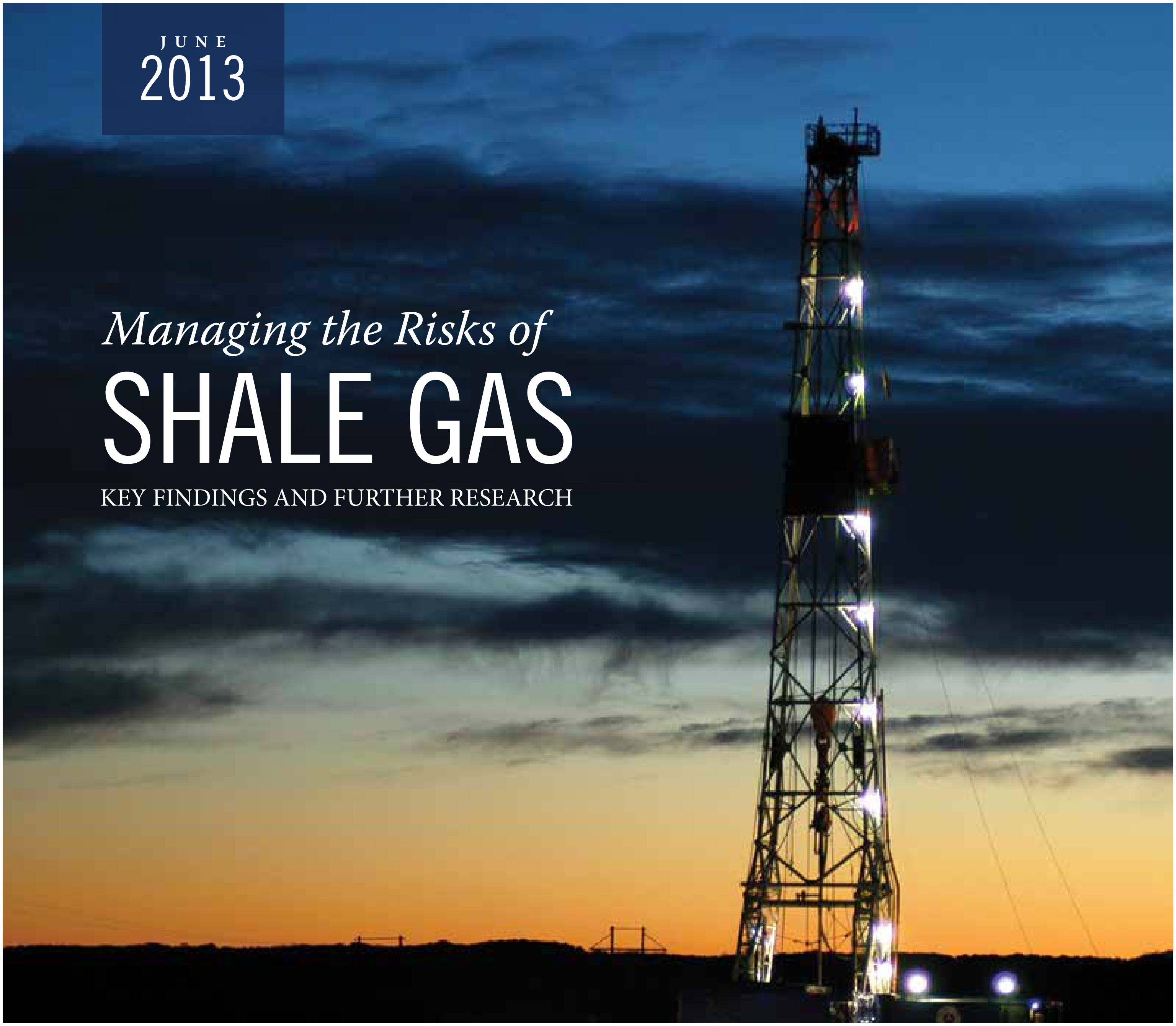

JUNE
2013

Managing the Risks of
SHALE GAS
KEY FINDINGS AND FURTHER RESEARCH

An initiative of RFF's Center for Energy Economics and Policy

RESOURCES FOR THE FUTURE

ALAN J. KRUPNICK

This summary was developed by RFF's Center for Energy Economics and Policy (CEEP) as an overview of its initiative, Managing the Risks of Shale Gas: Identifying a Pathway toward Responsible Development. Findings are published at www.rff.org/shalegasrisks.

The following experts wrote studies and reports throughout various phases of this initiative.

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RFF thanks the Alfred P. Sloan Foundation for its generous support of this initiative.

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Because of public concerns and an evolving regulatory landscape, maintaining and expanding the sustainable development of shale gas in the United States will require a better understanding of the associated environmental risks and the ways in which government and industry can best address those risks. For the past two years, researchers in RFF's Center for Energy Economics and Policy (CEEP) have been analyzing these issues. Managing the Risks of Shale Gas Development is CEEP's multi-faceted initiative to survey experts and the public to identify these risks, investigate some of the high priority risks, and assess regulatory frameworks at the state level.

This overview summarizes the key findings from the various RFF reports and studies developed as part of this research initiative. Also included in this overview is a section on cross-cutting findings that compares and integrates results across the various studies. The overview concludes with comments on opportunities for further research in these areas.

Contents

Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development

Alan J. Krupnick, Hal Gordon, and Sheila M. Olmstead

Pathways to Dialogue is the first survey-based analysis of experts from government agencies, industry, academia, 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.

In order to survey the experts, RFF researchers created the Risk Matrix for Shale Gas Development, a catalogue of all the plausible environmental risks associated with the development of shale gas. It includes 264 routine "risk pathways" and 14 accident pathways that link activities associated with shale gas exploration and development to their possible impacts on the environment. The risk matrix was the basis for the survey.

Although this survey does not rank any of the potential risks by level of importance, the fact that consensus exists around several risk pathways suggests that these should be targeted for early improvements in regulation and/or industry practice.

KEY FINDINGS

» There is a high degree of consensus among experts about the specific risks to mitigate.

» There are 15 "consensus risks" that survey respondents from all four expert groups most frequently identified as priorities for further regulatory or voluntary action (Figure 1). Of these, 13 are related to routine risks: 7 involve potential risks to surface water quality, 2 involve potential risks to air quality, 3 involve potential risks to groundwater quality, and 1 is related to habitat disruption. The remaining two consensus risks are related to accidents affecting groundwater: methane and fluid leaks from cement failure and casing failure.

» Self-identified "top experts" (those rating themselves as having high levels of expertise in given activities) gave priority to 11 of the 13 routine risk consensus pathways. The possible routine escape of methane into groundwater as a result of casing and cementing problems was often identified as a priority by top experts on drilling, including all of the top experts from NGOs.

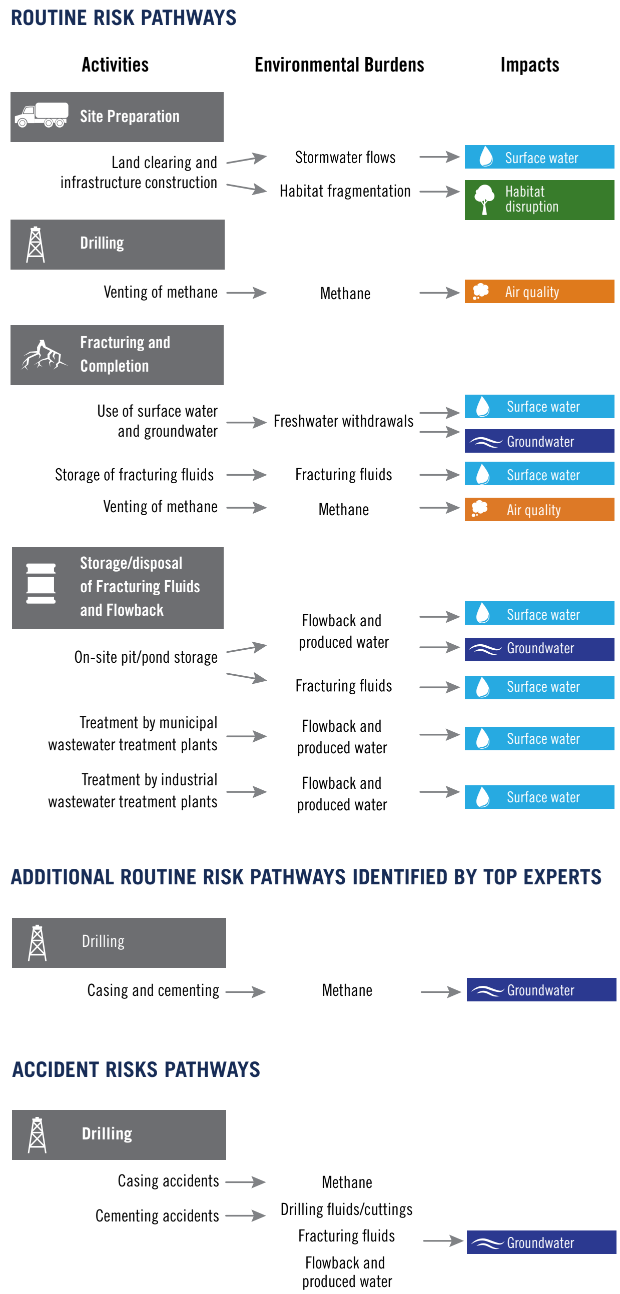
» Only 2 of the consensus routine risks identified by the experts are unique to the shale gas development process, and both have potential impacts on surface water. The remaining 11 relate to practices common to gas and oil development in general, such as the construction of roads, well pads, and pipelines and the potential for leaks in casing and cementing.

The experts were also asked to choose who should be the primary party with authority to address the risks: government or industry. NGO, academic, and government experts selected government more often than industry, whereas industry experts selected government and industry equally. However, when the focus is only on the consensus pathways, all groups agree that government should play the primary role.

View the risk matrix at www.rff.org/shaleriskmatrix.
Read the report at www.rff.org/shaleexpertsurvey.

Krupnick, Alan, Hal Gordon, and Sheila Olmstead. 2013. *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development.* Washington, DC: Resources for the Future.

Figure 1. 15 Consensus Risk Pathways



Attitudes and the Willingness to Pay for Reducing Shale Gas Risks

Juha Siikamäki and Alan J. Krupnick

RFF researchers surveyed the public to answer three key questions: How concerned is the public about the environmental and health risks associated with shale gas development? How much do people value reductions in such risks (or how much are people willing to pay)? How does the type of information that people receive about shale gas development and its risks affect their perceptions of risk and their willingness to pay to mitigate risks?

The researchers surveyed a random sample of 1,600 adults in Pennsylvania and Texas, asking them about their knowledge of shale gas development activities and their attitudes about potential risks. The survey explained what shale gas development is and provided one of three alternative "information treatments" describing the risks—one from the website of the American Petroleum Institute (API), another from the websites of several environmental NGOs, and a neutral description written by RFF researchers.

Because the actual levels of risk have not yet been conclusively determined by the scientific community, the survey also examined the public's preferences under three sets of baseline risks (that is, those risks that exist if govern-

Figure 2. Average Willingness to Pay Estimates for Risk Reduction by Texas and Pennsylvania Survey Respondents

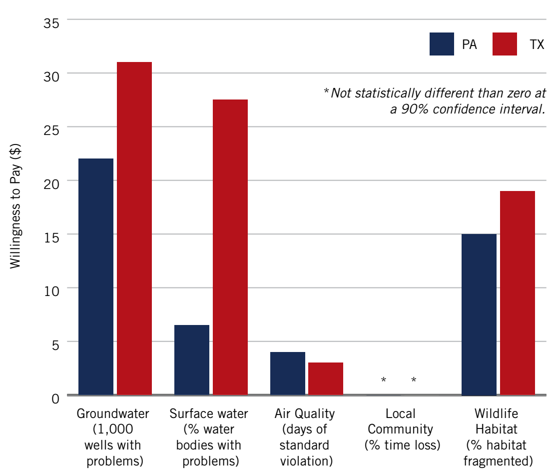
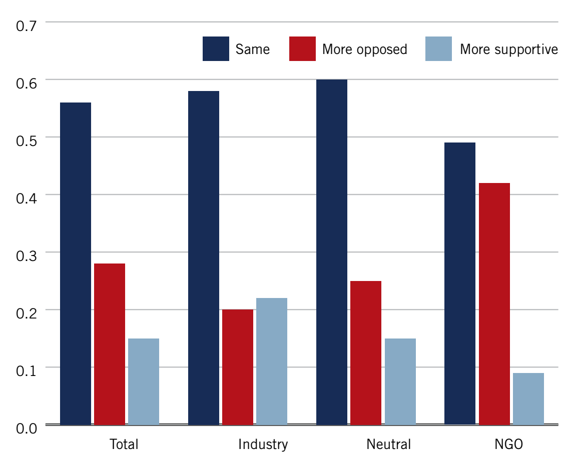


Figure 3. Changes in Attitudes by Survey Respondents, Post Information Treatments



ment enacts no further regulations and industry takes no further voluntary actions). Respondents were then asked to choose among several potential government programs for reducing risks to groundwater, surface water, air pollution, community disruption, and habitat fragmentation (each program associated with a cost) or to choose no program (for zero costs). At the end of the survey, the respondents were again asked about their attitudes toward risks and shale gas development to assess if the information provided changed their preferences.

KEY FINDINGS*

- Most respondents are worried about environmental risks, especially those related to groundwater and surface water, but a fraction are not concerned about any risks.
- In spite of being worried about risks, most respondents support shale gas development, implying that they want it done—but safely.
- Groundwater is a major concern in both states. On average, households in Texas and Pennsylvania are willing to pay around $20–$30 per year to eliminate risks for 1,000 drinking water wells, although households in Texas have greater willingness to pay (Figure 2).
- Respondents in both states are concerned about risks to surface water and wildlife habitat. However, the Texans surveyed are willing to pay more for reducing these risks in both cases. Neither are willing to pay anything to reduce community risks (for example, in terms of time lost from increased truck traffic and road congestion), possibly because the population-weighted sample primarily includes urban dwellers. Air quality effects are also a concern in both states, with willingness to pay about the same.
- Respondents' attitudes can be affected by the information they receive. The results suggest that NGOs, in particular, may be succeeding in eroding support for shale gas development. Information provided by industry appears to change some attitudes as well but is just about as likely to make people more opposed to development as more supportive of development (Figure 3).
- Respondents who received the neutral or NGO information treatment demonstrated a statistically similar willingness to pay to reduce environmental risks. However, respondents who received the API information treatment demonstrated a somewhat greater willingness to pay for all environmental attributes.
- The risk baseline has a limited effect on willingness to pay for specific risk reductions. However, in Texas the highest potential future risk generated a higher willingness to pay; Texans will pay more for having 1,000 fewer groundwater wells with problems when future risks are high.

* *These findings are preliminary. Analysis is currently ongoing. Future results will be published at www.rff.org/shalegasrisks.*

Shale Gas Development Impacts on Surface Water Quality in Pennsylvania

Sheila M. Olmstead, Lucija A. Muehlenbachs, Jhih-Shyang Shih, Ziyan Chu, and Alan J. Krupnick

Results from *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development* (page 2) indicate that experts from government, industry, NGOs, and academia are all concerned about the impacts from shale gas development on surface water. Currently, little empirical research exists on this topic.

To begin investigating these issues, RFF researchers conducted the first large-scale statistical examination of the extent to which shale gas development in Pennsylvania affects rivers and streams. The authors found that shale gas development can adversely affect surface water quality by increasing the downstream concentrations of two pollutants, chloride and total suspended solids (TSS).

The RFF team relied on more than 20,000 surface water quality observations taken over 11 years in Pennsylvania to estimate the effects of shale gas development on downstream water quality through 2011 (Figure 4). In 2011, Pennsylvania increased the stringency of wastewater treatment standards for several water pollutants, and the Marcellus Coalition, an industry group, engineered a voluntary ban on the shipment of shale gas waste to municipal sewage treatment plants and some industrial wastewater treatment plants. These changes partially address the elevated chloride concentrations found in this study. The finding of measurable downstream concentrations of TSS from shale gas infrastructure in Pennsylvania suggests that land management is important as well.

The researchers controlled for rainfall, general trends over time, intra-annual variation by watershed, and time-constant and location-constant characteristics of the location of the water monitors. The results were published in the *Proceedings of the National Academy of Sciences*.

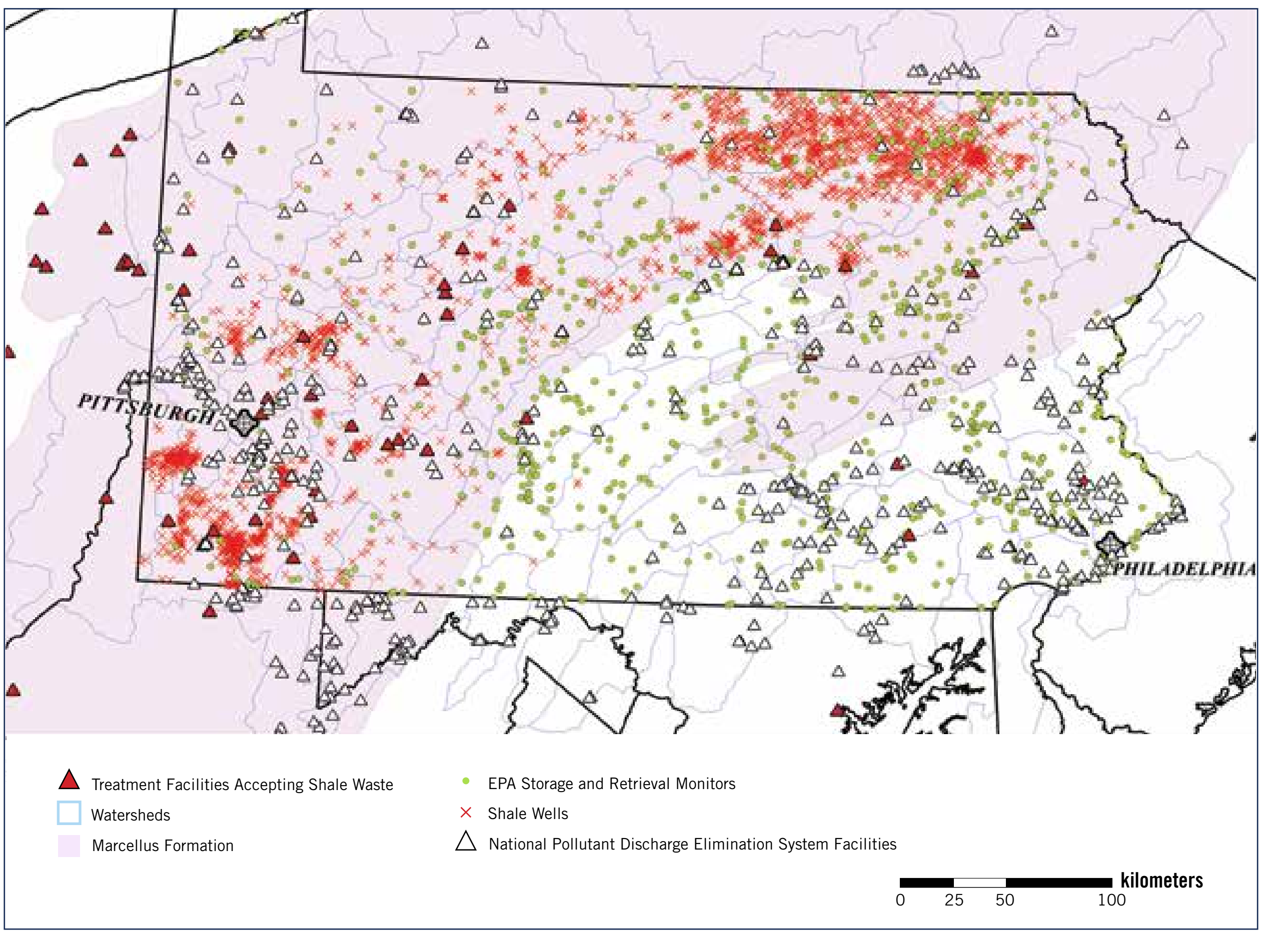
Read the paper at www.pnas.org/content/110/13/4962.full.pdf+html.

Olmstead, Sheila M., Lucija A. Muehlenbachs, Jhih-Shyang Shih, Ziyan Chu, and Alan J. Krupnick. 2013. Shale gas development impacts on surface water quality in Pennsylvania. *Proceedings of the National Academy of Sciences* 110(13): 4962–4967.

KEY FINDINGS

- The upstream treatment and release of shale gas wastewater by treatment plants raises downstream chloride concentrations in surface water, but it does not raise TSS concentrations. An increase of one upstream waste treatment facility accepting shale gas waste raises downstream chloride concentrations in a watershed by about 7 percent.
- The presence of well pads upstream raises the concentration of TSS but not chloride. An additional well pad upstream increases downstream TSS concentrations in a watershed by about 0.3 percent.
- There is no systematic statistical evidence of spills or leaks of flowback and produced water from shale gas well pads into waterways.

Figure 4. Surface Water Quality Monitors, Shale Gas Wells, and Wastewater Treatment Facilities in Pennsylvania Watersheds (2000–2011)



Wastewater Characteristics from Marcellus Shale Gas Development in Pennsylvania

Jhih-Shyang Shih, Sheila Olmstead, Ziyan Chu, Alan J. Krupnick, Lucija A. Muehlenbachs, James Saiers, and Shimon Anisfeld

One of the main byproducts of shale gas development using hydraulic fracturing is wastewater—including flowback and produced water—which contains salts (or total dissolved solids, TDS) as well as various organic and inorganic chemicals, metals, and naturally occurring radioactive materials. The chemical composition of this wastewater can vary by time, location, and type of operation. Wastewater is typically handled in one of three ways: onsite treatment for recycling and reuse, offsite shipment for deep well injection, or offsite shipment to centralized wastewater treatment facilities.

Results from *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development* (page 2) put wastewater treatment and disposal issues among the list of consensus priority risks to be addressed by industry and regulators. Further, analysis by RFF researchers of water quality impacts from shale gas development in Pennsylvania (page 6) suggests that treatment and release of this waste into rivers and streams degrades water quality. Given the results of both of the studies, RFF researchers began examining the chemical composition of samples of flowback and produced water collected under Pennsylvania's chemical assay program (FORM 26R Chemical Analysis of Residual Waste, Annual Report by the Generator).

These waste streams were destined for offsite shipment to treatment facilities. It is unknown to us whether these samples were representative of all such waste streams or only those shipped to waste treatment plants. In any event, knowing the chemical composition helps to define risks of a spill to the environment and helps to inform the discussion about whether current treatment technologies, existing capacities, and standards for wastewater treatment are sufficient to protect the environment and public health.

RFF researchers gathered data on the wastewater streams reaching 37 facilities in Pennsylvania, relying on information reported on the state's Form 26R, which is used by all companies that generate more than 2,200 pounds of residual waste in a single month from a single location to provide a chemical analysis of the waste. They obtained all submitted forms related to Marcellus shale gas waste between 2009 and 2011 and analyzed the chemical compositions of four types of wastewater from shale gas development, but primarily flowback and produced water.

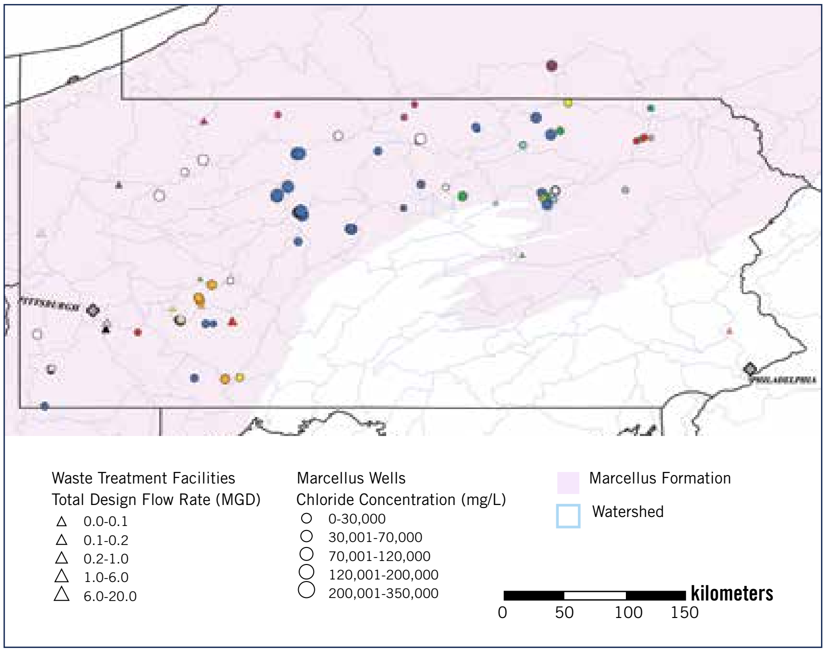


Figure 5. Wastewater Treatment Facilities and Proximity to Marcellus Wells

This figure shows information gathered on the wells (circles) and wastewater treatment facilities (triangles) from the Form 26R database. Each wastewater treatment facility has been assigned a unique color and the wells that transport wastewater to that facility are coded with the same color. The white circles on the map show wells for which the wastewater treatment facilities are unidentifiable.

KEY FINDINGS*

- High concentrations of various chemicals were observed in produced water before treatment. For example, when barium was detected, its median concentration was more than 200 times the US Environmental Protection Agency's maximum concentration limit of barium in drinking water and more than 40 times Pennsylvania's wastewater effluent standard. This detection occurred in 92 percent of samples. Concentrations of other pollutants—such as chloride, TDS, bromide, radium-228, and strontium—also exceeded these benchmarks, making apparent the necessity of effective treatment.
- While average concentrations are high compared to standards, wastewater composition and quantity are highly variable over the course of the shale gas extraction process, which could pose a challenge for effective wastewater treatment and management.
- Produced water has a very different water quality profile than flowback, typically having higher chloride, TDS, and radium-228 concentrations. This has implications for developing water recycling and reuse strategies, including strategies pertaining to the amount of water to recycle and the technology to use for recycling.
- Some wastewater is shipped very long distances even though there are closer wastewater treatment facilities (Figure 5); decisionmaking on wastewater disposal methods deserves further research.

* *These findings are preliminary. Analysis is currently ongoing. Future results will be published at www.rff.org/shalegasrisks.*

The Effects of Shale Gas Development on Property Values

Lucija A. Muehlenbachs, Beia Spiller, and Chris Timmins

Concerns have been raised about how shale gas development impacts groundwater and how those impacts may affect property values. For example, properties that utilize private water wells for drinking water may be negatively affected if methane or other contaminants migrate into the groundwater via faulty casing or cementing or via fractures connecting the shale formation. (Properties that receive drinking water from water service utilities, on the other hand, are less likely to face this risk.) Even if shale gas operations do not contaminate groundwater in the short run, the stigma from the possibility of future groundwater contamination may negatively affect property values, resulting in important long-term consequences for homeowners.

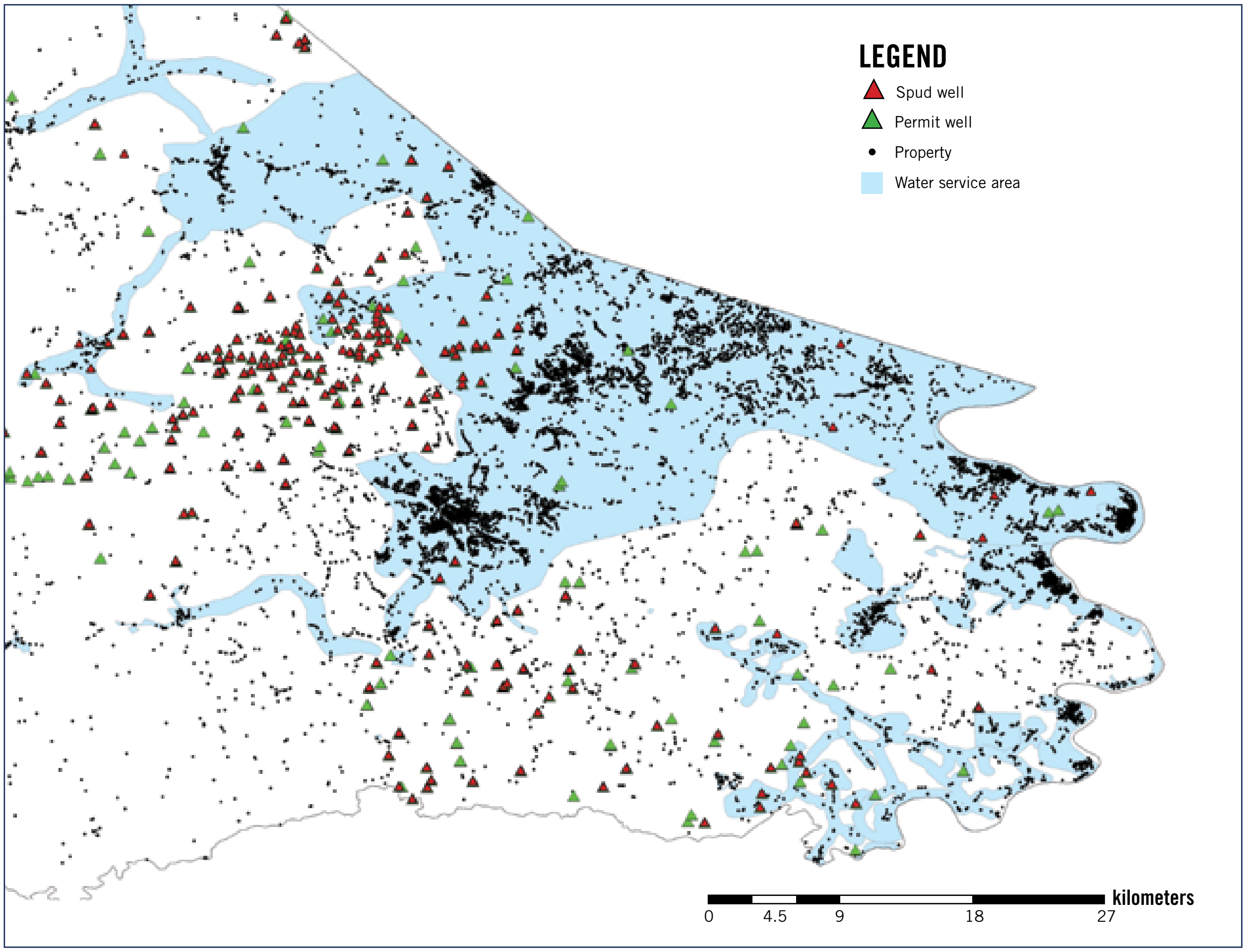
To better understand how shale gas development can affect property values, RFF researchers and colleagues analyzed residential property transactions from 2004 to 2009 in Washington County, Pennsylvania, at various distances from drilling sites (Figure 6). They then estimated the differential effect of shale gas development for groundwater-dependent properties relative to those properties with access to piped water.

An important caveat is that these estimates are relative to what is happening in the rest of the county. Therefore, to estimate the overall rise or fall of property values, ongoing work involves including data from counties without any shale gas development.

Read the discussion paper at www.rff.org/shalepropertyvalues.

Muehlenbachs, Lucija, Elisheba Spiller, and Chris Timmins. 2013. Shale Gas Development and the Costs of Groundwater Contamination Risk. RFF Discussion Paper 12-40. Washington, DC: Resources for the Future.

Figure 6. Property Sales and Permitted and Drilled Wells in Washington County, 2004–2009.



KEY FINDINGS

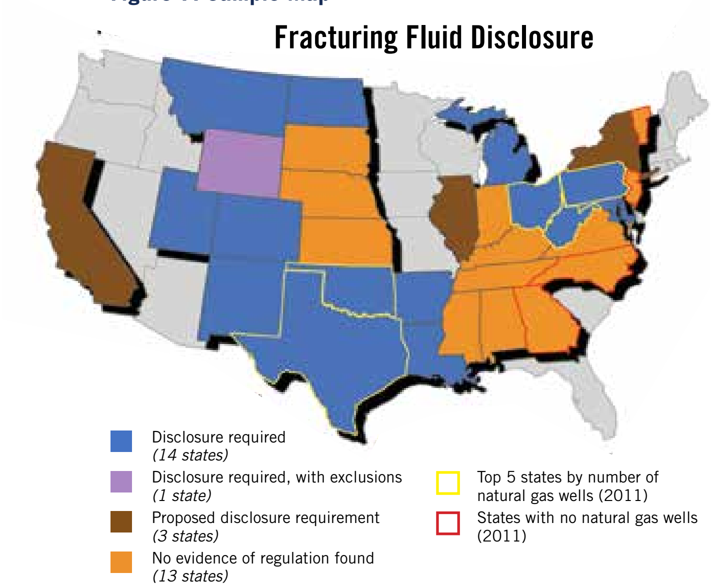
- Results for this county suggest that homes that are close to a shale gas well can have a 10 percent positive impact on their values if they have access to piped water—most likely due to gas lease payments.
- However, the property values of groundwater-dependent homes significantly decrease (16 percent) with proximity to shale wells.

The State of State Shale Gas Regulation

Nathan Richardson, Madeline Gottlieb, Alan J. Krupnick, and Hannah Wiseman

In *The State of State Shale Gas Regulation*, the authors describe, analyze, and compare 25 regulatory elements common to shale gas development across 31 states with current or potential development. Although not a complete review of all state shale gas regulations, it is the most comprehensive to date, allowing the differences and similarities among states to be systematically identified for the first time. Summarized information is presented in a series of maps and state-by-state tables (samples are shown in Figures 7 and 8). The authors also examined the types of regulatory tools used, the number of regulations per state, and the relative stringency of the regulations.

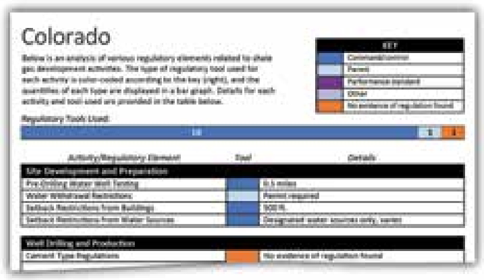
Figure 7. Sample Map



KEY FINDINGS

- There is a high degree of heterogeneity among states, especially in states' choices of which elements to regulate and how stringently to do so, but also to some degree in states' choices of regulatory tools.
- The states regulate anywhere from all 20 of the regulatory elements statistically examined in the study (West Virginia and, under its proposed regulatory package, New York) to only 10 elements (California and Virginia). The five states with the most gas wells (Texas, Oklahoma, Ohio, Pennsylvania, and West Virginia) regulate at least 16 elements, more than the national average of 15.6.
- States use a variety of tools to regulate shale gas activity, from command-and-control regulations to more flexible performance standards and case-by-case permitting. Command-and-control regulation is by far the most frequent tool used by the states, covering more than 80 percent of the regulatory elements. Case-by-case permitting accounts for 14 percent and performance standards account for approx-

Figure 8. Sample State Table



imately 1 percent of the elements.

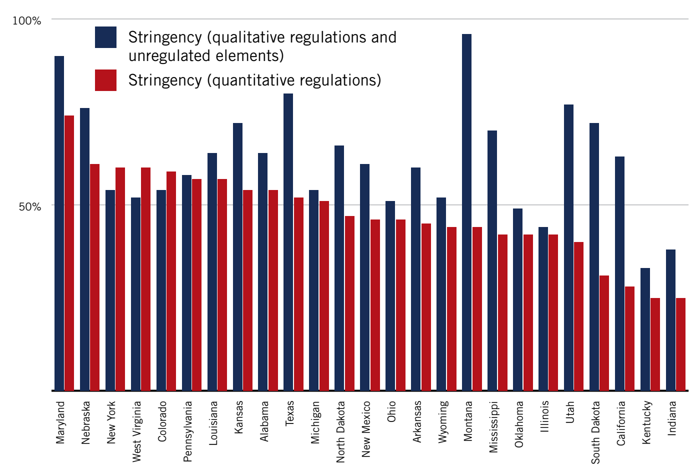
- » The stringency of regulations differs across states. For instance, some states have greater and therefore more stringent setback requirements than others. Stringency can also be measured in various ways. For example, when only considering the elements each state regulates quantitatively, Montana or Maryland appear to have the most stringent regulations across these elements (depending on how stringency is measured), and Virginia seems to regulate them the least stringently (Figure 9).
- » There is some lack of transparency in state shale gas regulations. Though regulations are publicly available, they are often difficult to find and interpret. Moreover, states' use of case-by-case permitting makes it challenging for researchers, the public, and to some extent even industry to determine what regulations and conditions are being set. Case-by-case permitting has valuable advantages, but these should be weighed against its greater burden on regulators to be transparent.

The researchers also analyzed the associations between observed regulatory heterogeneity and around 50 environmental, demographic, political, and other variables, and found a few significant associations. For example, states with more gas wells tend to regulate more elements, perhaps reflecting a greater need for regulation where there is a larger industry presence. Also, regulations that protect groundwater tend to be more stringent in states where groundwater makes up a greater fraction of overall water consumption. Although this analysis is preliminary and is limited by the scope of regulatory elements in the study, the fact that only a few significant associations were found should motivate a closer examination of the causes of the heterogeneity.

Read the report at www.rff.org/shalemaps.

Richardson, Nathan, Madeline Gottlieb, Alan Krupnick, and Hannah Wiseman. 2013. *The State of State Shale Gas Regulation*. Washington, DC: Resources for the Future.

Figure 9. Stringency of State Regulations



Cross-Cutting Findings

This section provides findings that cut across the research projects mentioned previously.

Risks to Rivers and Streams

One of the most important cross-cutting findings concerns surface water issues. In *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development* (page 2), the researchers found that seven of the routine consensus risk pathways involved surface water impacts: stormwater flows, freshwater withdrawals, leaks and spills of stored fracturing fluids, leaks from onsite pit and pond storage of flowback and produced water and fracturing fluids, and the treatment of flowback and produced water by municipal and by industrial wastewater treatment plants. The results from the public survey, *Attitudes and Willingness to Pay for Reducing Shale Gas Development Risks* (page 4), supported these concerns with significant willingness to pay of respondents both in Texas and Pennsylvania (although much less so in Pennsylvania) to reduce surface water quality risks.

The findings in *Shale Gas Development Impacts on Surface Water Quality in Pennsylvania* (page 6) also validated expert concerns about stormwater flows and surface water effects from wastewater plants treating and discharging flowback and produced water. However, the report may mitigate the concern about spills or leaks of flowback and produced water, since the results do not offer statistical evidence of such accidental releases from well sites. Although this does not mean that no such spills or leaks are occurring, it does mean that they were not occurring systematically in Pennsylvania through 2011.

Risks to Wells and Aquifers

RFF researchers examined the hypothesis—based on numerous media accounts—that there is a significant disconnect between views of experts (particularly those in industry) and views of the public regarding impacts on wells and aquifers. Most frequently cited is the public's idea that wells and aquifers are being polluted by methane or fracking fluids from fracking per se, as opposed to the industry view that such risks are exceedingly low because of the depth of the shale formation and the existence of solid capping rock above the shale to block escaping gases.

RFF researchers' surveys of the public and the experts examined both of these views. The public survey found that groundwater risks in general are of serious concern to the respondents in Texas and Pennsylvania in terms of the willingness to pay for risk reductions (page 4). A consensus concern for the experts, however, is the accidental escape of methane and fluids into groundwater through faulty casing or cementing. The experts make a distinction between the risks from fracking and the risks from faulty casing and cementing, whereas in the public survey no such distinction was made.

Likewise, the property value study (page 9) found that the proximity of homes to shale gas wells (for one county in Pennsylvania) negatively impacts the prices of homes dependent on groundwater for drinking water, compared to homes with access to piped water. This may be related to the public's perception of risks to groundwater, as noted in the public survey.

The findings in *Shale Gas Development Impacts on Surface Water Quality in Pennsylvania* (page 6) also validated expert concerns about stormwater flows and about surface water effects from wastewater plants treating and discharging flowback and produced water.

Surface Water Quality Impacts and Wastewater Characteristics

The analysis of surface water impacts from shale gas development (page 6) found that chlorides from treatment plants treating flowback and produced water show up in downstream surface water. Chlorides can be an issue in and of themselves if the concentrations are high enough, and chloride is a marker for other chemicals in flowback and produced water.

The chemical assay analysis of wastewater (page 7) demonstrated that chlorides in produced water are indeed very high. Because waste treatment plants do not desalinate water, it is not surprising that water quality monitors around the state detected elevated chloride concentrations associated with shale gas development activities. Specifically, chloride concentrations in produced water samples range from 16,100 mg/L to 192,000 mg/L, with a mean of 100,000 mg/L. (For some perspective, seawater has an average chloride concentration of 19,400 mg/L.) In Pennsylvania, where these samples were taken, chloride concentrations are far from uniform. Shale gas wells in the north central part of the state are much more likely to have high concentrations than those in the southwest and in the northeast. This is fortunate as the deep injection wells in Ohio that now are used to dispose of much of the produced water (as an alternative to treatment and release to surface water) are located relatively close to these areas with higher salinity.

Heterogeneity of Regulations and State Population Attitudes

According to the public survey (page 4), concerns about risks and the degree of support for or opposition to shale gas development are similar among Texans and Pennsylvanians. If public attitudes influence the development of regulations, then the analysis of state regulations (page 10) should demonstrate that these two states have similar regulatory activity.

In fact, Pennsylvania regulates just a few more elements than Texas (19 and 17 respectively, of the 20 examined), uses the command-and-control approach more frequently, and, for the more comprehensive stringency measures, sets more stringent regulations than Texas. However, using the less comprehensive stringency measures that consider only quantitative regulations, Texas regulates more stringently than Pennsylvania. Broadly speaking, the two states are comparable, matching the comparability in public attitudes.

Texans have a greater willingness to pay than Pennsylvanians to reduce surface water risks, although they are about equal in their willingness to pay to reduce groundwater risks.

When asked about their willingness to pay to reduce risks (page 4), however, Pennsylvanians and Texans are not as similar; indeed, Texans have a greater willingness to pay than Pennsylvanians to reduce surface water risks, although they are about equal in their willingness to pay to reduce groundwater risks. In comparing the regulatory data for both states, accumulated as part of the state regulatory research (page 10), Pennsylvania is more stringent than Texas in 6 of the 11 regulatory elements associated with surface water or groundwater. They have the same regulations in three cases, and Texas is more stringent than Pennsylvania in two cases. Thus, at least for this very limited comparison, differences in the willingness to pay of survey respondents in Texas and Pennsylvania are not obviously reflected in differences in these regulatory metrics.

Areas for Further Research

As in any major research effort, additional questions are raised and made more compelling by the new knowledge generated by the original research. This section touches on a few of these ideas.

In *Pathways to Dialogue: What the Experts Say about the Environmental Risks of Shale Gas Development* (page 2), the experts surveyed identified 15 risk pathways that all groups agreed should be a top priority for mitigation. The next step is to take a deep dive on these consensus risk pathways, and RFF researchers—in collaboration with colleagues at the Environmental Defense Fund and with support from the Alfred P. Sloan Foundation—are setting out to do just that. This new effort will further examine the environmental risks, research the mitigation technologies and costs, and identify industry best practices and the current regulatory situation for a subset of the consensus pathways. This information will then become the basis for stakeholder dialogues, designed to bring leaders together to suggest strategies to reduce these risks.

Another important area for further research is to better understand the costs and benefits to local communities from shale gas development. Figuring out how to maximize the net benefits—and particularly for the long term in these boom town communities—is an essential step toward making shale gas development sustainable and socially acceptable in the communities directly affected.

Figuring out how to maximize the net benefits—and particularly for the long term in these boom town communities—is an essential step toward making shale gas development sustainable and socially acceptable in the communities directly affected.

In addition, there are several topics that have not yet been studied enough to fully understand the potential impacts related to shale gas development. New research could be pursued on the following topics: the health and welfare effects of air and water pollution, increased truck traffic from these activities (including traffic accidents and congestion), and the effects of shale gas infrastructure on habitat fragmentation, particularly in and around recreational areas.

There are also major issues associated with the usage of water, not only in water-stressed areas like southwestern Texas, but in relatively water-rich states, like Pennsylvania, where the timing and location of withdrawals can damage habitat if not carefully managed. This should be examined more closely.

> How are regulations enforced? How much does it cost to comply with these regulations? Are the regulations successful at reducing environmental risks?

Fully understanding state shale gas regulation remains a challenge—the survey of state regulations took a broad look, but important questions remain. How are regulations enforced? How much does it cost to comply with these regulations? Are the regulations successful at reducing environmental risks? And regulations are changing as shale gas development is happening—necessitating a need for research to track, monitor, and assess the efficacy of new regulations.

Probably one of the most controversial regulatory areas is federalism—the appropriate level of government (local, state, regional, or federal) to carry out various regulatory functions. While the states and industry favor continued state dominance in matters regulating shale gas development, local governments have wanted more of a say over whether and how shale gas development occurs in their jurisdictions. And the federal government has been considering whether its role should be expanded, for example, by setting federal minimum standards for various elements of shale gas development activities or through leading by example and setting rules for shale gas development on federal lands. Economic theory provides a conceptual framework for thinking about these issues and a body of empirical work on how they play out. Applications to this debate would be useful. The response of the shale industry will also factor into these developments to the extent that industry changes business, engineering, safety, and other practices—voluntarily or in anticipation of new or additional regulation. Such changes are already a part of industry behavior.

These topics are only a sampling of those—in the area of environmental risk—that social scientists can pursue to further the debate over the role of shale gas in the nation's energy future. Together with natural and physical scientists and engineers, social scientists are working to reduce the environmental risks and uncertainties related to shale gas development and the market uncertainties associated with the growth in this resource. Social scientists also have a role to play in gauging the effects of the shale gas boom on energy markets, on sectors that can benefit from cheaper gas, and on the general economy.

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