interactions between unconventional gas resources and water resources? Input quality and quantity requirements and water treatment needs and impacts." Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

Both quality and quantity of water are of great public concern and the government has an obligation to ensure water safety is upheld, regardless of the decision made regarding hydraulic fracturing. In the case that development of hydraulic fracturing is pursued, the following items will need to be addressed through a robust, responsive and transparent regulatory environment, and must be consistent with the Nova Scotia Environment Act: Transparency and understanding of operations and processing chemicals used, and identification of any potential adverse impacts on water quality (both ground and surface water) due to operations; Detailed analysis of water demands prior to and during operations on a case-by-case basis; and Transparency and upfront detailing of procedures and requirements for wastewater disposal and/or treatment.

NSHF (2014). “Discussion Paper: The Potential Oil and Gas Resource Base in Nova Scotia Accessible by Hydraulic Fracturing”. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

This paper looks at the resource and infrastructure potential for onshore oil and gas extraction in Nova Scotia including the use of hydraulic fracturing techniques. The physical geology does recognize resource potential for conventional and unconventional oil and gas in specific areas (sedimentary basins) in the Province, mostly in rural areas. Limited on-shore petroleum development has occurred to date, but no commercial oil and gas production has been established. Local and export markets exist for both oil and natural gas with demand growing. As knowledge of the subsurface, including sedimentary rocks and hydrocarbons, is extremely limited, it is very difficult to quantify the potential or even rank the various basins in terms of overall prospectivity. The shales in basins closest to New Brunswick are of most interest to developers to date because New Brunswick basins have demonstrated commercial production of both gas and oil, and pipeline infrastructure is in place. Using published information, potential gas volumes have been estimated at 17-69 TCF in the Windsor- Kennetcook Basin and coal bed methane volumes at .28-1.18 TCF in the Sydney, Stellarton and Cumberland Basins. Other basins may or may not have potential but very limited data or information exists. Exploration activity is likely to be limited, at least for the next several years, until such time as the moratorium on hydraulic fracturing is reviewed, additional seismic and well data are acquired, and the complexities of developing frontier basins are addressed.

NSHF (2014). “Discussion Paper: Petroleum Operations, Costs and Opportunities in Nova Scotia”. Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

This paper provides a basic overview of the process of exploring for and producing hydrocarbons, with a focus on economic costs and benefits, not technical matters. It describes generally what is involved in each phase of activity – exploration, field development, production and abandonment – setting out the costs and benefits including opportunities for involvement by the local workforce and contractors. Accordingly, the reader is cautioned that the activity and associated cost and content estimates are highly speculative and should at best be considered indicative, rather than definitive, of what could occur if this activity were ever to be pursued in Nova Scotia.

NSHF (2014). “Discussion Paper: Hydraulic Fracturing and Public Health in Nova Scotia”.Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

The development of unconventional oil and gas resources in Nova Scotia has potential to strengthen economic development and energy security; two key determinants of the health of our population. The main risks to physical human health arise from potential exposures to toxic materials through contamination of drinking water sources and atmospheric exposure; the extent to which such exposures can be reduced through effective regulation and best industrial practice should be key considerations in any government decision of whether to allow or encourage development. While the physical risks of unconventional gas and oil development do not appear to differ radically from those of conventional developments, it is their proximity to human habitation which leads to increased concern. Although the current state of knowledge does not identify issues with hydraulic fracturing which would pose a catastrophic risk to human health in the short or medium term, uncertainties around long term environmental effects, particularly those related to climate change and its impact on the health of both current and future generations, are considerable and should inform government decision making.

NSHF (2014). "Discussion Paper: The Environmental Impacts of Hydraulic Fracturing in Nova Scotia – A public participatory risk assessment".Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process.

This paper takes a participatory risk assessment approach to understanding the environmental impacts associated with hydraulic fracturing in Nova Scotia. Analyzing 238 unique public submissions to the Expert Panel, it was found that a significant majority of these stakeholders oppose hydraulic fracturing and want to see a continued moratorium or ban in the province. The main perceived risks by those submitting comments on hydraulic fracturing in order of significance were related to: water, community and infrastructure, economy, waste and clean-up, human health, climate change and other environmental issues like increased potential for earthquakes and habitat fragmentation. These citizens' perspectives were compared to and supported by available scientific literature suggesting that hydraulic fracturing poses credible threats to human and environmental systems. Uncertainty exists regarding the manageability of environmental risks and externalities and a precautionary approach to developing hydraulic fracturing in Nova Scotia is recommended. Given the multi-faceted nature of this type of development, hydraulic fracturing may be considered a complex or 'wicked problem' that is difficult to resolve in purely scientific terms. Ongoing public consultation, interdisciplinary research and careful consideration of policies and regulations moving forward is required to ensure the balance between sustainability and economic renewal in Nova Scotia.

NSHF (2014). "Energy Well Integrity". Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

Unconventional oil and gas development using modern cementing and completion techniques usually leads to good wellbore integrity, but, as in any industrial activity, there will never be a 100% success in sealing all wellbores against all possibilities of future leakage. Technology advances have helped reduce the incidence of leaking wells and provide better quality control and leak detection capabilities. The most common long term well integrity issue after abandonment is slow gas seepage around the external casing, but the consequences of such leaks, though negative from a climate change perspective, are not a great public health threat because natural gas is not a toxic substance, the number of wells that display high rate leaks is low, and the overall average leakage rates appear to be low. When leakage is identified, corrective measures can rectify problems. Though rigorous statistics remain elusive (and this should be studied quantitatively), it seems that the number of significant problems encountered in Alberta and British Columbia, relatively mature regulatory environments, is not large. Because possible future unconventional resource development in Nova Scotia would take place using modern technology with multiple wellbores installed at each drilling site, it is a relatively straightforward task to establish good regulatory practices (guidelines and enforcement), quality control, and monitoring to ensure that the site is geologically understood, that wells are properly installed, and that well abandonment is done according to best practice guidelines. The establishment of an appropriate monitoring and regulatory system for onshore Nova Scotia will clearly be needed if large scale unconventional oil and gas resource development ever takes place. Nova Scotia geological conditions are reasonably stable; this should lead to a low incidence of poor wellbore integrity for the following reasons: 1) Moderate tectonic stresses and dense competent rock in the subsurface mean that wellbore quality will be excellent (good stability, little drill hole sloughing), facilitating the installation of high quality well casings, and therefore resulting in fewer cases of leaking wells in the long term. 2) Except in Nova Scotia's coalbed areas, there appear to be few gas sands at shallow to intermediate depth that might lead to problems with long term gas migration behind the casing. 3) Oil and gas in Nova Scotia are likely to be sweet (little or no associated hydrogen sulphide gas), making all operations easier and casing life longer, compared to some other jurisdictions.

NSHF (2014). “Discussion Paper: Potential Socioeconomic Effects of Unconventional Oil and Gas Development in Nova Scotia Communities”.Nova Scotia Hydraulic Fracturing Independent Review and Public Engagement Process

Community impacts of energy development may be both positive and negative, and are described in four key areas: the local economy, social and physical infrastructure, the natural environment, and social relations within communities. The energy boomtown literature of the 1970s and 1980s focused on the negative impacts of the boom-bust-recovery cycle. Subsequent research has shown positive impacts in most categories. Human communities are dynamic and complex, as are the biophysical ecosystems of which they are a part. This document describes some of the potential and observed effects of unconventional oil and gas development on communities, with an eye toward understanding the possible social-ecological costs and benefits of unconventional oil and gas development through hydraulic fracturing in Nova Scotia. Absent from our understanding are the potential medium- and long-term community effects of unconventional oil and gas development, and peer-reviewed research on these, as well as short-term effects, closer to home. Should Nova Scotia move forward with unconventional oil and gas development, we recommend that this absence of knowledge be addressed through the creation of an independent, long-term social ecological monitoring program. This will allow the Province, and its community stakeholders, to understand and proactively control the effects of unconventional oil and gas development at local, regional, and provincial scales.

NPCA (2013). “National Parks and Hydraulic Fracturing”

Hydraulic fracturing (or “fracking”) has the potential to rewrite America’s energy future, presenting the possibility of an energy-independent nation. This relatively new extraction method is now responsible for 90 percent of domestic oil and gas production, with thousands of wells peppering the countryside. The number of wells is expected to skyrocket during the next two decades. The Energy Information Administration estimates that the United States has 2,119 trillion cubic feet of natural gas and 25.2 billion barrels of crude oil recoverable through fracking. What will history say about this innovation? What will the impacts be on America’s public lands—especially our cherished national parks? Even the experts can’t predict fracking’s impacts. Will it contaminate the air we breathe in national parks? Will it harm native wildlife and the water and forests they depend on for survival? Will it damage the resources we value in our national parks? The answers are just beginning to emerge. Consequently, the National Parks Conservation Association recommends that policymakers require a measured, thoughtful approach to fracking, especially near national parks and in their surrounding landscapes. We must make every effort to understand and anticipate potential consequences—before they become irreversible. Without smart planning, comprehensive pollution monitoring, and the best available environmental protections, oil and gas development near national parks will diminish America’s natural and cultural heritage one park at a time. Only through sound decision-making can policymakers protect these important cultural and natural resources. The National Park Service should be engaged as a formal cooperating agency, and comprehensive environmental reviews should be required when oil and gas drilling is proposed in the airshed, watershed, or connected landscapes that surround a national park. The Park Service should be a full partner with other agencies and with industry in determining where to avoid energy development that may impact national park wildlife, national park visitors' experience, or park visitors' health.

NPCA (date unknown). "Impacts of Fracking in the Marcellus Shale Threatens National Parks"

Thirty-five national parks overlie or are in the vicinity of the geological formation called the "Marcellus Shale." Covering approximately 48,000 square miles, the Marcellus Shale formation occurs beneath the states of New York, Pennsylvania, Ohio, Maryland, Virginia, West Virginia, and Tennessee. An estimated 363 trillion cubic feet of natural gas could be recovered from the formation, enough to supply the entire United States at current rates of consumption for 15 years. While scientists have long known about the resources of the Marcellus Shale, modern advances in hydraulic fracturing, or "fracking," are allowing access to the country's shale gas reserves as never before. Fracking involves pumping millions of gallons of water, sand, and chemicals into a well to fracture the shale and release the natural gas trapped within. Currently, the chemicals used in fracking do not have to be disclosed to the public.

Nova Scotia (2011). "Review of Hydraulic Fracturing in oil and gas operations in Nova Scotia"

This article provides a summary of the final scope for a review of hydraulic fracturing in oil and gas operations in Nova Scotia. The Nova Scotia government has announced a joint review by the departments of Energy and Environment to examine the potential impacts of hydraulic fracturing in oil and gas operations in the province. The team of senior technical and policy staff will work collaboratively to identify potential environmental issues, determine how they are managed in other jurisdictions and identify industry best practices. The team will look at the ongoing technical reviews of other jurisdictions across Canada and in the United States and bring in outside experts in certain subject areas as required. The team will also review the Province's existing regulations and practices and make recommendations to the Ministers to ensure industry and regulatory best practice is being employed in the province. The scope is focused primarily on issues about water. The review will examine the following potential environmental issues: Effects on groundwater, use of and effects on surface water, impacts on land, such as potential soil contamination, management of additives in hydraulic fracturing fluids (disclosure), waste management, including surface ponds of produced waters (treatment and disposal), site restoration, submission requirements for hydraulic fracturing design, and financial security / insurance that operators are required to provide prior to conducting activity in the province.

NYCEP (date unknown). "Natural Gas Drilling Overview"

The Marcellus Shale is a layer of deep sedimentary rock, deposited by an ancient river delta, with the remains of it now forming the Catskill Mountains. Hydraulic fracturing, or hydrofracking, is the creation of fractures within a reservoir that contains oil or natural gas to increase flow and maximize production. A hydraulic fracture is formed when a fluid is pumped down the well at pressures that exceed the rock strength, causing open fractures to form in the rock. Hydraulic fracturing allows drilling companies to extract natural gas from shale reserves such as the Marcellus. Natural gas is trapped within fractures between the grains of this fine-grained rock. Staged from a massive platform (towering hundreds of feet above ground), drillers drill down vertically into the shale, turn 90 degrees to drill horizontally (sometimes over a mile in length), and then inject water, sand and chemicals under high pressure to release the gas. The pressurized water forms fractures in the rock, which sand and chemicals then prop open. There are many environmental impacts associated with hydraulic fracturing, or "hydrofracking." Among them are, water consumption, wastewater disposal, use of toxic chemicals, substantial truck traffic, air pollution, noise from the loud, twenty-four hour hydrofracking operations, potential groundwater and well water contamination, deforestation, road building and surface water runoff from these large industrial sites. The cumulative effect of these impacts may indeed transform entire communities – turning previously rural, agrarian areas into "fractured communities."

NZPCE (2012). "Evaluating the environmental impacts of fracking in New Zealand: An interim report"

The high-level conclusion from the work done to date in this investigation echoes, and is broadly consistent with, the reviews of fracking that have been done elsewhere in the world. That conclusion is that the environmental risks associated with fracking can be managed effectively provided, to quote the United Kingdom Royal Society, "operational best practices are implemented and enforced through regulation". But at this stage I cannot be confident that operational best practices are actually being implemented and enforced in this country. Therefore, the investigation will now enter a second phase that will turn the spotlight on how well the environmental risks associated with fracking are actually regulated and monitored. Consequently this report is being released as an interim report, and as such contains seven interim findings, rather than the usual formal recommendations.Natural gas is the most benign of the fossil fuels; it burns cleanly and provides more energy for each molecule of carbon dioxide emitted than any other fossil fuel. The fall in greenhouse gas emissions in the United States over recent years is in part due to cheap gas obtained through fracking replacing coal. Consequently, some see fracking as helping slow climate change because it allows coal to be phased out and can act as a 'transition' fuel to a low-carbon future. Others argue that huge amounts of gas (and oil to a lesser extent) will continue to lock the world into a fossil fuel future and crowd out investment in alternative sources of energy. This dilemma is examined in this report, but no conclusions either way can be drawn.

Office of the Chief Medical Officer of Health (OCMOH) (2012). "Chief Medical Officer of Health's Recommendations Concerning Shale Gas Development in New Brunswick"

While large-scale development of a shale gas industry in New Brunswick may offer an economic growth opportunity for the province, it will be important to ensure that the overall health gains are greater than the losses. Economic status of individuals and communities can be an important determinant of their health, however there are many other factors resulting from industry development that can have strong negative impacts. Unless proper controls are put in place there is a risk of spoiling any benefits from economic gains through adverse health outcomes. This report identifies the known issues that should be addressed and the unknowns which require further investigation. The recommendations propose actions that should be taken in areas such as health equity, assessment of health impacts, monitoring of health and environmental impacts, strengthening of the planning process, ensuring transparency and community participation, filling knowledge gaps, requiring appropriate environmental controls, and enabling more effective government oversight.

Olawoyin et al. (2012). "Environmental Safety Assessment of Drilling Operations in the Marcellus-Shale Gas Development". Society of Petroleum Engineers. **18**(02): 212-220

The process of gas development is intensive and involves risk to the environment. Statistics confirm that 0.5 to 1% of wells drilled result in a blowout. Causes of these exploration risks are identified as violations of environmental laws enforced by the Pennsylvania Department of Environmental Protections (DEP), operational pollution (accidental spills and leaks), and operator's policy. In addressing this concern, a risk-assessment methodology was used to evaluate all violations by operators in the State of Pennsylvania from January 2008 to November 2010, by use of Statistical Analysis Software(SAS). The most significant causes of environmental damage and risk were determined by use of the doubly repeated measure analysis of covariance(ANCOVA). The category effect and interaction effect were used to prove the usefulness of the developed model, which helps explain the safety level of the locality. There were a total of 2,601 violations between 2008 and 2010 committed by 65 different operators in the Marcellus Shale, out of which only27 of the operators showed significance difference based on environmentally damaging violations (ranked 5 to 10). A statistical comparison was made to understand the difference between the operators based on the 2,601 total violations. The most significant incidents are ranked (on the basis of Bordacount (Saari 1985)) 3, 5, 9, 10, which accounts for 67% of all the violations.These data reflect several environmental concerns that are currently prevalent in the Marcellus-shale area. This research identifies environmental incidents,causes and effects of exploration risk, and safety impediments in the Marcellus gas play. It also presents guidelines for feasible options to minimize environmental risks and consequently increase the degree of safety in the area.Recommendations on how to mitigate these impending problems are presented.

Olmstead et al. (2012). "Shale gas development impacts on surface water quality in Pennsylvania". Proceedings of the National Academy of Sciences. **110**(13): 4962–4967

Concern has been raised in the scientific literature about the environmental implications of extracting natural gas from deep shale formations, and published studies suggest that shale gas development may affect local groundwater quality. The potential for surface water quality degradation has been discussed in prior work, although no empirical analysis of this issue has been published. The potential for large-scale surface water quality degradation has affected regulatory approaches to shale gas development in some US states, despite the dearth of evidence. This paper conducts a large-scale examination of the extent to which shale gas development activities affect surface water quality. Focusing on the Marcellus Shale in Pennsylvania, we estimate the effect of shale gas wells and the release of treated shale gas waste by permitted treatment facilities on observed downstream concentrations of chloride (Cl^-) and total suspended solids (TSS), controlling for other factors. Results suggest that (i) the treatment of shale gas waste by treatment plants in a watershed raises downstream Cl^- concentrations but not TSS concentrations, and (ii) the presence of shale gas wells in a watershed raises downstream TSS concentrations but not Cl^- concentrations. These results can inform future voluntary measures taken by shale gas operators and policy approaches taken by regulators to protect surface water quality as the scale of this economically important activity increases.

Orem et al. (2014). "Organic substances in produced and formation water from unconventional natural gas extraction in coal and shale". International Journal of Coal Geology. **126**: 20–31

Organic substances in produced and formation water from coalbed methane (CBM) and gas shale plays from across the USA were examined in this study. Disposal of produced waters from gas extraction in coal and shale is an important environmental issue because of the large volumes of water involved and the variable quality of this water. Organic substances in produced water may be environmentally relevant as pollutants, but have been little studied. Results from five CBM plays and two gas shale plays (including the Marcellus Shale) show a myriad of organic chemicals present in the produced and formation water.

Organic compound classes present in produced and formation water in CBM plays include: polycyclic aromatic hydrocarbons (PAHs), heterocyclic compounds, alkyl phenols, aromatic amines, alkyl aromatics (alkyl benzenes, alkyl biphenyls), long-chain fatty acids, and aliphatic hydrocarbons. Concentrations of individual compounds range from <1 to 100 µg/L, but total PAHs (the dominant compound class for most CBM samples) range from 50 to 100 µg/L. Total dissolved organic carbon (TOC) in CBM produced water is generally in the 1–4 mg/L range. Excursions from this general pattern in produced waters from individual wells arise from contaminants introduced by production activities (oils, grease, adhesives, etc.). Organic substances in produced and formation water from gas shale unimpacted by production chemicals have a similar range of compound classes as CBM produced water, and TOC levels of about 8 mg/L. However, produced water from the Marcellus Shale using hydraulic fracturing has TOC levels as high as 5500 mg/L and a range of added organic chemicals including, solvents, biocides, scale inhibitors, and other organic chemicals at levels of 1000 s of µg/L for individual compounds. Levels of these hydraulic fracturing chemicals and TOC decrease rapidly over the first 20 days of water recovery and some level of residual organic contaminants remain up to 250 days after hydraulic fracturing. Although the environmental impacts of the organics in produced water are not well defined, results suggest that care should be exercised in the disposal and release of produced waters containing these organic substances into the environment because of the potential toxicity of many of these substances.

Osborn et al. (2011). "Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing". Proceedings of the National Academy of Sciences. **108**(20): 8172–8176

Directional drilling and hydraulic-fracturing technologies are dramatically increasing natural-gas extraction. In aquifers overlying the Marcellus and Utica shale formations of northeastern Pennsylvania and upstate New York, we document systematic evidence for methane contamination of drinking water associated with shale gas extraction. In active gas-extraction areas (one or more gas wells within 1 km), average and maximum methane concentrations in drinking-water wells increased with proximity to the nearest gas well and were 19.2 and 64 mg CH_4 L^{-1} (n ¼ 26), a potential explosion hazard; in contrast, dissolved methane samples in neighboring non extraction sites (no gas wells within 1 km) within similar geologic formations and hydrogeologic regimes averaged only 1.1 mgL^{-1} ($P < 0.05$; n ¼ 34). Average $\delta^{13}C$-CH_4 values of dissolved methane in shallow groundwater were significantly less negative for active than for nonactive sites (−37 ± 7‰ and −54 ± 11‰, respectively; $P < 0.0001$). These $\delta^{13}C$-CH_4 data, coupled with the ratios of methane-to-higher-chain hydrocarbons, and $\delta^{2}H$-CH_4 values, are consistent with deeper thermogenic methane sources such as the Marcellus and Utica shales at the active sites and matched gas geochemistry from gas wells nearby. In contrast, lower-concentration samples from shallow groundwater at nonactive sites had isotopic signatures reflecting a more biogenic or mixed biogenic/thermogenic methane source. We found no evidence for contamination of drinking-water samples with deep saline brines or fracturing fluids. We conclude that greater stewardship, data, and—possibly—regulation are needed to ensure the sustainable future of shale-gas extraction and to improve public confidence in its use.

Osborn et al. (2011). "Reply to Saba and Orzechowski and Schon: Methane contamination of drinking water accompanying gas well drilling and hydraulic fracturing". Proceedings of the National Academy of Sciences. **108**(37): E665–E666

Two letters by Saba and Orzechowski (2011) and Schon (2011) address our research linking elevated methane and ethane concentrations to shale-gas drilling and hydraulic fracturing. We respond briefly here and point readers to a supplementary document for more details. An assertion, and misconception, in both letters is that, because we found small amounts of mixed biogenic and thermogenic gas in 85% of groundwater samples, the thermogenic gas we observed near shale-gas wells occurred naturally. What we showed instead (figures 3 and 4 of Osborn et al. 2011) was that drinking water was more likely to have high methane and ethane concentrations when homeowners lived within 1 km of a gas well. We also showed that the isotopic signatures for both δ13C and δ2H of methane found in high concentrations in private water wells closely matched the signatures of methane coming out of gas wells, and that the ratios of methane to ethane and propane were different (figure 4b (Osborn et al. 2011)). Furthermore, the methane present in high concentrations in water wells was more thermogenic in both its 13C and 2H signatures than background values more than 1 km from a gas well. There are indeed low concentrations of thermogenic methane found across the region. That methane does not, however, look like the methane found in drinking water near gas wells.

OWN (Ohio Watershed Network) (date unknown). "Gas Drilling Impacts on Water Quality. Hydraulic fracturing for natural gas extraction: Impacts on water resources. An interview with Penn State Water Quality Specialist Bryan Swistock"

Hydraulic fracturing is a controversial method currently in use to extract methane gas from the Marcellus and Utica shale deposits. Concerns have been raised about the impacts of hydraulic fracturing or "fracking" on water quality and quantity. On April 13 Joe Bonnell interviewed Bryan Swistock, Water Quality Specialist for Penn State Cooperative Extension. Bryan has been conducting educational programs about the impacts of fracking on water for the past four years. In this interview, Bryan provides an overview of these impacts and recommendations for landowners and water quality advocates in Ohio based on the Pennsylvania experience.

Pacsi et al. (2014). "Spatial and Temporal Impacts on Water Consumption in Texas from Shale Gas Development and Use". ACS Sustainable Chemistry and Engineering. **2**: 2028−2035

Despite the water intensity of hydraulic fracturing, recent life cycle analyses have concluded that increased shale gas development will lead to net decreases in water consumption if the increased natural gas production is used at natural gas combined cycle power plants, shifting electricity generation away from coal-fired steam cycle power plants. This work expands on these studies by estimating the spatial and temporal patterns of changes in consumptive water use in Texas river basins during a period of rapid shale gas development and use in electricity generation from August 2008 through December 2009. While water consumption decreased in Texas overall, some river basins saw increased water consumption and others saw decreased water consumption, depending on the extent of extraction activity in the basin, the mix of power plants using cooling water in that basin, and price-based changes in the power sector. Due to the temporal and spatial heterogeneity in the consumptive water impacts of natural gas development and use in the power sector, local and regional water use impacts must also be considered in addition to the overall supply chain impacts.

Papoulias and Velasco (2013). "Histopathological Analysis of Fish from Acorn Fork Creek, Kentucky, Exposed to Hydraulic Fracturing Fluid Releases". Southeastern Naturalist. **12**(4): 92–111

Fracking fluids were released into Acorn Fork, KY, a designated Outstanding State Resource Water, and habitat for the threatened Chrosomus cumberlandensis (Blackside Dace). As a result, stream pH dropped to 5.6 and stream conductivity increased to 35,000 μS/cm, and aquatic invertebrates and fish were killed or distressed. The objective of this study was to describe post-fracking water quality in Acorn Fork and evaluate if the changes in water quality could have extirpated Blackside Dace populations. Semotilus atromaculatus (Creek Chub) and Lepomis cyanellus (Green Sunfish) were collected from Acorn Fork a month after fracking in lieu of unavailable Blackside Dace. Tissues were histologically analyzed for indicators of stress and percent of fish with lesions. Fish exposed to affected Acorn Fork waters showed general signs of stress and had a higher incidence of gill lesions than unexposed reference fish. Gill lesions observed were consistent with exposure to low pH and toxic concentrations of heavy metals. Gill uptake of aluminum and iron was demonstrated at sites with correspondingly high concentrations of these metals. The abrupt and persistent changes in post-fracking water quality resulted in toxic conditions that could have been deleterious to Blackside Dace health and survival.

Parfitt (2011). “Fracking Up Our Water, Hydro Power and Climate, BC’s Reckless Pursuit of Shale Gas”. Climate Justice Project

In all, the report makes 18 policy recommendations that would ensure greater protection of green resources in the face of an expanding brown industry. However, a bigger task lies ahead. How will BC wean itself off of dependency on fossil fuels — a challenge the province shares with every other jurisdiction on earth? Ultimately the province needs to enact policies that result in a steady ratcheting down in the use of non-renewable fossil fuels that are destabilizing the earth’s climate, with a corresponding rise in the use of energy sources that do not pump ever more greenhouse gases into the atmosphere. This is what ultimately makes environmental and economic sense. We cannot base our economy, or the funding of public programs like health care and education, on the steady depletion of non-renewable, polluting fuels.

Parliamentary Commissioner for the Environment (2012). “Evaluating the environmental impacts of fracking in New Zealand: An interim report”

The high-level conclusion from the work done to date in this investigation echoes, and is broadly consistent with, the reviews of fracking that have been done elsewhere in the world. That conclusion is that the environmental risks associated with fracking can be managed effectively provided, to quote the United Kingdom Royal Society, “operational best practices are implemented and enforced through regulation”. But at this stage I cannot be confident that operational best practices are actually being implemented and enforced in this country. Therefore, the investigation will now enter a second phase that will turn the spotlight on how well the environmental risks associated with fracking are actually regulated and monitored. Consequently this report is being released as an interim report, and as such contains seven interim findings. The big environmental issue that sits behind fracking is climate change. Natural gas is the most benign of the fossil fuels; it burns cleanly and provides more energy for each molecule of carbon dioxide emitted than any other fossil fuel. The fall in greenhouse gas emissions in the United States over recent years is in part due to cheap gas obtained through fracking replacing coal. Consequently, some see fracking as helping slow climate change because it allows coal to be phased out and can act as a ‘transition’ fuel to a low-carbon future. Others argue that huge amounts of gas (and oil to a lesser extent) will continue to lock the world into a fossil fuel future and crowd out investment in alternative sources of energy. This dilemma is examined in this report, but no conclusions either way can be drawn.

Patil et al. (2000). “Multiscale Assessment of Landscapes and Watersheds with Synoptic Multivariate Spatial Data in Environmental and Ecological Statistics”. Mathematical and Computer Modelling. **32**: 257-272

The paper attempts to provide a multiscale assessment of landscapes and watersheds using synoptic multivariate spatial data. Multiscale assessment is a frontier problem in environmental and ecological statistics today. The paper briefly deals with univariate surface data, multivariate signal data, and multicover categorical data, and applies stochastic conceptualization involving dendrogram trees and conditional entropies with special reference to the landscapes and watersheds of Pennsylvania.

Pennsylvania Department of Environmental Protection (2013). “Establishment of a Process for Evaluating the Proposed Use of Mine Influenced Water (MIW) for Natural Gas Extraction”

The goals of this project were; 1 to promote the voluntary use of MIW by the oil and gas industry and establish a framework in which MIW can be used for natural gas extraction and 2 establish a process for DEP to review and evaluate proposals for use of MIW for natural gas extraction activities. This paper outlines: (i) a process for DEP review of proposals to utilize MIW; (ii) possible options for storing MIW used for natural gas extraction activities; and, (iii) potential solutions to address long-term liability issues. DEP is available to any interested parties to discuss potential sites and technical issues, to help structure a project with respect to permitting requirements and liability issues, and to assist with developing partnerships between oil and gas industry representatives and local watershed organizations or other organizations involved in MIW treatment or abandoned mine reclamation efforts.

Penn State Extension (2012). “Water’s Journey Through the Shale Gas Drilling and Production Processes in the Mid-Atlantic Region”

Water’s journey through the Marcellus shale drilling and production processes is complex and roundabout. Some water no longer cycles because it is trapped in the shale as a consequence of hydraulic fracturing. We need to understand where the water from this industry comes from, how it is handled and what the industry adds to it, how it is treated, and how much of it returns to the water cycle. We also need to know about places where water essentially leaves the water cycle or is moved across watershed boundaries. Having this knowledge helps us identify points of concern about water quality and/or quantity. This publication discusses water use by the industry at multiple levels—regional, local, and the drilling pad itself. At each level different issues are important. For example, at a regional level, some water managers are concerned about tracking out-of-basin transfers of water for fracing and wastewater treatment. At the local level, we want to be sure that streams are not dewatered (pass-by flow requirements would prevent this), especially during drought. At the drilling pad level, concerns often center around what chemicals are added to the frac water and the potential for damage to local water resources due to accidents, spills, and leaks.

Pennsylvania Independent Oil and Gas Association and Marcellus Shale Coalition (2013). “Field Sampling Plan, Characterization of Naturally Occurring Radioactive Materials in the Oil and Gas Field”

The Pennsylvania Independent Oil and Gas Association (PIOGA) and the Marcellus Shale Coalition (MSC) have developed this Field Sampling Plan (Plan) to describe the manner to collect data and analyze samples of naturally occurring radioactive material (NORM) and technologically enhanced NORM (TENORM) related to the oil and gas (O&G) exploration activities. The purpose of this study is to obtain representative samples from potential sources of NORM associated with all aspects of O & G drilling and operations and reach definitive conclusions about the potential for exposure. Sites and facilities that are candidates to be sampled include conventional and unconventional drilling through geological formations and associated waste water operations throughout the Commonwealth of Pennsylvania (PA).

Precht and Dempster (2012). “Jurisdictional Review of Hydraulic Fracturing Regulation”

Paul Precht and Don Dempster were engaged to assist Nova Scotia’s Hydraulic Fracturing Review Committee, which is co-chaired by the Nova Scotia Department of Energy and Nova Scotia Environment, in its review of regulatory approaches to hydraulic fracturing in selected jurisdictions in North America. The goal of this jurisdictional review is to: a) assist Nova Scotia in learning how other jurisdictions regulate unconventional resource development in particular with regard to hydraulic fracturing and; b) identify current regulatory best practices for activities related to hydraulic fracturing. This report will describe the process for conducting the review, and then will present a highly detailed summary of information respecting the various jurisdictions included in the review.

Prohaska and Thonhauser (2012). “The Importance of Wellbore Integrity for Groundwater Protection in Shale Gas Well Construction”. SHIP-Shale Gas Information Platform

One of the major public concerns in shale gas development is the protection of groundwater from fluids that are flowing in a cemented steel casing from the shale gas reservoir to the surface. In the United States, more than 40,000 shale gas wells have been completed in the last two decades.Any onshore wellbore that is drilled for any purpose (oil, gas, water, geothermal, injection, and disposal) needs to have a seal to protect groundwater bearing strata from drilling fluids, production fluids or work-over fluids. This is a major requirement that must be met from the very beginning of the entire wellbore construction process and throughout the lifetime of the wellbore, but also for any time after final abandonment. Casing pipe and cement are the barriers that must guarantee groundwater protection. Scientific studies currently discuss the risk of liquids migrating upwards through the rock formations overlying the fractured reservoir rocks. While the risk of migration of liquids is probably extremely low, migration of gas, on the other hand, is a more likely scenario. Some studies suggest that natural gas from fractured reservoirs has entered into aquifers, but migration pathways are poorly constrained. It should be noted that the process of hydraulic fracturing itself bears little risk of groundwater contamination. Most incidents that occur during shale gas production are attributed to procedures and operations peripheral to hydraulic fracturing, such as waste management and disposal as well as production, on-lease transport, and storage, e.g. of chemicals.

Quebec CEESGS (2014). “Strategic environmental assessment on shale gas: knowledge gained and principal findings”

The initial mandate of the SEA committee was to prepare a strategic environmental assessment plan and see to its performance, focusing on the four objectives set by the Bureau d’audiences publiques sur l'environnement (BAPE) in its report on sustainable development in the shale gas industry. Analysis of the shale gas industry in terms of the principles of sustainable development raises a number of social, economic and environmental issues, as well as issues of governance. These include; environmental and social issues, social acceptability, social value and oversight of the industry.

Quebec CEESGS (2014). "Implementation plan for the strategic environmental assessment on shale gas"

Defining the implementation plan for the strategic environmental assessment (SEA) on shale gas is the first step in the mandate of the expert committee charged with conducting that assessment. Its objective is therefore to define the issues to be considered and to outline a series of studies to: a) Evaluate the environmental risks and impacts associated with this type of exploitation; b) Evaluate the impacts on agriculture, forestry and tourism of eventually developing the shale gas sector; c) Evaluate the socioeconomic desirability of exploiting this resource; d) Define scenarios that would maximize revenue for the government; e) Define the guidelines and parameters of a regulatory framework for the environmental assessment of gas exploration and exploitation projects, and for the execution of such projects, applicable to the St. Lawrence Valley and elsewhere in Québec as the case may be; f) Suggest ways of proceeding to establish guidelines on the role of municipalities and regional representatives in determining policies in the event that the industry is developed in their region; g) Evaluate the desirability of setting up scientific observatories to acquire knowledge on an ongoing basis and to ensure that regulations are kept up to date.

Rahm (2011). "Regulating hydraulic fracturing in shale gas plays: The case of Texas". Energy Policy. **39**: 2974–2981

The ability to economically produce natural gas from unconventional shale gas reservoirs has been made possible recently through the application of horizontal drilling and hydraulic fracturing. This new technique has radically changed the energy future of the United States. The U.S. has shifted from a waning producer of natural gas to a growing producer. The Energy Information Administration forecasts that by 2035 nearly half of U.S. natural gas will come from shale gas. Texas is a major player in these developments. Of the eight states and coastal areas that account for the bulk of U.S. gas, Texas has the largest proved reserves. Texas' Barnett Shale already produces six percent of the continental U.S.' gas and exploration of Texas' other shale gas regions is just beginning. Shale gas production is highly controversial, in part because of environmental concerns. Some U.S. states have put hydraulic fracturing moratoriums in place because of fear of drinking water contamination. The federal government has gotten involved and some states, like Texas, have accused it of overreaching. The contention over shale gas drilling in the U.S. may be a bellwether for other parts of the world that are now moving forward with their own shale gas production.

Rahm (2014). "Evolving shale gas management: water resource risks, impacts, and lessons learned". Environmental Science Processes & Impacts. **16**: 1400–1412.

Unconventional shale gas development promises to significantly alter energy portfolios and economies around the world. It also poses a variety of environmental risks, particularly with respect to the management of water resources. We review current scientific understanding of risks associated with the following: water withdrawals for hydraulic fracturing; wastewater treatment, discharge and disposal;

methane and fluid migration in the subsurface; and spills and erosion at the surface. Some of these risks are relatively unique to shale gas development, while others are variations of risks that we already face from a variety of industries and activities. All of these risks depend largely on the pace and scale of development that occurs within a particular region. We focus on the United States, where the shale gas boom has been on-going for several years, paying particular attention to the Marcellus Shale, where a majority of peer-reviewed study has taken place. Governments, regulatory agencies, industry, and other stakeholders are challenged with responding to these risks, and we discuss policies and practices that have been adopted or considered by these various groups. Adaptive Management, a structured framework for addressing complex environmental issues, is discussed as a way to reduce polarization of important discussions on risk, and to more formally engage science in policy-making, along with other economic, social and value considerations. Data suggests that some risks can be substantially reduced through policy and best practice, but also that significant uncertainty persists regarding other risks. We suggest that monitoring and data collection related to water resource risks be established as part of planning for shale gas development before activity begins, and that resources are allocated to provide for appropriate oversight at various levels of governance.

Rham and Rhia (2012). “Toward strategic management of shale gas development: Regional, collective impacts on water resources”. Environmental Science and Policy. **17**:12-23.

Shale gas resources are relatively plentiful in the United States and in many countries and regions around the world. Development of these resources is moving ahead amidst concerns regarding environmental risks, especially to water resources. The complex nature of this distributed extractive industry, combined with limited impact data, makes establishing possible effects and designing appropriate regulatory responses challenging. Here we move beyond the project level impact assessment approach to use regional collective impact analysis in order to assess a subset of potential water management policy options. Specifically, we examine hypothetical water withdrawals for hydraulic fracturing and the subsequent treatment of wastewater that could be returned or produced from future active shale gas wells in the currently undeveloped Susquehanna River Basin region of New York. Our results indicate that proposed water withdrawal management strategies may not provide greater environmental protection than simpler approaches. We suggest a strategy that maximizes protectiveness while reducing regulatory complexity. For wastewater treatment, we show that the Susquehanna River Basin region of New York State has limited capacity to treat wastewater using extant municipal infrastructure. We suggest that modest private investment in industrial treatment facilities can achieve treatment goals without putting public systems at risk. We conclude that regulation of deterministic water resource impacts of shale gas extraction should be approached on a regional, collective basis, and suggest that water resource management objectives can be met by balancing the need for development with environmental considerations and regulatory constraints.

Rahman et al. (2007). “Unsuccessful hydraulic fracturing cases in Australia: Investigation into causes of failures and their remedies”. Journal of Petroleum Science and Engineering. **57**: 70–81

This paper presents the results of investigations into two field cases in Australia where expensive fracture treatments did not yield expected benefits. Field_1 contains a thin gas reservoir in which more than 20 vertical wells were drilled and hydraulically fractured. The post-frac well tests yielded low production rates prompting to a comprehensive study. Among other reservoir properties, the in-situ stresses were characterized and found to be in the reverse faulting stress regime. Through 3D mixed-mode simulation of hydraulic fracture propagation, the first part of this paper shows that the vertical fracture initiated from the vertical wellbore would turn and twist to be horizontal during propagation and would require extremely high treatment pressure and leave very little conduit for flow. These were the main reasons for multiple screen-outs during treatments and post-frac low production rates from the reservoir. A number of potentially effective hydraulic fracture treatments have been recommended for the reservoir. Field_2 contains a tight-gas reservoir, which a number of operators have attempted to develop by hydraulic fracturing over the last 30 years. After every attempt, the post-frac flow rate was lower than the pre-frac rate and therefore the well was plugged and abandoned. The second part of this paper presents the results of a comprehensive investigation into the field. The investigation has established the inadequacy of the treatment carried out in the reservoir to achieve the expected production rate, and demonstrated how more effective treatments could be designed by using a constrained hydraulic fracturing optimization model.

Ridlington and Rumpler (2013). "Fracking by the Numbers, Key Impacts of Dirty Drilling at the State and National Level". Environment New York Research and Policy Center

Over the past decade, the oil and gas industry has fused two technologies—hydraulic fracturing and horizontal drilling—in a highly polluting effort to unlock oil and gas in underground rock formations across the United States. As fracking expands rapidly across the country, there are a growing number of documented cases of drinking water contamination and illness among nearby residents. Yet it has often been difficult for the public to grasp the scale and scope of these and other fracking threats. Fracking is already underway in 17 states, with more than 80,000 wells drilled or permitted since 2005. Moreover, the oil and gas industry is aggressively seeking to expand fracking to new states—from New York to California to North Carolina—and to areas that provide drinking water to millions of Americans. This report seeks to quantify some of the key impacts of fracking to date—including the production of toxic wastewater, water use, chemicals use, air pollution, land damage and global warming emissions.

Ricardo-AEA (2014). "Shale gas risk assessment for Maryland". Report for Chesapeake Climate Action Network and Citizen Shale. Ricardo-AEA/R/ED58951

This study provides an assessment of the potential environmental risks and impacts associated with the development of shale gas resources in Maryland. This assessment built on a risk assessment for the development of unconventional hydrocarbons in Europe, carried out by a consortium led by Ricardo-AEA. This approach enables a systematic evaluation of all potentially significant environmental aspects, at all relevant phases of the development of shale gas resources, and takes account of impacts associated with both individual wells/wellpads, and developments across Garrett and Allegany Counties, the parts of Maryland where shale gas resources could potentially be developed. As a strategic risk assessment, this study does not take account of site-specific controls which may be applied at individual developments. Its value is therefore in identifying the key environmental risk issues which state policy-makers should take into account when taking a decision with regard to the potential development of shale gas resources in the state.

Richardson et al. (2013). "The State of State Shale Gas Regulation". Resources for the Future (RFF) Report

Production of natural gas from deep shale deposits in the United States by way of horizontal drilling and hydraulic fracturing (fracking) has rapidly increased in recent years. This boom, along with estimates of large untapped reserves and predictions of future production increases, has led to great optimism. But many are also deeply concerned about the environmental consequences of shale gas production, including possible damage to ground and surface water, habitat destruction, and air pollution. The primary aim of the report is to give a broad overview of the similarities and differences among states as of March 2013—their choices about what parts of the development process to regulate, how stringently to do so, and what regulatory tools to use. In at least the first two of these respects, we found that the heterogeneity among states is great, though not necessarily unexpected. We also found a lack of transparency in some aspects of regulation in some states, particularly those that use a permitting process to regulate case by case, rather than published administrative rules.

Rivard et al. (2014). "An overview of Canadian shale gas production and environmental concerns". International Journal of Coal Geology. **126**: 64–76

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.

Rokosh et al. (2000). "What is Shale Gas? An Introduction to Shale-Gas Geology in Alberta". Energy Resources Conservation Board, Alberta Geological Survey. ERCB/AGS Open File Report 2008-08

The purpose of this report is to define and describe gas shales and discuss Alberta's potential for shale gas production. Shale is traditionally regarded as a potential source rock and seal/cap rock for conventional hydrocarbon reservoirs. More recently, shale has been recognized as a potential unconventional reservoir for hydrocarbons, although with lower permeability and a larger content of organic matter than conventional reservoirs. In a shale reservoir, gas typically occurs in two modes: adsorbed on organic matter within the shale bed in a similar manner to coal bed methane, and as free gas in porosity within the shale matrix, similar to conventional reservoirs. The low permeability of shale reservoirs dictates that specialized completions techniques are necessary to enable production. This report discusses relevant geological and geochemical criteria required for viable shale gas plays, including the type, amount and maturation of organic matter within a shale bed, gas contents and permeability. The nature of the reservoir, including mineralogy, fractures, porosity and permeability will determine suitability for different completions technologies and influence drainage area from a wellbore. Numerous shale plays in the United States are in production. A selection of plays is discussed as possible analogues for Alberta shale gas potential. Similarities and differences, with emphasis on geological, geochemical and mineralogical components are presented to highlight the potential for Alberta shale gas production.

Rokosh et al. (2009). “Geochemical and Sedimentological Investigation of the Banff and Exshaw Formations for Shale Gas Potential: Initial Results” Energy Resources Conservation Board, Alberta Geological Survey ERCB/AGS Open File Report 2008-10

Alberta Geological Survey has started a project to quantify shale gas resources in the province by collecting 72 core samples and 59 outcrop samples from the Mississippian Banff and Exshaw formations. A series of 10 analyses was run on selected samples: isotherm, Rock Eval™ 6, total organic carbon (TOC), organic petrology, bulk mineralogy, clay mineralogy, permeametry, helium and mercury porosimetry, scanning electron microscopy, environmental scanning electron microscopy and thin section examination. Gas capacity has been calculated using a base case of 100% desorption, as well as a case assuming 25% free gas. A few thin sections and electron microscope descriptions are included, with the remainder becoming available when descriptions are complete. To develop assessment units for Banff shale gas, regional stratigraphic cross-sections and maps of the Banff are being created. Two cross-sections and one map are included, with the remainder of the sections and maps to be released when they are completed.

Rokosh et al. (2009). “Geochemical and Sedimentological Investigation of the Colorado Group for Shale Gas Potential: Initial Results”. Energy Resources Conservation Board, Alberta Geological Survey. ERCB/AGS Open File Report 2008-09

Alberta Geological Survey has started a project to quantify shale gas resources in the province by collecting 74 outcrop samples and 203 core samples from the Cretaceous Colorado Group. A series of ten analyses was run on selected samples, including isotherm, Rock Eval™ 6, total organic carbon, organic petrology, bulk mineralogy, clay mineralogy, permeametry, helium and mercury porosimetry, scanning electron microscopy, environmental scanning electron microscopy and thin section examination. Gas capacity has been calculated on a billion cubic feet per square mile (Bcf/sq. mi.) basis, assuming a base case of 100% desorption and a case assuming 25% free gas. A few thin sections and electron microscope descriptions are included, with the remainder becoming available when descriptions are complete.

Rokosh et al. (2012). “Summary of Alberta’s Shale- and Siltstone-Hosted Hydrocarbon Resource Potential”. Energy Resources Conservation Board. ERCB/AGS Open File Report 2012-06

The Energy Resource Appraisal Group of the Energy Resources Conservation Board provides information related to the oil and gas resource endowment of Alberta. The intent of this report is to provide baseline data, information, and understanding of the geology, distribution, reservoir characteristics, and hydrocarbon resource potential of Alberta shales. We examined several shale and siltstone formations in Alberta that exhibit favourable hydrocarbon resource characteristics. We determined the in-place resource estimates for the key shale and siltstone formations in Alberta that we think are most likely to be developed first. The geographic resource distribution, fluid types, and reservoir characteristics conducive to development were also determined. Hydrocarbons hosted in conventional reservoirs were not included in this evaluation. In cases for which conventional, tight, and shale resources were present in a rock formation, only the shale- and siltstone-hosted hydrocarbons were evaluated. We evaluated the geology, distribution, characteristics, and hydrocarbon potential of key shale and/or siltstone formations (units) in Alberta. Five units show immediate potential: the Duvernay Formation, the Muskwa Formation, the Montney Formation, the Nordegg Member, and the basal Banff and Exshaw formations (sometimes referred to as the Alberta Bakken by industry). The study also includes a preliminary assessment of the Colorado, Wilrich, Rierdon, and Bantry Shale units. These units were systematically mapped, sampled, and evaluated for their hydrocarbon potential. In total, 3385 samples were collected and evaluated for this summary report. The results allow us to understand the size and distribution of shale-gas resources in Alberta and may be used to assist in the planning of resource allocation and conservation, commingling and rights assignment, royalty assessment, land and water use, and environmental stewardship.

the Royal Society for the Protection of Birds (RSPB) (2014). "Are we fit to frack? Policy recommendations for a robust regulatory framework for the shale gas industry in the UK"

We believe commercial shale gas extraction should only go ahead in the UK if it can be objectively demonstrated that the regulatory framework for the industry is fit for purpose, and offers sufficient protection to the natural and historic environment. A summary of recommendations to ensure this are: 1. Avoid sensitive areas for wildlife and water resources by creating shale gas extraction exclusion zones. 2. Make Environmental Impact Assessments (EIA) mandatory for shale gas extraction proposals. 3. Require shale gas operators to pay for a world-class regulatory regime. 4. Prevent taxpayers from bearing the costs of accidental pollution. 5. Make water companies statutory consultees in the planning process. 6. Require all hydraulic fracturing operations to operate under a Groundwater Permit. 7. Make sure Best Available Techniques (BAT) for mine waste management are rigorously defined and regularly reviewed. 8. Ensure full transparency of the shale gas industry and its environmental impact. 9. Ensure monitoring and testing of shale gas operations is rigorous and independent. 10. Minimise and monitor methane emissions.

Rozell and Reaven (2012). "Water Pollution Risk Associated with Natural Gas Extraction from the Marcellus Shale". Risk Analysis. **32**(8): 1382-1393

In recent years, shale gas formations have become economically viable through the use of horizontal drilling and hydraulic fracturing. These techniques carry potential environmental risk due to their high water use and substantial risk for water pollution. Using probability bounds analysis, we assessed the likelihood of water contamination from natural gas extraction in the Marcellus Shale. Probability bounds analysis is well suited when data are sparse and parameters highly uncertain. The study model identified five pathways of water contamination: transportation spills, well casing leaks, leaks through fractured rock, drilling site discharge, and wastewater disposal. Probability boxes were generated for each pathway. The potential contamination risk and epistemic uncertainty associated with hydraulic fracturing wastewater disposal was several orders of magnitude larger than the other pathways. Even in a best-case scenario, it was very likely that an individual well would release at least 200 m3 of contaminated fluids. Because the total number of wells in the Marcellus Shale region could range into the tens of thousands, this substantial potential risk suggested that additional steps be taken to reduce the potential for contaminated fluid leaks. To reduce the considerable epistemic uncertainty, more data should be collected on the ability of industrial and municipal wastewater treatment facilities to remove contaminants from used hydraulic fracturing fluid.

Saba and Orzechowski (2011). “Lack of data to support a relationship between methane contamination of drinking water wells and hydraulic fracturing”. Proceedings of the National Academy of Sciences. **108**(37): E663

Osborn et al. (2011) sampled 68 water wells located in upstate New York (Genesee formation) and northeast Pennsylvania (Catskill and Lockhaven formations). The study opined that there is systematic evidence of increased concentrations of thermogenic methane in water wells near active gas extraction areas compared with water wells outside active gas extraction areas. Average methane concentrations were 19.2 and 1.1 mg L−1 for active and nonactive areas, respectively. By using isotope analysis, the study concluded that the thermogenic methane in the water wells is consistent with Marcellus shale gases. However, the Genesee data show that average methane concentrations in nonactive area water wells was 1.5 mg L−1 and the only sampled active area water well was 0.3 mg L−1 (table 1 in Osborn et al. 2011). This correlation is opposite of what Osborn et al. (2011) concluded.

Saiers and Barth (2012). “Potential Contaminant Pathways from Hydraulically Fractured Shale Aquifers”. Groundwater. **50**(6): 826-828

In a recent article, T. Myers used MODFLOW to examine the impacts of hydraulic fracturing of the Marcellus Shale (“the Marcellus”) on groundwater flow patterns. Myers’ model includes a layer representing the Marcellus, a 1500-m overburden of sandstone and one high permeability “fracture” connecting the Marcellus directly to the surface. Myers conducts steady-state and transient groundwater flow simulations for scenarios without and with injection into a horizontal well (to approximate conditions during hydraulic stimulation of the shale layer), and he examines the sensitivity of the model calculations to changes in hydraulic conductivity of the shale and overlying sandstone. His results suggest the flow system would reach a new equilibrium in 3 to 6 years following hydraulic fracturing, and he concludes that the hydrologic stress of hydraulic fracturing could allow for advective transport of frac fluids and formation water to drinking water aquifers in less than 10 years (Myers 2012). We recognize models represent only approximations of reality, but Myers’ modeling framework neglects critical hydrologic processes, misrepresents physical conditions that drive groundwater flow, and is underpinned by simplifications that are too severe and unnecessary. Owing to these shortcomings, Myers’ findings should not be interpreted as reasonable predictions of the response of groundwater flow and contaminant migration to hydraulic fracturing. Although we have little confidence in Myers’ predictions, we are not drawing conclusions on the risk of shallow-aquifer contamination by the hydraulic-fracturing process. Rather, we recommend implementation of approaches capable of yielding more reliable estimates of fluid migration and solute transport in subsurface environments surrounding shale-gas reservoirs. Improved simulations must be underpinned by more faithful representations of processes and conditions and should be informed by additional field measurements needed to parameterize and calibrate appropriately formulated models.

San Antonio River Authority (SARA) (2013). “Best Practices Handbook To Assist Communities In The Eagle Ford Shale - Identification and Implementation of Best Practices”

This handbook was prepared to help the communities within the SARA watershed protect the surroundings of the watershed, as well as their own community assets and interests. This handbook, which includes a manual of best practices, seeks to address issues that affect the watershed and the surrounding communities, as well as provide a means for enacting the practices. In no way does this handbook intend to impede or hinder the burgeoning energy exploration and production activities in the

Eagle Ford Shale, but rather assist communities in coping with the growing demands on them. Upon reviewing available literature, including published reports, various public agency data, and news articles related to other shale gas plays, several primary lessons learned became evident. The encompassing lesson learned for communities experiencing shale gas exploration and development activities is that the earlier and better they plan, the more influence they have in protecting their communities for the long term while positively reaping the economic benefits.

Sang et al. (2014). "Effect of Hydrofracking Fluid on Colloid Transport in the Unsaturated Zone". Environmental Science and Technology. **48**: 8266−8274

Hydraulic fracturing is expanding rapidly in the US to meet increasing energy demand and requires high volumes of hydrofracking fluid to displace natural gas from shale. Accidental spills and deliberate land application of hydrofracking fluids, which return to the surface during hydrofracking, are common causes of environmental contamination. Since the chemistry of hydrofracking fluids favors transport of colloids and mineral particles through rock cracks, it may also facilitate transport of in situ colloids and associated pollutants in unsaturated soils. We investigated this by subsequently injecting deionized water and flowback fluid at increasing flow rates into unsaturated sand columns containing colloids. Colloid retention and mobilization was measured in the column effluent and visualized in situ with bright field microscopy. While <5% of initial colloids were released by flushing with deionized water, 32−36% were released by flushing with flowback fluid in two distinct breakthrough peaks. These peaks resulted from 1) surface tension reduction and steric repulsion and 2) slow kinetic disaggregation of colloid flocs. Increasing the flow rate of the flowback fluid mobilized an additional 36% of colloids, due to the expansion of water filled pore space. This study suggests that hydrofracking fluid may also indirectly contaminate groundwater by remobilizing existing colloidal pollutants.

Schon (2011). "Hydraulic fracturing not responsible for methane migration". Proceedings of the National Academy of Sciences. **108**(37): E664.

Although Osborn et al. (2011) provided important geochemical measurements of dissolved methane in a portion of the Appalachian basin, their report does not fully appreciate the geologic history of this region and misrepresents potential risks of modern drilling and completion techniques used to develop shale-gas resources. The fear that hydraulic fracturing is responsible for methane migration from the Marcellus shale into shallow groundwater is contrasted by direct observations in microseismic studies that even the longest fractures induced by the hydraulic fracturing process remain thousands of feet below groundwater resources.

Schmidt (2011). "Blind Rush? Shale Gas Boom Proceeds Amid Human Health Questions" Environmental Health Perspectives. **19**(8): a348–a353

The Energy Information Administration estimates that technically recoverable shale gas reserves have the potential to satisfy domestic consumption in the United States (based on 2010 figures) for more than 30 years. But for shale gas to meet its potential, millions of Americans will have to live with drill rigs in or near their own neighborhoods. And that opens the door to a range of potential environmental health problems: pipelines and wellheads can explode, the process produces toxic air emissions, and fracking generates liquid wastes that can contaminate surface and drinking water supplies. The Texas Department of State Health Services, which conducted its own analysis of blood samples from DISH residents. But the state's investigation showed that blood levels of numerous chemicals in DISH residents weren't any higher than those predicted for 95% of the U.S. population. However, published epidemiologic studies relating shale gas production to health are virtually non-existent, and that makes it challenging to scientifically validate anecdotal reports of health outcomes.

Schroeck and Karisny (2013). "Hydraulic Fracturing and Water Management in the Great Lakes". Case Western Reserve Law Review. **63**(4): 1167-1185

This Article will look at new ways of utilizing the Lawrence River Basin Sustainable Water Resources Agreement and Great Lakes–St. Lawrence River Basin Water Resources Compact to protect the Great Lakes Basin from the environmental hazards posed by fracking. Patchwork management of the hydraulic fracturing process in the Great Lakes region has left huge regulatory gaps at the federal, state, and provincial levels. These gaps leave the Lakes vulnerable to the wide array of possible water resource harms posed by fracking, including aquifer contamination. Selective implementation of provisions in the Agreement and the Compact could fill these gaps and help curb fracking's impact on Great Lakes water, but in order to create a truly comprehensive regulatory system for fracking, more is needed. The Council should apply its powers, granted in the Compact, to promulgate new rules and regulations that will bring the Compact up to date with the Great Lakes Regions' recent shale gas "boom," and ensure that our valuable water resources are being managed according to the spirit of the Compact.

Schumacher and Morrissey (2013). "The legal landscape of "fracking": the oil and gas industry's game-changing technique is its biggest hurdle"

By the end of this decade, the United States will surpass Saudi Arabia as the world's largest oil producer, and will be nearly energy independent by 2035. This was the astonishing prediction made by the International Energy Agency in its latest World Energy Outlook report. The forecast is all the more surprising when one recalls that just a decade ago, the U.S. was thought to be running out of domestic natural gas and oil and was looking at becoming a long-term net importer. What a difference a decade makes! The technology primarily responsible for launching the U.S. into the number one spot—a place it has not occupied, at least with respect to oil, since the 1970s—is a combination of horizontal drilling and hydraulic fracturing. This article briefly describes the types of regulatory structures being developed for hydraulic fracturing at the state and federal level in the United States to protect public health, safety, and the environment. It also describes the current public dialogue that is driving many of the changes being proposed or made. Finally, we suggest what may lay ahead for the industry in the future. Before delving into the national regulatory scheme, it is helpful to understand both the issues and the players who are driving the national conversation about shale gas development.

Shaffer et al. (2013). "Desalination and Reuse of High-Salinity Shale Gas Produced Water: Drivers, Technologies, and Future Directions". Environmental Science and Technology. **47**(17): 9569–9583

In the rapidly developing shale gas industry, managing produced water is a major challenge for maintaining the profitability of shale gas extraction while protecting public health and the environment. We review the current state of practice for produced water management across the United States and discuss the interrelated regulatory, infrastructure, and economic drivers for produced water reuse. Within this framework, we examine the Marcellus shale play, a region in the eastern United States where produced water is currently reused without desalination. In the Marcellus region, and in other shale plays worldwide with similar constraints, contraction of current reuse opportunities within the shale gas industry and growing restrictions on produced water disposal will provide strong incentives for produced water desalination for reuse outside the industry. The most challenging scenarios for the selection of desalination for reuse over other management strategies will be those involving high-salinity produced water, which must be desalinated with thermal separation processes. We explore desalination technologies for treatment of high-salinity shale gas produced water, and we critically review mechanical vapor compression (MVC), membrane distillation (MD), and forward osmosis (FO) as the technologies best suited for desalination of high-salinity produced water for reuse outside the shale gas industry. The advantages and challenges of applying MVC, MD, and FO technologies to produced water desalination are discussed, and directions for future research and development are identified. We find that desalination for reuse of produced water is technically feasible and can be economically relevant. However, because produced water management is primarily an economic decision, expanding desalination for reuse is dependent on process and material improvements to reduce capital and operating costs.

Shale Gas Roundtable (2013). “Shale Gas Roundtable: Deliberations, Findings, and Recommendations”

The Shale Gas Roundtable was created in the fall of 2011 to explore natural gas development in Southwestern Pennsylvania. The Roundtable operated by building and sustaining relationships among relevant regional stakeholders; identifying critical focus areas through dialogue, research, and collaboration; assessing those focus areas; and developing recommendations that promote responsible regional shale gas development. This final report represents the culmination of our work. It contains eight core, overarching recommendations that emerged from our overall effort and specific recommendations within each of the four focus areas. The report also includes substantial background and educational information in both the main text and appendices. From the production to the distribution stages, the natural gas midstream system has a wide range of potential impacts on individual landowners, the environment, public health, the local and state economy, and the individual consumer. As midstream infrastructure in Pennsylvania continues to expand to serve new producing wells, the short--- and long---term consequences of this development will require careful monitoring and management with the best interests of the public in mind. The recommendations contained in this report would improve the Commonwealth’s ability to minimize environmental damage; enhance the efficiency of development; monitor and protect the public’s safety; and manage the impacts of cumulative pipeline placement decisions on Pennsylvania’s communities, landowners, and citizens.

Sham (2012). “Evaluating and Mitigating the Impacts of Shale Gas Extraction on Landscape Fragmentation and Hydrologic Impacts”

This is a series of slides produced for the 2012 Ground Water Protection Council Annual Forum, Nashville, TN,. The conclusions from the slides are; a) Shale gas extraction (SGE) is increasing at a fast pace,. b) SGEhale gas extraction is expected to increase in years ahead,. c) Landscape fragmentation and land development/hydrologic modifications from SGEhale gas extraction can have serious repercussions,. de) Most of the focus has been on restoration, not preservation with regards to SGE processes and landscape fragmentation and. ef) There is potential to help mitigate adverse effects from SGE processes in the planning stage.

Shariq (2013). “Uncertainties Associated with the Reuse of Treated Hydraulic Fracturing Wastewater for Crop Irrigation”. Environmental Science and Technology. **47**: 2435−2436

Production of hydraulic fracturing wastewater has increased proportionally with the escalation of natural gas and oil extraction throughout the United States. One wastewater management strategy currently implemented in California and Wyoming is the reuse of diluted treated hydraulic fracturing wastewater (THFW) for crop irrigation. Uncertainties regarding the quantity of THFW applied as irrigation, the concentrations and toxicities of chemical constituents in THFW, and the bioaccumulation characteristics of exposed crops require further analysis in order to assess the long-term safety of this practice with respect to food supplies and public health. An analysis of these uncertainties can provide a scientific foundation for the sustainable reuse of THFW for irrigation and contribute to the broader understanding of the natural gas and oil production life cycle.

Sica (2011). “Scales over Shale: How Pennsylvania Got Fracked”. Thesis, Pennsylvania State University

Shale gas has become one of Pennsylvania’s major resources in recent years and the gas boom has proceeded in spite of uncertainty over the environmental risks of its production process. This thesis argues that location alone cannot explain why shale gas boomed in Pennsylvania. Using interviews with corporate and state executives, I argue that the scalar dimensions of the neoliberal environmental governance of shale gas were critical to understanding why shale gas boomed in Pennsylvania. These actors supported the preemption of local scales of governance by the state as a scalar fix for capital accumulation from shale gas development. They also legitimated the scalar fix by assembling a neat stack of scale frames that made shale gas seem to benefit everyone. These scale frames made shale gas appear as if it would provide local employment, regional supplies of cheap gas, national energy security, abundant gas for tight global markets, and a mitigating strategy for global climate change. In arguing this point, I present a history of how shale gas became a resource that outlines the critical role of the state in that process.

Sierra Club Atlantic (2011). “Hydraulic Fracturing in Atlantic Canada”

Unconventional Natural Gas” Extraction has become a contentious issue in Atlantic Canada. Recent advancements in technology in this field have made previously inaccessible natural gas deposits accessible. With vast fields of natural gas now available, this industry could become a source of much needed economic development for this region. However, Sierra Club Canada - Atlantic Canada Chapter recommends a legislated ban on hydraulic fracturing operations in all four of the Atlantic Provinces. This recommendation is based on scientific evidence that indicates hydraulic fracturing operations for natural gas pose serious and long term negative impacts to our water resources, to our air, and the potential to damage to our local and regional economies. To date there has been no verifiable independent proof that these operations can be conducted safely and with minimal environmental impact. Furthermore, using natural gas to meet energy demands delays the much needed transition from fossil fuel energy sources to renewable energy sources that represents a more sustainable future.

Sijtsma et al. (2012). “Evaluation of landscape impacts – enriching the economist’s toolbox with the hotspotindex” In: W. Heijman, & C. M. J. v. d. Heide (Eds.), The Economic Value of Landscapes. London: Routledge. 136-164.

In the Netherlands, cost-benefit analysis has gained an increasingly important role in the evaluation of so-called "integrated" spatial projects (spatial transformation projects) that aim to simultaneously improve the economic, social and ecological qualities of an area. Such projects strive to realize, for example, a combination of infrastructure, housing, nature development, and business parks. The evaluation of these projects is thus a challenging task due to the wide range of complex impacts that intervene at different geographical scales, such as impacts of building, the development of nature areas, and landscaping, to name three. As developers of local and regional projects request financial support from the Dutch government, a clear distinction between impacts at local, regional and national scale is more often required. This chapter will focus on the measurement of landscape impacts. Landscape is defined in the European Landscape Convention as an area, as perceived by people, whose character is the result of the action and interaction of natural and/or human factors. The evaluation of landscape impacts should, accordingly, be based on perceptions of landscapes. Several authors have identified a number of different discourses, each having its own perception on the values of the landscape.

Singh et al. (2014). "Undisclosed chemicals — implications for risk assessment: A case study from the mining industry". Environment International. **68**: 1–15

Many of the chemicals used in industry can be hazardous to human health and the environment, and some formulations can have undisclosed ingredients and hazards, increasing the uncertainty of the risks posed by their use. The need for a better understanding of the extent of undisclosed information in chemicals arose from collecting data on the hazards and exposures of chemicals used in typical mining operations (copper, platinum and coal). Four main categories of undisclosed chemicals were defined (incomplete disclosure; chemicals with unspecific identities; relative quantities of ingredients not stated; and trade secret ingredients) by reviewing material safety data sheet (MSDS) omissions in previous studies. A significant number of chemicals (20% of 957 different chemicals) across the three sites had a range of undisclosed information,withmajority of the chemicals (39%) having unspecific identities. The majority of undisclosed information was found in commercially available motor oils followed by cleaning products and mechanical maintenance products, as opposed to reagents critical to the main mining processes. All three types of chemicals had trade secrets, unspecific chemical identities and incomplete disclosures. These types of undisclosed information pose a hindrance to a full understanding of the hazards, which is made worse when combined with additional MSDS omissions such as acute toxicity endpoints (LD50) and/or acute aquatic toxicity endpoints (LC50), as well as inadequate hazard classifications of ingredients. The communication of the hazard information in the MSDSs varied according to the chemical type, the manufacturer and the regulations governing the MSDSs. Undisclosed information can undermine occupational health protection, compromise the safety of workers in industry, hinder risk assessment procedures and cause uncertainty about future health. It comes down to the duty of care that industries have towards their employees. With a wide range of chemicals increasingly used, there is a balance that needs to be reached between disclosure requirements, trade secret provisions and definitions of hazardous ingredients for market needs, and the information required to protect the health of their workers.

Slonecker et al. (2012). "Landscape Consequences of Natural Gas Extraction in Bradford and Washington Counties, Pennsylvania, 2004–2010". U.S. Geological Survey Open-file Report 2012 – 1154.

Increased demands for cleaner burning energy, coupled with the relatively recent technological advances in accessing unconventional hydrocarbon-rich geologic formations, led to an intense effort to find and extract natural gas from various underground sources around the country. One of these sources, the Marcellus Shale, located in the Allegheny Plateau, is undergoing extensive drilling and production. The technology used to extract gas in the Marcellus Shale is known as hydraulic fracturing and has garnered much attention because of its use of large amounts of fresh water, its use of proprietary fluids for the hydraulic-fracturing process, its potential to release contaminants into the environment, and its potential effect on water resources. Nonetheless, development of natural gas extraction wells in the Marcellus Shale is only part of the overall natural gas story in the area of Pennsylvania. Coalbed methane, which is sometimes extracted using the same technique, is often located in the same general area as the Marcellus Shale and is frequently developed in clusters across the landscape. The combined effects of these two natural gas extraction methods create potentially serious patterns of disturbance on the landscape. This document quantifies the landscape changes and consequences of natural gas extraction for Bradford County and Washington County, Pennsylvania, between 2004 and 2010. Patterns of landscape disturbance related to natural gas extraction activities were collected and digitized using National Agriculture Imagery Program (NAIP) imagery for 2004, 2005/2006, 2008, and 2010. The disturbance patterns were then used to measure changes in land cover and land use using the National Land Cover Database (NLCD) of 2001. A series of landscape metrics is used to quantify these changes and are included in this publication.

SM (date unknown) “Human Impacts Upon Watersheds”

A stream is impacted by land uses in the watershed. Loudoun watersheds have a mix of different land uses that result in a variety of different potential sources of pollution that affect it. Major land uses include forest, agricultural and pasture, residential, commercial, and industrial. Some sources of pollution affect the water quality on a continuous basis such as cattle that use a stream for drinking water. Other sources of pollution may be intermittent such as marginally operating septic tanks that overflow after heavy rainfalls when the ground is saturated with water. Some sources of pollution may flow from a single point source such as a pipe discharging gray or laundry water from a residence. Other sources may be more diffused in their impact upon a stream such as runoff from lands pasturing cattle and urban areas.

Small et al. (2014). “Risks and Risk Governance in Unconventional Shale Gas Development”. Environmental Science and Technology. **48**: 8289−8297

A broad assessment is provided of the current state of knowledge regarding the risks associated with shale gas development and their governance. For the principal domains of risk, we identify observed and potential hazards and promising mitigation options to address them, characterizing current knowledge and research needs. Important unresolved research questions are identified for each area of risk; however, certain domains exhibit especially acute deficits of knowledge and attention, including integrated studies of public health, ecosystems, air quality, socioeconomic impacts on communities, and climate change. For these, current research and analysis are insufficient to either confirm or preclude important impacts. The rapidly evolving landscape of shale gas governance in the U.S. is also assessed, noting challenges and opportunities associated with the current decentralized (state-focused) system of regulation. We briefly review emerging approaches to shale gas governance in other nations, and consider new governance initiatives and options in the U.S. involving voluntary industry certification, comprehensive development plans, financial instruments, and possible future federal roles. In order to encompass the multiple relevant disciplines, address the complexities of the evolving shale gas system and reduce the many key uncertainties needed for improved management, a coordinated multiagency federal research effort will need to be implemented.

Smith and Ferguson (2013). “”Fracking democracy”: Issue management and locus of policy decision-making in the Marcellus Shale gas drilling debate”.

This study examined a two-year period in which natural gas development in the Marcellus Shale region of Pennsylvania expanded rapidly, as did public policy proposals meant to deal with the myriad legal, economic, and environmental issues that accompanied this growth. Focusing on the use of legitimacy strategies during the critical phase of the issue of hydraulic fracturing, the study examined how activists and energy industry advocates argued that different levels of government policy making – local, state, and federal – should be the locus of policy decisions. Both the “fractivists” and the energy industry sought to legitimize state-level legislators and regulators. Activists viewed federal-level intervention as legitimate leverage for their work in the state, while the energy industry saw federal regulators as redundant and restrictive. Finally, while both sides viewed local authorities as legitimate actors, the energy industry sought to limit their ability to act against the development of new wells.

Soeder et al. (2014). “An approach for assessing engineering risk from shale gas wells in the United States”. International Journal of Coal Geology. **126**(1): 4–19

In response to a series of “energy crises” in the 1970s, the United States government began investigating the potential of unconventional, domestic sources of energy to offset imported oil. Hydraulic fracturing applied to vertical tight sand and coal bed methane wells achieved some degree of success during a period of high energy prices in the early 1980s, but shale gas remained largely untapped until the late 1990s with the application of directional drilling, a mature technology adapted from deepwater offshore platforms that allowed horizontal wells to penetrate kilometers of organic-rich shale, and staged hydraulic fracturing, which created high permeability flowpaths from the horizontal wells into a much greater volume of the target formations than previous completion methods.

These new engineering techniques opened up vast unconventional natural gas and oil reserves, but also raised concerns about potential environmental impacts. These include short-term and long-term impacts to air and water quality from rig operations, potential migration of gas, fluids and chemicals through the ground, and effects on small watersheds and landscapes from roads, pads and other surface structures.

Engineering risk assessment commonly uses integrated assessment models (IAMs), which define sources of risk from features, events and processes. The risk from each system element is assessed using high-fidelity models. Output from these is simplified into reduced-order models, so that a large, integrated site performance assessment can be run using the IAM. The technique has been applied to engineered systems in geologic settings for sequestering carbon dioxide, and it is also applicable to shale gas, albeit with some modifications of the various system elements.

Preliminary findings indicate that shale gas well drilling and hydraulic fracturing techniques are generally safe when properly applied. Incident reports recorded by state environmental agencies suggest that human error resulting from the disregard of prescribed practices is the greatest cause of environmental incidents. This can only be addressed through education, regulations and enforcement.

Sommeriva et al. (2014). “Observations of the Release of Non-methane Hydrocarbons from Fractured Shale”. Environmental Science and Technology. **48**: 8891−8896

The organic content of shale has become of commercial interest as a source of hydrocarbons, owing to the development of hydraulic fracturing (“fracking”). While the main focus is on the extraction of methane, shale also contains significant amounts of non-methane hydrocarbons (NMHCs). We describe the first real-time observations of the release of NMHCs from a fractured shale. Samples from the Bowland-Hodder formation (England) were analyzed under different conditions using mass spectrometry, with the objective of understanding the dynamic process of gas release upon fracturing of the shale. A wide range of NMHCs (alkanes, cycloalkanes, aromatics, and bicyclic hydrocarbons) are released at parts per million or parts per billion level with temperature- and humidity-dependent release rates, which can be rationalized in terms of the physicochemical characteristics of different hydrocarbon classes. Our results indicate that higher energy inputs (i.e., temperatures) significantly increase the amount of NMHCs released from shale, while humidity tends to suppress it; additionally, a large fraction of the gas is released within the first hour after the shale has been fractured. These findings suggest that other hydrocarbons of commercial interest may be extracted from shale and open the possibility to optimize the “fracking” process, improving gas yields and reducing environmental impacts.

Souther et al. (2014). “Biotic impacts of energy development from shale: research priorities and knowledge gaps”. Frontiers in Ecology and the Environment. **12**(6): 330–338

As the development of shale energy reserves continues to expand, substantial knowledge gaps remain regarding effects of these activities on plants and animals. Using criteria related to the environmental risks and current understanding of these impacts, we suggest that top research priorities are related to probabilistic events that lead to contamination of fresh water, such as equipment failure, illegal activities, accidents, chemical migration, and wastewater escape, as well as cumulative ecological impacts of shale development. Although other threats are considered lower priorities, these rankings are relative, general, and dependent on the scarce peer reviewed literature pertaining directly to shale development. Certain components of relatively low-ranking threats (eg winter O3, air pollution) may warrant greater prioritization, especially in particular regions or ecosystems. Furthermore, these rankings are based on the assumption that feasibility of mitigation translates to effective mitigation. For example, water scarcity has documented negative effects on aquatic organisms, and can be avoided by managing water withdrawals. Nevertheless, water management continues to be a major conservation issue in water-limited ecosystems. When the ecological consequences of shale development are easily foreseeable (ie deterministic), research focused on mitigation is generally a higher priority than determining basic effects on biota. In other cases (eg land application of wastewater), the need for research may be circumvented by a change in state or federal regulation.

Given the rapid expansion of shale development, the scientific community should prioritize research to examine threats with the greatest potential for biotic harm. Here, we identify four high-priority research areas, but acknowledge that these priorities are likely to change as scientific understanding, government regulations, and mitigation strategies develop. Rather than a rigid guideline, the approach presented here is a call to action for scientists, industry leaders, and decision makers. We must actively cooperate to understand the ecological risks associated with shale energy development and work to minimize its impacts on natural systems.

Sovacool (2014). “Cornucopia or curse? Reviewing the costs and benefits of shale gas hydraulic fracturing (fracking)”. Renewable and Sustainable Energy Reviews. **37**: 249–264

This study assesses the overall technical, economic, environmental, and social costs and benefits of the hydraulic fracturing (“fracking”) of natural gas. Drawn from a review of more than 100 studies looking at shale gas in the past 10 years, most of them peer-reviewed, this article begins by briefly explaining the process of hydrofracking and summarizing recent market trends up until late 2013. Then, the study discusses a series of advantages and disadvantages to hydrofracking. It notes that done properly, shale gas development can enhance energy security and the availability of energy fuels, lower natural gas prices, offer a cleaner environmental footprint than some other fossil fuels, and enable local economic development. However, done poorly production can be prone to accidents and leakage, contribute to environmental degradation, induce earthquakes, and, when externalities are accounted for, produce more net economic losses than profits. The study concludes that the pursuit and utilization of shale gas thus presents policymakers, planners, and investors with a series of pernicious tradeoffs and tough choices.

Steyaert and Ollivier (2007). “The European Water Framework Directive: How Ecological Assumptions Frame Technical and Social Change”. Ecology and Society. **12**(1): 25

The European Water Framework Directive (WFD) is built upon significant cognitive developments in the field of ecological science but also encourages active involvement of all interested parties in its implementation. The coexistence in the same policy text of both substantive and procedural approaches to policy development stimulated this research as did our concerns about the implications of substantive ecological visions within the WFD policy for promoting, or not, social learning processes through participatory designs. We have used a qualitative analysis of the WFD text which shows the ecological dimension of the WFD dedicates its quasi-exclusive attention to a particular current of thought in ecosystems science focusing on ecosystems status and stability and considering human activities as disturbance factors. This particular worldview is juxtaposed within the WFD with a more utilitarian one that gives rise to many policy exemptions without changing the general underlying ecological model. We discuss these policy statements in the light of the tension between substantive and procedural policy developments. We argue that the dominant substantive approach of the WFD, comprising particular ecological assumptions built upon "compositionalism," seems to be contradictory with its espoused intention of involving the public. We discuss that current of thought in regard to more functionalist thinking and adaptive management, which offers greater opportunities for social learning, i.e., place a set of interdependent stakeholders in an intersubjective position in which they operate a "social construction" of water problems through the co-production of knowledge.

Steyl et al. (2012). “State of the art: Fracking for shale gas exploration in South-Africa and the impact on water resources”. WRC Report No. KV 294/11

This report attempts to summarize the current knowledge on hydraulic fracturing in the public domain as well as give a review of South Africa’s regional geology and geohydrology. The observation and findings made in this work is neither totally comprehensive nor exhaustive since very little data is available in the public domain on hydraulic fracturing in South Africa. The report attempts to address issues which arise from a scientific perspective point, i.e. geology, geohydrology and possible contamination matters. Since geology plays such a pivotal role in the development of shale gas in the Karoo an extensive section was included to highlight possible challenges. A number of case studies from international sources were also presented to illustrate risk areas and assist with possible monitoring processes. In the monitoring section different scenarios were evaluated, which might have an effect on the environment or the regulatory body. Finally, recommendations were made in the instance if hydraulic fracturing is considered as a possibility to be used in South Africa. Concerns were addressed in a systematic methodology which highlighted the likelihood of it occurring. Migration of fluid, surface spills and water use posed the most probable points of impact. The application of good management practices would significantly reduce these events from occurring. Additionally monitoring by the regulatory body would ensure a continuation of good practices.

State Review of Oil and Gas Environmental Regulations (STRONGER) (2013). “STRONGER Revised Hydraulic Fracturing Workgroup Scope of Work”.

Due to recent developments in technology, exploration and production of oil and natural gas from tight formations such as the Bakken, Barnett, Eagle Ford, Fayetteville, Haynesville, Marcellus and Utica Shales are occurring. The use of horizontal drilling and high volume hydraulic fracturing are increasing. The use of these technologies, especially in areas that have not had historic production, have led to public concerns and demands for more regulatory oversight. Questions continue to be raised about the impacts on water resources from the large volumes of surface and ground water being used for hydraulic fracturing, the potential impacts that may result from fracturing operations, the proper disposal of used fluids once hydraulic fracturing is completed, and the potential impacts on public health from air emissions associated with fracturing operations. Although there is an increasing demand for oil and natural gas, some individuals and organizations are calling for moratoria on hydraulic fracturing and nonconventional development until these issues are satisfactorily addressed. In response, states have been updating their regulatory programs to address these concerns.Although the hydraulic fracturing guidelines were recently developed, several issues have been raised during reviews and STRONGER Board discussions. These include the management of source water supply (recycling/reuse, alternative sources such as acid mine drainage), criteria for groundwater protection through proper well construction (cementing and casing), groundwater monitoring, and monitoring of Bradenhead annular pressures during hydraulic fracturing operations. Consequently, the STRONGER Board has decided to reconvene the Hydraulic Fracturing Workgroup to review these and perhaps other issues identified by the workgroup and to recommend revisions to the hydraulic fracturing guidelines.

Stokstad (2014). “Will fracking put too much fizz in your water?”. Science. **344**(6191): 1468-1471

There's little question that hydraulic fracturing, or fracking, techniques have helped spark a boom in shale gas production in the United States. Along with the benefits, however, have come concerns. One big one: the potential to harm water quality. Although fracking typically targets geological formations that are more than a kilometer down—far deeper than most drinking water wells and aquifers—many communities worry that their drinking water could become contaminated with methane or drilling fluids. Fracking opponents point to widespread complaints of contamination near gas wells. But industry advocates claim that there has never been a documented case of fracking harming drinking water. Who's right? A growing corps of researchers is trying to find out.

Stolper et a.l (2014). “Formation temperatures of thermogenic and biogenic methane”. Science. **344**(6191): 1500-1503

Methane is an important greenhouse gas and energy resource generated dominantly by methanogens at low temperatures and through the breakdown of organic molecules at high temperatures. However, methane-formation temperatures in nature are often poorly constrained. We measured formation temperatures of thermogenic and biogenic methane using a “clumped isotope” technique. Thermogenic gases yield formation temperatures between 157° and 221°C, within the nominal gas window, and biogenic gases yield formation temperatures consistent with their comparatively lower-temperature formational environments (<50°C). In systems where gases have migrated and other proxies for gas-generation temperature yield ambiguous results, methane clumped-isotope temperatures distinguish among and allow for independent tests of possible gas-formation models.

Stringfellow et al (2014). “Physical, chemical, and biological characteristics of compounds used in hydraulic fracturing”. Journal of Hazardous Materials. **275**: 37-54.

Hydraulic fracturing (HF), a method to enhance oil and gas production, has become increasingly common throughout the U.S. As such, it is important to characterize the chemicals found in HF fluids to evaluate potential environmental fate, including fate in treatment systems, and human health impacts. Eighty-one common HF chemical additives were identified and categorized according to their functions. Physical and chemical characteristics of these additives were determined using publicly available chemical information databases. Fifty-five of the compounds are organic and twenty-seven of these are considered readily or inherently biodegradable. Seventeen chemicals have high theoretical chemical oxygen demand and are used in concentrations that present potential treatment challenges. Most of the HF chemicals evaluated are non-toxic or of low toxicity and only three are classified as Category 2 oral toxins according to standards in the Globally Harmonized System of Classification and Labeling of Chemicals; however, toxicity information was not located for thirty of the HF chemicals evaluated. Volatilization is not expected to be a significant exposure pathway for most HF chemicals. Gaps in toxicity and other chemical properties suggest deficiencies in the current state of knowledge, highlighting the need for further assessment to understand potential issues associated with HF chemicals in the environment.

Sumi (2013). “The Regulation of Shale Gas Development: State of Play”. (Prepared for Council of Canadians). EB 2012-0451/2012-0433/2013-0074. Exhibit L.UGL.COC.2

The purpose of this report is to provide an overview of the potential environmental and regulatory issues that may affect gas production from shale basins in the United States, and in particular, supply from those basins presented as significant future sources of natural gas for the residents of the Ontario and the Greater Toronto Area (the “GTA”). Environmental impacts and regulatory safeguards are viewed as major challenges with respect to shale gas development. For example, in a 2011 KPMG poll, oil and gas industry executives perceived environmental and sustainability concerns as the biggest challenge facing shale gas development (41 percent), with regulatory concerns voted as the second (27 percent). The key conclusions of this paper are:Information about the environmental and public health impacts of shale gas development continues to grow, revealing a diverse array of very serious effects. State regulatory agencies in Pennsylvania, West Virginia and Ohio were ill-prepared for the pace of drilling, and the environmental impacts that accompanied the shale gas boom. Both state and federal government continue to develop and strengthen regulations to address some of the impacts, but the large gap between known impacts and existing regulations means more safeguards are needed. Voluntary and regulatory mechanisms to mitigate environmental impacts can impose significant costs on shale gas development. If governments respond with effective regulatory and economic measures to the environmental challenges facing the shale gas industry, the cost of shale development will certainly rise, and in some cases is likely to become uneconomic. In other cases, the risks associated with shale gas development may be considered too great to allow for any development of this energy resource, and moratoriums now in place in the Marcellus shale may become permanent and spread to other jurisdictions.

Texas Department of State Health Services (2010). DISH Texas Exposure Investigation

In response to citizen concerns and preliminary environmental sampling results, the Texas Department of State Health Services (TxDSHS) collected blood and urine samples from 28 people living in and near the town of DISH. DISH is located over the Barnett Shale, a large geologic formation that is one of the largest onshore natural gas fields in North America. Over the last several years the increased number of gas wells and compressor stations has caused concern among some residents. The information obtained from this investigation did not indicate that community-wide exposures from gas wells or compressor stations were occurring in the sample population. This conclusion is based on the pattern of VOC values found in the samples. Other sources of exposure such as cigarette smoking, the presence of disinfectant by-products in drinking water, and consumer or occupational/hobby related products could explain many of the findings.

Thedori et al. (2014). "Hydraulic fracturing and the management, disposal, and reuse of frac flowback waters: Views from the public in the Marcellus Shale". <u>Energy Research & Social Science</u>. **2**: 66-74.

Issues associated with the public's views on hydraulic fracturing and the management, disposal, and reuse of frac flowback wastewaters are empirically examined in this paper. The data used in the analyses were collected in a general population survey from a random sample drawn from 21 counties located in the geological Central Core and Tier 1 of the Marcellus Shale region in Pennsylvania. Differences in the information reported by survey respondents living in high well-density counties (20 or more wells per 100 square miles) and their counterparts living in low well-density counties (fewer than 20 wells per 100 square miles) were examined. Substantive findings from the overall sample, as well as statistically significant differences between the two groups of respondents, are reported. The results contained in this paper should prove beneficial to members of the general public, community leaders, oil and gas industry representatives, government and regulatory agency personnel, environmental and non-governmental organization representatives, and other interested stakeholders.

Thompson (2012). "Fracking boom spurs environmental audit". <u>Nature</u>. **485**: 556-557

For Ohio, a Midwestern state hit hard by recession, the promise of an energy boom driven by hydraulic fracturing, or 'fracking', would seem to be a sure route to financial health. Far less certain is whether the technique has an impact on human health. Fracking uses high-pressure fluids to fracture shale formations deep below ground, releasing the natural gas trapped within. With the number of gas wells in Ohio that use fracking set to mushroom from 77 to more than 2,300 in the next three years, the state is the latest to try to regulate a rapidly growing industry while grappling with a serious knowledge gap. No one knows what substances — and at what levels — people near the gas fields are exposed to in the air and water, and what, if any, health threat they might pose. In a nod to those concerns, Ohio's legislature passed a bill on 24 May, awaiting signing by the state governor as Nature went to press, that requires companies to disclose the chemicals they use during the fracking process and during the construction and servicing of the wells. However, the bill does not compel companies to divulge a complete list of the ingredients in their fracking fluid before it is pumped underground. Some of those ingredients are deemed trade secrets, a position that troubles environmental groups and increases the problem for researchers trying to understand the risks.

UCS - Union of concerned scientists (2013). “Toward an evidence-based fracking debate. Science, Democracy, and Community Right to Know in Unconventional Oil and Gas Development” UCS Publications.

In this report, we survey the current state of science and laws in the United States, identify barriers to effective decision making, and offer recommendations for developing a transparent and evidence-based dialogue on unconventional oil and gas development enabled by hydraulic fracturing. The rapid growth of unconventional oil and gas development has outpaced the public’s ability to make informed, evidence-based decisions about the best way to ensure healthy, prosperous communities. The best available science about the effects of hydraulic fracturing, wastewater disposal, and other activities on communities should inform decision makers and the public. Robust and ongoing scientific research is needed to understand the environmental and public health impacts associated with unconventional oil and gas development, spanning all the processes from hydraulic fracturing to the disposal of hazardous waste. Science can inform communities about such effects, but research must be fast-tracked and made publicly accessible. Inappropriate corporate interference in the science and policy-making process must be addressed. Protection of public health and well-being should take priority over private special interests. The exemptions that allow companies to keep vital information about their activities secret must be lifted. Federal, state, and local governments should make information accessible to researchers, decision makers, and the public. Greater transparency, more oversight, and more comprehensive laws and regulations at all levels are necessary in order to protect public health and the environment.

UM SNRE (2010). “Chapter 6 - Landscape-level solar development and ecological impacts”. Renewable Energy Development in the California Desert.

Although there are many ecological impacts that can occur at the site-level, there is also the potential for even greater landscape-level impacts, especially when considering the cumulative effects of multiple facilities across the California desert. These impacts have implications for the functioning of ecological processes and the status of species well beyond the boundaries of the facility site, and can result in fundamental changes to the ecology and biology of the region. Landscape-level impacts could result from disruptions of or alterations to ecological processes including habitat connectivity, sand transport systems, carbon sequestration, and surface albedo. The extent and type of impacts are dependent on the geographic placement of the facilities within the context of the CDCA, the total amount of land and water consumed, and the nature or intensity of the impact. To the extent that these landscape-level impacts may disrupt ecological functions and species interactions, the sum of these impacts may determine if, where, and what biodiversity can persist in the face of utility-scale solar development. Therefore, an analysis of the likely landscape-level ecological impacts is a critical component in understanding the potential cumulative environmental effects of these projects.

United Kingdom, House of Lords Economic Affairs Committee (2014). “Chapter 7: Environmental impact of development of shale gas in the UK”.
http://www.publications.parliament.uk/pa/ld201314/ldselect/ldeconaf/172/17210.htm

Shale gas generates contradictory views, strongly held. The aim of this report is to stand back from the passion on both sides, and focus on the facts. We have taken evidence from a wide range of witnesses, from the most fervent anti-shale campaigners to the most enthusiastic proponents. In particular, however, we have sought a wide range of the most expert advice and we have come to our best judgment from a cool appraisal of all sides of the case.

Upadhyay and Bu (2010). “Visual Impacts of Natural Gas Drilling in the Marcellus Shale Region”. Cornell University, Dept. of City and Regional Planning: CRP 3072 Land Use, Environmental Planning, and Urban Design Workshop

This report looks at the ways in which natural gas drilling in the Marcellus Shale impacts the natural landscape in Pennsylvania. The visual impacts of natural gas drilling are an important concern for residents and visitors of high-frequency drilling areas, both due to aesthetics and to impacts on property values and other industries, such as tourism. This report is designed to provide readers with a better understanding of the overall visual impact on an area affected by natural gas drilling. The primary focus will be on the aesthetic impact of drilling pads during all stages of drilling, both during the day and at night. The report will also focus on the indirect visual impacts of drilling, such as workers’ dwellings, water impoundments, and trucking. Next, it will look at the concentration and density of drilling sites in the landscape, aerial visual impacts, and the significance of the impacts. The findings will be applied to New York State, where natural gas drilling is expected to occur within the next decade. Three dimensional modeling will be used to show the effects of potential gas drilling in Ithaca, NY. Lastly, the report will discuss current and possible methods of mitigating visual impacts, and will provide some conclusions and recommendations. This report is not intended to persuade readers to have any particular opinion on the visual impacts of drilling. It is intended only to show the various ways in which natural gas drilling has a visual impact on the landscape.

URS (2011). “Water-related Issues Associated with Gas Production in the Marcellus Shale”. URS Corporation

The process of high-volume hydraulic fracturing uses relatively large volumes of water, from about 0.5 to 6 million gallons per well. Water is typically withdrawn from surface water or groundwater sources and stored at each well pad or at centralized facilities until ready to be used. The water is then mixed with proprietary concentrations of proppant and other additives (the mixture is referred to as fracturing fluid), and pumped down into the well at high pressure to fracture the shale. A portion of the fracturing fluid returns to the surface as “flowback” fluid, which requires appropriate treatment and disposal. This report addresses the following topics related to Marcellus Shale operations: a. Fracturing fluid additives, b. Flowback fluids, c. Sufficiency of regulations and guidelines, d. On-site flowback fluids treatment or recycling technologies, e. Potential ‘green’ (environmentally-friendly) hydraulic fracturing technologies, f. Alternate water sources for hydraulic fracturing operations, and g. Water well sampling needs.

USCRS (2012). “The EPA Draft Report of Groundwater Contamination near Pavillion, Wyoming: Main Findings and Stakeholder Responses”. CRS Report for Congress

On December 8, 2011, the U.S. Environmental Protection Agency (EPA) issued a draft report on its investigation of groundwater contamination near the town of Pavillion, Wyoming. This CRS report provides a synopsis of the statutory authority for EPA’s investigation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), a summary of the primary findings in the EPA Draft Report, and a brief discussion of issues raised subsequent to the release of the draft report by proponents and opponents of the use of hydraulic fracturing for natural gas development. Additionally, this report identifies the next steps EPA may take regarding this investigation. Although the EPA Draft Report focused on one specific region where hydraulic fracturing was employed to enhance the production of natural gas, it has raised concerns about hydraulic fracturing practices in general, and whether EPA’s findings at Pavillion are more broadly applicable to other regions of the country.

USDOE (2009). “State Oil and Natural Gas Regulations Designed to Protect Water Resources”. U.S. Department of Energy

State regulation of oil and natural gas exploration and production activities are approved under state laws that typically include a prohibition against causing harm to the environment. This premise is at the heart of the regulatory process. The regulation of oil and gas field activities is managed best at the state level where regional and local conditions are understood and where regulations can be tailored to fit the needs of the local environment. Hence, the experience, knowledge and information necessary to regulate effectively most commonly rests with state regulatory agencies. Many state agencies use programmatic tools and documents to apply state laws including regulations, formal and informal guidance, field rules, and Best Management Practices (BMPs). They are also equipped to conduct field inspections, enforcement/oversight, and witnessing of specific operations like well construction, testing and plugging. Regulations alone cannot convey the full measure of a regulatory program. To gain a more complete understanding of how regulatory programs actually function, one has to evaluate the use of state guides, manuals, environmental policy processes, environmental impact statements, requirements established by permit and many other practices. However, that is not the purpose of this study. This study evaluates the language of state oil and gas regulations as they relate to the direct protection of water resources. It is not an evaluation of state programs.

USDOE (2011). “The SEAB Shale Gas Production Subcommittee Second Ninety Day Report”. U.S. Department of Energy

The Shale Gas Subcommittee of the Secretary of Energy Advisory Board is charged with identifying measures that can be taken to reduce the environmental impact and to help assure the safety of shale gas production. Shale gas has become an important part of the nation’s energy mix. It has grown rapidly from almost nothing at the beginning of the century to near 30 percent of natural gas production. Americans deserve assurance that the full economic, environmental and energy security benefits of shale gas development will be realized without sacrificing public health, environmental protection and safety. On August 18, 2011 the Subcommittee presented its initial Ninety-Day Report including twenty recommendations that the Subcommittee believes, if implemented, would assure that the nation’s considerable shale gas resources are being developed responsibly, in a way that protects human health and the environment and is most beneficial to the nation. The Secretary of Energy's charge to the Subcommittee is included in Annex A and members of the Subcommittee are given in Annex B. In this report the Subcommittee focuses on implementation of the twenty recommendations presented in its Ninety-day report. The Executive Summary of these recommendations is presented in Annex C.

USGAO (2010). "Energy and Water Nexus: A Better and Coordinated Understanding of Water Resources Could Help Mitigate the Impacts of Potential Oil Shale Development". USGAO Report, GAO-11-35

Oil shale development could have significant impacts on the quality and quantity of water resources, but the magnitude of these impacts is unknown because technologies are years from being commercially proven, the size of a future oil shale industry is uncertain, and knowledge of current water conditions and groundwater flow is limited. In the absence of effective mitigation measures, water resources could be impacted from ground disturbances caused by the construction of roads and production facilities; withdrawing water from streams and aquifers for oil shale operations, underground mining and extraction; and discharging waters produced from or used in operations. Estimates vary widely for the amount of water needed to commercially produce oil shale primarily because of the unproven nature of some technologies and because the various ways of generating power for operations use differing quantities of water. GAO's review of available studies indicated that the expected total water needs for the entire life cycle of oil shale production ranges from about 1 barrel (or 42 gallons) to 12 barrels of water per barrel of oil produced from in-situ (underground heating) operations, with an average of about 5 barrels, and from about 2 to 4 barrels of water per barrel of oil produced from mining operations with surface heating. Water is likely to be available for the initial development of an oil shale industry, but the size of an industry in Colorado or Utah may eventually be limited by water availability. Water limitations may arise from increases in water demand from municipal and industrial users, the potential of reduced water supplies from a warming climate, fulfilling obligations under interstate water compacts, and the need to provide additional water to protect threatened and endangered fishes. The federal government sponsors research on the impacts of oil shale on water resources through DOE and Interior. DOE manages 13 projects whose water-related costs total about $4.3 million, and Interior sponsored two water-related projects, totalling about $500,000. Despite this research, nearly all of the officials and experts that GAO contacted said that there are insufficient data to understand baseline conditions of water resources in the oil shale regions of Colorado and Utah and that additional research is needed to understand the movement of groundwater and its interaction with surface water. Federal agency officials also said they seldom coordinate water-related oil shale research among themselves or with state agencies that regulate water. Most officials noted that agencies could benefit from such coordination.

USGAO (2012). "Oil and Gas: Information on Shale Resources, Development, and Environmental and Public Health Risks". USGAO Report, GAO-12-72

Oil and gas development, whether conventional or shale oil and gas, pose inherent environmental and public health risks, but the extent of these risks associated with shale oil and gas development is unknown, in part, because the studies GAO reviewed do not generally take into account the potential long-term, cumulative effects. For example, according to a number of studies and publications GAO reviewed, shale oil and gas development poses risks to air quality, generally as the result of (1) engine exhaust from increased truck traffic, (2) emissions from diesel-powered pumps used to power equipment, (3) gas that is flared (burned) or vented (released directly into the atmosphere) for operational reasons, and (4) unintentional emissions of pollutants from faulty equipment or impoundments—temporary storage areas. Similarly, a number of studies and publications GAO reviewed indicate that shale oil and gas development poses risks to water quality from contamination of surface water and groundwater as a result of erosion from ground disturbances, spills and releases of chemicals and other fluids, or underground migration of gases and chemicals. For example, tanks storing toxic chemicals or hoses and pipes used to convey wastes to the tanks could leak, or impoundments containing wastes could overflow as a result of extensive rainfall. According to the New York Department of Environmental Conservation's 2011 Supplemental Generic Environmental Impact Statement, spilled, leaked, or released chemicals or wastes could flow to a surface water body or infiltrate the ground, reaching and contaminating subsurface soils and aquifers. In addition, shale oil and gas development poses a risk to land resources and wildlife habitat as a result of constructing, operating, and maintaining the infrastructure necessary to develop oil and gas; using toxic chemicals; and injecting fluids underground. However, the extent of these risks is unknown. The extent and severity of environmental and public health risks identified in the studies and publications GAO reviewed may vary significantly across shale basins and also within basins because of location- and process-specific factors, including the location and rate of development; geological characteristics, such as permeability, thickness, and porosity of the formations; climatic conditions; business practices; and regulatory and enforcement activities.

USGS (2012). "Dissolved Methane in New York Groundwater". USGS Open-File Report 2012–1162. 6

New York State is underlain by numerous bedrock formations of Cambrian to Devonian age that produce natural gas and to a lesser extent oil. The first commercial gas well in the United States was dug in the early 1820s in Fredonia, south of Buffalo, New York, and produced methane from Devonian-age black shale. Methane naturally discharges to the land surface at some locations in New York. At Chestnut Ridge County Park in Erie County, just south of Buffalo, N.Y., several surface seeps of natural gas occur from Devonian black shale, including one behind a waterfall. Methane occurs locally in the groundwater of New York; as a result, it may be present in drinking-water wells, in the water produced from those wells, and in the associated water-supply systems. The use of hydraulic fracturing to release natural gas from these shale formations has raised concerns with water-well owners and water-resource managers across the Marcellus and Utica Shale region (West Virginia, Pennsylvania, New York and parts of several other adjoining States). Molofsky and others (2011) documented the widespread natural occurrence of methane in drinking-water wells in Susquehanna County, Pennsylvania. In the same county, Osborn and others (2011) identified elevated methane concentrations in selected drinking-water wells in the vicinity of Marcellus gas-development activities, although pre-development samples were not available for comparison. In order to manage water resources in areas of gas-well drilling and hydraulic fracturing in New York, the natural occurrence of methane in the State's aquifers needs to be documented. This brief report presents a compilation of data on dissolved methane concentrations in the groundwater of New York available from the U.S. Geological Survey (USGS) National Water Information System (NWIS) (http://waterdata.usgs.gov/nwis).

UTD (2011). "Hydraulic fracturing debated in House". Issues in Science and Technology

The House Science, Space and Technology Committee held a May 5 hearing to examine whether additional studies need to be conducted to determine the safety of hydraulic fracturing (also called fracking), a method use to extract natural gas from underground. The hearing took place in the wake of a natural-gas well eruption and leak, a report published in the Proceedings of the National Academy of Sciences stating that hydraulic fracturing can contaminate drinking water with methane, and a report from

House Democrats asserting that chemicals used in hydraulic fracturing could contaminate drinking water. Chairman Ralph Hall (R-TX), who is opposed to additional government studies, called an Environmental Protection Agency (EPA) study that is being drafted "yet another example of this administration's desire to stop domestic energy development through regulation."

Uth (2014). "Technical risks and best available technology (BAT) of hydraulic fracturing in unconventional natural gas resources". Environmental Earth Sciences. **72**: 2163–2171

Description of risks associated with (a) the technical installations above ground at the well site, (b) the transport of environmentally hazardous substances on roads and in pipelines, and (c) the technical design of the wellbore that can arise during specified normal operation and any deviations there from (accident). The assessment is based on a worst-case scenario approach that allows for definition of the measures necessary to avoid accidents and limit their consequences, in accordance with the state-of-the-art requirements (Best available technology (BAT)). The measures, thus, defined were then compared with given technical and organizational preventive measures for a typical installation, and the completeness and suitability of these measures were evaluated. The investigation is based on information and documentation that were provided by ExxonMobil Production Deutschland GmbH on selected drilling sites, as well as on the literature. Simulations were run for eight main scenarios and 28 subsidiary scenarios. The state-of-the-art (BAT) and good management practice were defined for measures aimed at preventing drilling site incidents and limiting their effects, and were then compared with and assessed in light of standard practices. The said comparison then formed the basis for the formulation of recommendations aimed at improving protection of the population and environment. The main recommendation is that hydrofracking operations should be conducted in accordance with prevailing chemical industry standards, even if adherence to these requirements is not prescribed by law. This especially pertains to requirements concerning the following: the manner in which substances that are hazardous to water are handled; pipeline requirements for natural gas, backflow water and formation water transport; and instituting modern cultures of safety, including providing information concerning risks and the elaboration of risk management action plans. Recommendations were also made as regards well integrity testing, in view of the critical nature of this matter and the need for integrated risk communication.

UVELC (2014). "Improving the Regulation of Fracking Wastewater Disposal in BC". UVELC. ELC File No. 2014-01-04

The Fort Nelson First Nation (FNFN) recently asked the University of Victoria Environmental Law Centre to develop recommendations for reform of BC's laws governing disposal wells for fracking wastewater. This report is the result. The Nation's territory encompasses three of the province's four major shale gas plays, the prime sources of BC natural gas. Extensive gas fracking operations already exist in this area; however, the FNFN expect BC LNG development will lead to a 600% increase in fracking operations in their territory in the near future. The FNFN is concerned about the impacts of fracking activity in their territory on groundwater and human health. Fracking operations use massive amounts of water that are contaminated with a variety of toxic substances. Operators dispose of flowback water and produced water from fracking operations into underground disposal wells. These wells are typically old wells whose integrity and operation are poorly monitored. Because the quality of the seal placed on such wells can degrade over time, there are concerns that these wells may contaminate aquifers used for drinking water, as well as the surface water systems the aquifers connect to. Therefore, the FNFN asked us to address the following questions: How are fracking wastewater disposal wells currently regulated in BC? What regulatory best practices exist in other jurisdictions and authorities? How can these best practice examples be incorporated into BC disposal well regulations to better protect health and the environment? This memo is divided into four parts. The first part of the memo tersely identifies the key broad legal issues. The second part provides an overview of the current regulatory framework governing disposal wells in BC. This part also briefly discusses concerns raised by the history of lax disposal well regulation – and the fact that most waste water has been injected into very old wells that may be subject to failure. The third part of this memo provides four "best practice" case studies from the International Energy Agency, the Canadian Association of Petroleum Producers, the United States and Natural Resources Defence Council, and the European Commission. The fourth and final part of the memo is perhaps the most important. It synthesizes the best practice case studies to make key recommendations to strengthen the BC regulatory framework and better protect environment and health."

Vengosh et al. (2013). "The effects of shale gas exploration and hydraulic fracturing on the quality of water resources in the United States". Procedia Earth and Planetary Science. **7**: 863 – 866

Advances in drilling technologies and production strategies such as horizontal drilling and hydraulic fracturing have significantly improved the production of natural gas by stimulating fluid flow from wells. Since 2008, these technological developments have spurred exponential growth of gas well drilling across the U.S. While the new drilling for shale gas and hydraulic fracturing technologies have dramatically changed the energy landscape in the U.S., recent scientific findings show evidence for contamination of water resources. This paper provides key observations for the potential risks of shale gas drilling and hydraulic fracturing on the quality of water resources and include: (1) stray gas contamination of shallow groundwater overlying shale gas basins; (2) pathways and hydraulic connectivity between the deep shale gas formations and the overlying shallow drinking water aquifers; and (3) inadequate disposal of produced and flowback waters associated with shale gas exploration that causes contamination of surface waters and long-term ecological effects. By using geochemical (e.g., Br/Cl) integrated with oxygen, hydrogen, strontium, radium, and boron isotopic tracers, we have characterized the geochemical fingerprints of brines from several shale gas basins in the USA, including the Utica and Marcellus brines in the Appalachian Basin and the Fayetteville brines in Arkansas. We use these geochemical fingerprints to delineate the impact of shale gas associated fluids on the environment.

Vengosh et al. (2014). "A Critical Review of the Risks to Water Resources from Unconventional Shale Gas Development and Hydraulic Fracturing in the United States". Environmental Science and Technology. **48**(15): 8334–8348

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 over-extraction 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.

Vidic et al (2013). "Impact of Shale Gas Development on Regional Water Quality". Science. **340**

Unconventional natural gas resources offer an opportunity to access a relatively clean fossil fuel that could potentially lead to energy independence for some countries. Horizontal drilling and hydraulic fracturing make the extraction of tightly bound natural gas from shale formations economically feasible. These technologies are not free from environmental risks, however, especially those related to regional water quality, such as gas migration, contaminant transport through induced and natural fractures, wastewater discharge, and accidental spills. We review the current understanding of environmental issues associated with unconventional gas extraction. Improved understanding of the fate and transport of contaminants of concern and increased long-term monitoring and data dissemination will help manage these water-quality risks today and in the future.

Volz et al. (2011). "Contaminant Characterization of Effluent from Pennsylvania Brine Treatment Inc., Josephine Facility: Implications for Disposal of Oil and Gas Flowback Fluids from Brine Treatment Plants". United States Environmental Protection Agency.

This report contains results from sampling and analysis of wastewater effluent entering Blacklick Creek, Indiana County Pennsylvania from the Pennsylvania Brine Treatment (PBT) Josephine Facility conducted by the Center for Healthy Environments and Communities (CHEC). The PBT-Josephine Facility accepts only wastewater from the oil and gas industry, including flowback water from Marcellus Shale gas extraction operations. This report describes the concentrations of selected analyzed contaminants in the effluent water and compares the contaminant effluent concentrations to standards, guidelines and criteria set by federal and state regulatory and investigative agencies for the protection of human and aquatic health.

Walsh et al. (2010). "Geochemical characteristics of leachate from the Marcellus shale, Otsego county, New York; results of a 100-day laboratory test". Geological Society of America Abstracts with Programs. **42**(1): 122

The potential environmental impacts of natural gas drilling in the Marcellus Shale have caused considerable public concern in New York State. One of the principle concerns is the potential for metals to be leached from drill cuttings, and the migration of this leachate into surface water and/or shallow groundwater. The purpose of this project is to characterize the geochemistry of leachate produced from Marcellus Shale over time. Three weathered rock samples were collected from the basal layer of the Marcellus Shale exposed in a road cut along U.S. Route 20 in Cherry Valley, New York, at the northern most boundary of the Allegheny Plateau. Samples were crushed by hand to a pebble size with a diameter ranging from 4.00 mm to 12.7 mm. X-ray fluorescence techniques identified the whole-rock composition of metals (i.e. Fe, Mn, Mg, Na, Cl, Ba, Sr, K, As, and Ca) in each sample prior to leaching. In the laboratory, 1000 mL of water was percolated through approximately 10 grams of crushed sample. The resulting leachate was collected and re-percolated through the sample once a day for 100 days at 25 °C. Water samples were collected at 25-, 50-, 75-, and 100-day intervals and analyzed for pH, electrical conductivity, dissolved metals (i.e. Fe, Mn, Mg, Na, Cl, Ba, Sr, K, and Ca) using an ICP-ES, anions (i.e. SO_4 and Cl) using an adsorption spectrophotometer, arsenic using a Hach test kit, and carbonate alkalinity by titration. The mobility of metals from drill cores will be

determined by comparing the dissolved concentrations to the whole-rock concentrations for each species. The dissolved concentrations will also be compared to New York State water quality guidelines to identify potential contaminants of concern associated with Marcellus Shale drill core leachate.

Warner et al. (2012). “Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania”. Proceedings of the National Academy of Sciences. **109**(30): 11961–11966.

The debate surrounding the safety of shale gas development in the Appalachian Basin has generated increased awareness of drinking water quality in rural communities. Concerns include the potential for migration of stray gas, metal-rich formation brines, and hydraulic fracturing and/or flowback fluids to drinking water aquifers. A critical question common to these environmental risks is the hydraulic connectivity between the shale gas formations and the overlying shallow drinking water aquifers. We present geochemical evidence from northeastern Pennsylvania showing that pathways, unrelated to recent drilling activities, exist in some locations between deep underlying formations and shallow drinking water aquifers. Integration of chemical data (Br, Cl, Na, Ba, Sr, and Li) and isotopic ratios (87Sr/86Sr, 2H/H, 18O/16O, and 228Ra/226Ra) from this and previous studies in 426 shallow groundwater samples and 83 northern Appalachian brine samples suggest that mixing relationships between shallow ground water and a deep formation brine causes groundwater salinization in some locations. The strong geochemical fingerprint in the salinized (Cl > 20 mg/L) groundwater sampled from the Alluvium, Catskill, and Lock Haven aquifers suggests possible migration of Marcellus brine through naturally occurring pathways. The occurrences of saline water do not correlate with the location of shale-gas wells and are consistent with reported data before rapid shale-gas development in the region; however, the presence of these fluids suggests conductive pathways and specific geostructural and/or hydrodynamic regimes in northeastern Pennsylvania that are at increased risk for contamination of shallow drinking water resources, particularly by fugitive gases, because of natural hydraulic connections to deeper formations.

Warner et al. (2013). “Geochemical and isotopic variations in shallow groundwater in areas of the Fayetteville Shale development, north-central Arkansas”. Applied Geochemistry. **35**: 207-220.

Exploration of unconventional natural gas reservoirs such as impermeable shale basins through the use of horizontal drilling and hydraulic fracturing has changed the energy landscape in the USA providing a vast new energy source. The accelerated production of natural gas has triggered a debate concerning the safety and possible environmental impacts of these operations. This study investigates one of the critical aspects of the environmental effects; the possible degradation of water quality in shallow aquifers overlying producing shale formations. The geochemistry of domestic groundwater wells was investigated in aquifers overlying the Fayetteville Shale in north-central Arkansas, where approximately 4000 wells have been drilled since 2004 to extract unconventional natural gas. Monitoring was performed on 127 drinking water wells and the geochemistry of major ions, trace metals, CH4 gas content and its C isotopes (d13CCH4), and select isotope tracers (d11B, 87Sr/86Sr, d2H, d18O, d13CDIC) compared to the composition of flowback-water samples directly from Fayetteville Shale gas wells. Dissolved CH4 was detected in 63% of the drinking-water wells (32 of 51 samples), but only six wells exceeded concentrations of 0.5 mg CH4/L. The d13CCH4 of dissolved CH4 ranged from 42.3‰ to 74.7‰, with the most negative values characteristic of a biogenic source also associated with the highest observed CH4 concentrations, with a possible minor contribution of trace amounts of thermogenic CH4. The majority of these values are distinct from the reported thermogenic composition of the Fayetteville Shale gas

(d13CCH4 = 35.4‰ to 41.9‰).
Based on major element chemistry, four shallow groundwater types were identified: (1) low (<100 mg/L) total dissolved solids (TDS), (2) TDS > 100 mg/L and Ca–HCO3 dominated, (3) TDS > 100 mg/L and Na–HCO3 dominated, and (4) slightly saline groundwater with TDS > 100 mg/L and Cl > 20 mg/L with elevated Br/Cl ratios (>0.001). The Sr (87Sr/86Sr = 0.7097–0.7166), C (d13CDIC = 21.3‰ to 4.7‰), and B (d11B = 3.9–32.9‰) isotopes clearly reflect water–rock interactions within the aquifer rocks, while the stable O and H isotopic composition mimics the local meteoric water composition. Overall, there was a geochemical gradient from low-mineralized recharge water to more evolved Ca–HCO3, and higher-mineralized Na–HCO3 composition generated by a combination of carbonate dissolution, silicate weathering and reverse base-exchange reactions. The chemical and isotopic compositions of the bulk shallow groundwater samples were distinct from the Na–Cl type Fayetteville flowback/produced waters (TDS 10,000–20,000 mg/L). Yet, the high Br/Cl variations in a small subset of saline shallow groundwater suggest that they were derived from dilution of saline water similar to the brine in the Fayetteville Shale. Nonetheless, no spatial relationship was found between CH4 and salinity occurrences in shallow drinking water wells with proximity to shale-gas drilling sites. The integration of multiple geochemical and isotopic proxies shows no direct evidence of contamination in shallow drinking-water aquifers associated with natural gas extraction from the Fayetteville Shale.

Warner et al. (2013). "Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania". Environmental Science and Technology. **47**(20): 11849-11857.

The safe disposal of liquid wastes associated with oil and gas production in the United States is a major challenge given their large volumes and typically high levels of contaminants. In Pennsylvania, oil and gas wastewater is sometimes treated at brine treatment facilities and discharged to local streams. This study examined the water quality and isotopic compositions of discharged effluents, surface waters, and stream sediments associated with a treatment facility site in western Pennsylvania. The elevated levels of chloride and bromide, combined with the strontium, radium, oxygen, and hydrogen isotopic compositions of the effluents reflect the composition of Marcellus Shale produced waters. The discharge of the effluent from the treatment facility increased downstream concentrations of chloride and bromide above background levels. Barium and radium were substantially (>90%) reduced in the treated effluents compared to concentrations in Marcellus Shale produced waters. Nonetheless, ^{226}Ra levels in stream sediments (544–8759 Bq/kg) at the point of discharge were ~200 times greater than upstream and background sediments (22–44 Bq/kg) and above radioactive waste disposal threshold regulations, posing potential environmental risks of radium bioaccumulation in localized areas of shale gas wastewater disposal.

Water in the West (2013). "Water and Energy Nexus: A Literature Review". Water in the West, Stanford University

This Water-Energy Literature Review is offered as a snapshot of current understanding about the water-energy nexus. It is meant to invite engagement and investments in future interdisciplinary research to target water use efficiency in the energy sector and energy efficiency, or reductions in energy intensities, in the water and wastewater sectors. While it constitutes a broad overview of national water-energy research, this Review has been informed by the robust public-policy and utility-sector efforts to address the energy intensity of California's water supplies across the water life cycle. Readers interested in more information about the water-energy nexus are encouraged to delve deeper into the considerable literature reviewed in this document.

Water Research Foundation (2011). “Hydraulic Fracturing Issues and Research Needs for the Water Community”. WaterRF

The purpose of this project was to identify research topics that could improve understanding of (a) the potential risks of hydraulic fracturing and associated natural gas development activities to drinking water supplies; and (b) strategies for reducing identified risks. The research topics identified through this project are an initial step in determining research projects that may be sponsored by the Water Research Foundation (WaterRF). WaterRF is a nonprofit organization that sponsors research into issues of concern for its member agencies in order to help water utilities cost-effectively provide safe drinking water to consumers. WaterRF has been supporting research for over 40 years on a diverse range of topics. As new issues emerge for its members, WaterRF conducts targeted workshops in order to develop information for future Requests for Proposals by its Research Advisory Council.

This report summarizes information collected during the project and discussions conducted during the Workshop on Natural Gas Development Issues for Drinking Water Utilities held on October 27-28, 2010 in Baltimore, Maryland. Natural gas development utilizing hydraulic fracturing has the potential to impact water utilities in many ways. As such, the final list of research ideas was broad and consisted of projects designed to analyze effective regulations, understand risks, predict chemical characteristics, monitor source waters, evaluate infrastructure impacts, conduct emergency planning, improve communication between utilities and the gas industry, and manage wastewater.

Water UK (2013). “Impacts of shale gas on water and wastewater” Water UK briefing: shale gas

The evidence base on the magnitude of the impact of shale gas on drinking water and wastewater services in the UK is limited but nonetheless risks do exist. Although water companies would not wish to hinder economic development, there is a view that the impacts on water need to be addressed and need to be addressed at the outset.

Watson (2010). “Report of Cabot Oil & Gas Corporation's Utilization of Effective Techniques for Protecting Fresh Water Zones/Horizons During Natural Gas Drilling – Completion and Plugging Activities”

A study was conducted of several natural gas wells in Susquehanna County, Pennsylvania that were installed and operated by Cabot Oil & Gas Corporation (Cabot). The investigation included a comprehensive analysis of the structural and mechanical integrity of the natural gas wells with a focus on whether appropriate techniques were utilized to protect fresh water zones. The study concludes that Cabot used and is using procedures for drilling, casing and cementing wells that (i) meet or exceed the requirements of the Pennsylvania Oil & Gas Act, (ii) are adequate to protect Pennsylvania's drinking water, (iii) are not causing or allowing methane migration into Pennsylvania's drinking water.

Weber et al. (2012). “Cumulative Effects Assessment: Linking Social, Ecological, and Governance Dimensions”. Ecology and Society. **17**(2): 22

Setting social, economic, and ecological objectives is ultimately a process of social choice informed by science. In this special feature we provide a multidisciplinary framework for the use of cumulative effects assessment in land use planning. Forest ecosystems are facing considerable challenges driven by population growth and increasing demands for resources. In a suite of case studies that span the boreal forest of Western Canada to the interior Atlantic forest of Paraguay we show how transparent and defensible methods for scenario analysis can be applied in data-limited regions and how social dimensions of land use change can be incorporated in these methods, particularly in aboriginal communities that have lived in these ecosystems for generations. The case studies explore how scenario analysis can be used to evaluate various land use options and highlight specific challenges with identifying social and ecological responses, determining thresholds and targets for land use, and integrating local and traditional knowledge in land use planning. Given that land use planning is ultimately a value-laden and often politically charged process we also provide some perspective on various collective and expert-based processes for identifying cumulative impacts and thresholds. The need for good science to inform and be informed by culturally appropriate democratic processes calls for well-planned and multifaceted approaches both to achieve an informed understanding of both residents and governments of the interactive and additive changes caused by development, and to design action agendas to influence such change at the ecological and social level.

Weltman-Fahs & Taylor (2013). “Hydraulic Fracturing and Brook Trout Habitat in the Marcellus Shale Region: Potential Impacts and Research Needs”. Fisheries. **38**(1): 4-15

Expansion of natural gas drilling into the Marcellus Shale formation is an emerging threat to the conservation and restoration of native brook trout (*Salvelinus fontinalis*) populations. Improved drilling and extraction technologies (horizontal drilling and hydraulic fracturing) have led to rapid and extensive natural gas development in areas overlying the Marcellus Shale. The expansion of hydraulic fracturing poses multiple threats to surface waters, which can be tied to key ecological attributes that limit brook trout populations. Here, we expand current conceptual models to identify three potential pathways of risk between surface water threats associated with increased natural gas development and life history attributes of brook trout: hydrological, physical, and chemical. Our goal is to highlight research needs for fisheries scientists and work in conjunction with resource managers to influence the development of strategies that will preserve brook trout habitat and address Marcellus Shale gas development threats to eastern North America’s only native stream salmonid.

Western Governors Association (2013). “State of Energy in the West”

The Western United States plays a critical role in meeting our nation’s energy needs. From conventional fuels to renewable energy, the West’s resources provide the majority of the United States’ energy supply. These resources are good news for the West and its residents. They also present a challenge: Can the Western states create an approach to development that delivers energy in a way that is secure, affordable and respects the environment? In order to address that concern, my colleagues and I at the Western Governors’ Association (WGA) created The State of Energy in the West, a comprehensive survey of the vast energy resources in the West, from coal to solar energy, wind power to petroleum. We hope that Congress and the Obama Administration are able to follow this example of bipartisan cooperation in order to address energy on a national scale. Western Governors consider these efforts a first step toward a blueprint for the country to help create an energy policy that promotes economic growth while protecting our valued natural and environmental resources.

Western Governors Association (2013). “Energy Perspectives”

The Western United States play a critical role in meeting our nation’s energy needs. From conventional fuels to renewable energy, the West’s resources provide the majority of the United States’ energy supply. These resources are good news for the West and its residents. They also present a challenge: Can the Western states create an approach to development that delivers energy in a way that is secure, affordable and respects the environment? To address that concern, my colleagues and I at the Western Governors’ Association (WGA) created Energy Perspectives, a collection of essays by Western governors and Canadian premiers on their specific energy plans. We hope that Congress and the Obama Administration are able to follow this example of bipartisan cooperation in order to address energy on a national scale. Western Governors consider these efforts a first step toward a blueprint for the country to help create an energy policy that promotes economic growth while protecting our valued natural and environmental resources.

Western Organization of Research Councils (2013). “Gone for Good. Fracking and Water Loss in the West”. WORC.

Hydraulic fracturing (or “fracking”) in combination with horizontal drilling has been a key vehicle for the recent upsurge in oil and gas production in the United States. This well stimulation technique is used for both oil and gas production. Much of the public concern about fracking nationally has focused on the threat of water contamination from the chemicals used. Especially in the arid West, however, fracking poses an additional and even more serious threat: water consumption and availability. By volume, water is by far the largest constituent of fracking fluid. After water has been laden with other substances and pressed into the service of hydraulic fracturing, it is typically injected into deep wells.
The purpose of this report is to outline the status of water consumption for fracking in four states: Colorado; Montana; North Dakota; and Wyoming. The report also outlines and evaluates current regulatory frameworks for fracking water usage in each of those states. Regulating the water use connected with fracking has to this point, like all water use regulation, been a state rather than a federal responsibility. From the research undertaken to compile this report, it seems clear that water use for fracking is reaching a crisis point in the region. There is mounting evidence that the current level of water use for oil and gas production simply cannot be sustained, and that projected increases in use may lead to a crisis. Something has to give.

Wiggett (2012). “Water - Chemical Treatment and Management”. Society of Petroleum Engineers. **8**

Recycling produced water for re-use in gas and oil fields for hydraulic fracturing and re-injection to maintain reservoir pressure is becoming increasingly important due to the scarcity of this natural resource. This is especially the case when these activities are not near a readily available source of ‘free water’ such as seawater or an aquifer. This paper considers ways to use water management to lower operational expenditures OPEX by eliminating freshwater sourcing, transportation, storage and its treatment as well as the storage, transportation, treatment and disposal of produced or flow-back water. The water management approach enables operators to re-use produced waters in hydraulic fracturing fluids. Pre-treatment testing and analysis characterizes the chemistry of the water to ensure an effective fracturing fluid design and to determine the appropriate water treatment solution for every application. By using a comprehensive water treatment suite of technologies, we demonstrate that virtually any oilfield water can be treated. Post-treatment testing confirms the water meets the customer's specific

requirements. Integrating water management service technical expertise with water chemistry and chemical treatments maximizes hydrocarbon production, minimizes reservoir damage, and reduces the costs of freshwater sourcing by as much as 90%. The techniques also offer real routes for oil operators to meet regulatory requirements, mitigating environmental impact.

Wilkinson et al. (2014). "Environmental Stewardship: Lessons for European Unconventional Gas from the United States and Australia". Society of Petroleum Engineers. **6**(3): 112-121

Europe is on the cusp of an expansion in the development of unconventional gas resources and many analysts are turning to the United States and Australia to learn lessons from markets at different stages of the development curve. Most attention has been focused on similarities and differences in geology, service industry and gas price whilst consideration of environmental stewardship has been dominated by concerns over the potential environmental and health impacts of hydraulic fracturing. Broader issues of local water security, waste water management and landscape impact have, in contrast, received less attention. To address these issues, the authors take an alternative look at the European market, using experiences in the United States and Australia to consider the risk management practices, regulatory measures and stakeholder engagement techniques that have achieved greatest success in stimulating the industry whilst at the same time protecting environmental assets. Although the industries in the US and Australia exhibit notable differences to that which may develop in Europe, several overarching observations can be made. The importance of joint-stakeholder working, transparency and carefully defined boundaries of jurisdiction are some of the key factors. Drawing lessons from these examples and others, the authors conclude by identifying three initiatives essential to the emergence of a viable, publically acceptable and sustainable unconventional gas industry in Europe: • Collection of robust and reliable environmental baseline data; • Using and communicating sound science; and • Implementing collaborative governance. Failure to implement these initiatives could stifle projects, breed uncertainty, promote conflict with existing industries and the public and potentially, discourage investment. Conversely, by implementing the three recommendations, Europe would be better placed to encourage unconventional gas development in a manner that secures social and economic benefits whilst maintaining high levels of environmental stewardship.

Williams & Cooper (2014). "The Environmental Fate of Oil and Gas Biocides: A Review". NACE. **15**

The environmental fate characteristics of industrial biocides used in oil and gas applications are of increasing concern due to the industry's drive for sustainable best practices and regulatory pressure on water use and disposal. A detailed understanding of the environmental impact of biocides is critical to their safe use and requires extensive testing. This paper will review current data on the environmental fate and ecotoxicity of commonly used non-oxidizing and oxidizing biocides in oil and gas applications. The associated toxicity to non-target aquatic species and the ecotoxicity profiles for aquatic invertebrates, fish, and algae are presented. Environmental toxicity may be reduced or eliminated following degradation of the biocide active ingredients under environment conditions. Key elements of the environmental fate profile include biodegradability, bioaccumulation, end-product formation, and chemical stability (hydrolysis, photolysis). The specific pathways of biotic and abiotic decomposition and current methods for deactivation of the biocides are reviewed. Collectively, this information provides guidance on the selection and use of oil and gas biocides for various types of applications.

Wilson et al. (2014). "Sources of high total dissolved solids to drinking water supply in Southwestern Pennsylvania". Journal of Environmental Engineering. **140**: B4014003.

Fossil fuel extraction activities generate wastewaters that are often high in total dissolved solids (TDS) and specific constituents that can affect drinking water, if these wastewaters enter surface waters. Control of TDS in source waters is difficult without identification of the potential sources of high TDS wastewater associated with fossil fuel activities. Characteristics of natural waters, oil and gas-produced waters, and coal-related wastewaters were analyzed to extract information about constituent concentrations and anion ratios. Statistical analysis of the anion ratios indicates that the SO_4/Cl ratio is higher in coal-related wastewaters than in oil and gas-produced waters, suggesting that wastewaters can be distinguished based on this ratio. An approach that compared the SO_4/Cl ratio with bromide concentration for the wastewaters can serve to separate oil and gas-produced waters from brine treatment plant discharges, and from the various coal-related wastewaters. This method was applied to surface water quality data collected from two tributaries in Southwestern Pennsylvania from September 2009 to September 2012. Results show that this constituent and ratio method, combined with mixing curve calculations, can be used to identify water quality changes in these two tributaries. Similar mixing models, when applied to regionally relevant high TDS wastewater data, may be used in other areas experiencing water quality changes resulting from fossil fuel extraction activities.

Wiseman & Gradijan (2011). "Regulation of Shale Gas Development, Including Hydraulic Fracturing". The Energy Institute University of Texas. **129**

As gas and oil development from shales has expanded in the United States, potential environmental contamination, health effects, nuisances, and impacts on local roads, among other possible effects, have raised concern. The public has tended to direct its focus toward one stage of the shale development process called slickwater "hydraulic fracturing"—also called fracing, fracking, or hydrofracking—wherein an operator, after drilling a well, typically injects large quantities of water combined with relatively small quantities of chemicals down the well bore to fracture the shale around it or to expand existing fractures, thus exposing more surface area within the stratum and enabling gas or oil production. This paper provides a brief overview of federal regulation of oil and gas development and fracturing and describes in detail the extent to which state statutes, regulations, and policies address the potential effects of hydraulic fracturing as well as other stages of shale gas development. The paper also briefly addresses local and regional regulation. In the course of describing these regulations, the paper suggests how regulation could better respond to science-based concerns about shale gas development.

Zaccarelli et al. (2008). "Source/Sink Patterns of Disturbance and Cross-Scale Mismatches in a Panarchy of Social-Ecological Landscapes". Ecology and Society. **13**(1): 26

Land-use change is one of the major factors affecting global environmental change and represents a primary human effect on natural systems. Taking into account the scales and patterns of human land uses as source/sink disturbance systems, we describe a framework to characterize and interpret the spatial patterns of disturbances along a continuum of scales in a panarchy of nested jurisdictional social-ecological landscapes (SELs) like region, provinces, and counties. We detect and quantify those scales through the patterns of disturbance relative to land use/land cover exhibited on satellite imagery over a 4-yr period in the Apulia region, South Italy. By using moving windows to measure composition (amount) and spatial configuration (contagion) of disturbance, we identify multiscale disturbance source/sink trajectories in the pattern metric space defined by composition and configuration of disturbance. We group disturbance trajectories along a continuum of scales for each location (pixel) according to broad land-use classes for each SEL level in the panarchy to identify spatial scales and geographical regions where disturbance is more or less concentrated in space indicating disturbance sources, sinks, and mismatches. We also group locations by clustering, and results are compared in the same pattern space and interpreted with respect to disturbance trajectories derived from random, multifractal and hierarchical neutral models. We show that in the real geographical world spatial mismatches of disturbances can occur at particular scale ranges because of cross scale disparities in land uses for the amount and contagion of disturbance, leading to more or less exacerbation of contrasting source/sink systems along certain scale domains. All cross-scale source/sink issues can produce both negative and positive effects on the scales above and below their levels, i.e., cross-scale effects. Through the framework outlined in our examples, managers, as well as stakeholders belonging to SELs in the panarchy, can be aware of specific scale ranges of disturbance where mismatches might occur and that will help them to value where and how to intervene in the panarchy of SELs to enhance the benefits and to minimize negative effects.

Zhang et al. (2014). “Co-precipitation of Radium with Barium and Strontium Sulfate and Its Impact on the Fate of Radium during Treatment of Produced Water from Unconventional Gas Extraction”. Environmental Science and Technology. **48**(8): 4596-4603.

Radium occurs in flowback and produced waters from hydraulic fracturing for unconventional gas extraction along with high concentrations of barium and strontium and elevated salinity. Radium is often removed from this wastewater by co-precipitation with barium or other alkaline earth metals. The distribution equation for Ra in the precipitate is derived from the equilibrium of the lattice replacement reaction (inclusion) between the Ra^{2+} ion and the carrier ions (e.g., Ba^{2+} and Sr^{2+}) in aqueous and solid phases and is often applied to describe the fate of radium in these systems. Although the theoretical distribution coefficient for Ra–$SrSO_4$ (K_d = 237) is much larger than that for Ra–$BaSO_4$ (K_d = 1.54), previous studies have focused on Ra–$BaSO_4$ equilibrium. This study evaluates the equilibria and kinetics of co-precipitation reactions in Ra–Ba–SO_4 and Ra–Sr–SO_4 binary systems and the Ra–Ba–Sr–SO_4 ternary system under varying ionic strength (IS) conditions that are representative of brines generated during unconventional gas extraction. Results show that radium removal generally follows the theoretical distribution law in binary systems and is enhanced in the Ra–Ba–SO_4 system and restrained in the Ra–Sr–SO_4 system by high IS. However, the experimental distribution coefficient (K_d') varies widely and cannot be accurately described by the distribution equation, which depends on IS, kinetics of carrier precipitation and does not account for radium removal by adsorption. Radium removal in the ternary system is controlled by the co-precipitation of Ra–Ba–SO_4, which is attributed to the rapid $BaSO_4$ nucleation rate and closer ionic radii of Ra^{2+} with Ba^{2+} than with Sr^{2+}. Carrier (i.e., barite) recycling during water treatment was shown to be effective in enhancing radium removal even after co-precipitation was completed. Calculations based on experimental results show that Ra levels in the precipitate generated in centralized waste treatment facilities far exceed regulatory limits for disposal in municipal sanitary landfills and require careful monitoring of allowed source term loading (ASTL) for technically enhanced naturally occurring materials (TENORM) in these landfills. Several alternatives for sustainable management of TENORM are discussed.

Ziemkiewicz et al. (2014). “Practical measures for reducing the risk of environmental contamination in shale energy production”. Environmental Science Processes & Impacts. DOI: 10.1039/c3em00510k

Gas recovery from shale formations has been made possible by advances in horizontal drilling and hydraulic fracturing technology. Rapid adoption of these methods has created a surge in natural gas production in the United States and increased public concern about its environmental and human health effects. We surveyed the environmental literature relevant to shale gas development and studied over fifteen well sites and impoundments in West Virginia to evaluate pollution caused by air emissions, light and noise during drilling. Our study also characterized liquid and solid waste streams generated by drilling and hydraulic fracturing and evaluated the integrity of impoundments used to store fluids produced by hydraulic fracturing. While most shale gas wells are completed with little or no environmental contamination, we found that many of the problems associated with shale gas development resulted from inattention to accepted engineering practices such as impoundment construction, improper liner installation and a lack of institutional controls. Recommendations are provided based on the literature and our field studies. They will address not all but a great many of the deficiencies that result in environmental release of contaminants from shale gas development. We also identified areas where new technologies are needed to fully address contaminant releases to air and water.

Ziemkiewicz et al. (2014). "Exposure pathways related to shale gas development and procedures for reducing environmental and public risk". Journal of Natural Gas Science and Engineering. 16: 77-84.

Hydraulic fracturing, combined with horizontal well development, has resulted in rapid expansion of gas production in the Appalachian Marcellus shale formation. In the past three years, over 2000 horizontal/hydraulic fracture (HHF) wells have been developed in Pennsylvania, presenting significant potential for environmental degradation and human health risk if wastes are not isolated and handled properly. This study examined the waste streams from HHF development in the Marcellus formation and proposes protective measures that would minimize exposure. The results showed that flowback, drilling muds, and HHF fluids all exceeded SDWA limits to varying degrees. Due to the contaminants found in these substances, proper handling and containment is essential to prevent harm to the environment. Field evaluations on a subset of pits and impoundments indicated several construction and maintenance deficiencies related to the containment systems and transport pipelines. The geomembrane liners were evaluated for tears and anchoring deficiencies, while liquid transfer pipes were assessed for bracing support against rupture. An out-of-sample probability analysis using the binomial distribution identifies trends to focus field construction and maintenance efforts in order to minimize exposure pathways of frac fluids to the environment.