Information Collection, Access, and Dissemination to Support Evidence-Based Shale Gas Policies

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To ensure that unconventional shale gas development (UGD) yields net social benefits, we need to identify the magnitude and distribution of its benefits and costs and develop effective technological, management, and regulatory strategies to minimize potential adverse effects. A major obstacle to achieve these goals is the gaps in the collection, access, and dissemination of information. This paper focuses on information gaps to assess a narrow subset of the potential links between UGD and well-water contamination, drawing particularly from the experience in Pennsylvania. It suggests strategies for legislators, regulators, industry, and researchers to address these information gaps, while protecting legitimate privacy concerns. The benefits from an improved understanding of the impact of this industry and resulting innovations to mitigate its impacts justifies the cost of data collection, access, and dissemination.

1. Studying UGD Impacts on Water Contamination and Innovating Mitigation Strategies: Information Gaps

The US faces the challenge to pursue unconventional gas development (UGD) in a manner that minimizes its potential adverse impact on health, the environment, and local communities.[1–8] The Shale Gas Subcommittee of the Secretary of Energy Advisory Board acknowledged the significant contribution of shale gas to economic activity and emphasized the importance of developing US shale gas “in a way that protects human health and the environment and is most beneficial to the nation.” The Subcommittee’s recommendation for immediate implementation is “to improve public information about shale gas operations.”[9] Informed public debate on the lifecycle of UGD is critical because of the uncertainties in its benefits and risks,[9] the unequal distribution of these benefits and risks in society,[9] and the need to make evidence-based trade-offs between the benefits and costs of risk mitigation strategies.

Information disclosure policies—the collection, access, and dissemination of information—contribute toward a greater understanding of risks and the innovation of risk-management strategies in industrial activities[10–14] including UGD. Unfortunately, information gaps have hindered efforts to fully assess the impact of UGD on health, the environment, and local communities and to design technical, management, and regulatory strategies that mitigate potential adverse effects.[14] This paper examines information gaps in the assessment of a narrow subset of potential links between UGD and well-water contamination, focusing primarily on Pennsylvania (PA). Information gaps to fully assess risks posed by UGD to surface water, air, and land[1,2,4,6,15,16] are outside the scope of this paper.

The Marcellus Shale, the largest shale play in the US, with estimated recoverable shale gas reserves as large as 43 trillion cubic feet[17] (1 ft³ ≈ 28.3 L) covers a large portion of PA.[18] The number of wells in PA increased from eight in 2005 to 7234 wells in 2014.[17] With few exceptions, states have full control over most stages of the drilling and fracturing processes, which includes standards on well construction and waste disposal.[19] The state law passed in 2012, Act 13, overhauled regulations in this sector.[20] The PA Department of Environmental Protection (DEP) is the primary regulator of the oil and gas industry in PA and had 202 staff members in its Oil and Gas Program in 2013.[21] In the assessment of the PA Auditor General, the DEP’s staff, funding, and access to information technology has been limited relative to the pace of growth and the size of the shale industry it regulates.[22]

Disclosure policies complement the DEP’s regulatory activities and provide transparency on its activities. The Auditor General of PA[22] and the nonprofit multi-stakeholder organization, the State Review of Oil and Natural Gas Environmental Regulations (STRONGER)[21] have recommended improvements for the DEP’s data collection, access, and dissemination policies. Several of these improvements require the PA legislature to increase the DEP’s resources and to revise PA legislation, which sets the legal framework for the DEP’s operations.

The paper is organized as follows. Section 2 summarizes the risks posed by UGD to water resources and reported cases of water contamination in PA. Section 3 describes how
information gaps hinder our understanding of the extent of the contribution of UGD to water contamination. Section 4 discusses how information collection, access, and dissemination can help improve risk management in the shale industry. Section 5 examines seven cases in which the collection, access, or dissemination of information is restricted. A comparison of these cases with the experiences from other industries, a subset of shale companies, and other US states indicates that effective disclosure policies can be implemented. These policies collect and reveal information critical for health and environmental protection, yet protect the privacy of individuals and companies’ trade secrets, although the balance struck among these competing interests remains contested. Section 6 summarizes actions required from the PA legislature, the DEP, industry, and researchers to improve information collection, access, and dissemination in PA.

2. Risks from UGD and Reported Cases of Water Contamination

The risks posed by UGD to water quality include: “1) the contamination of shallow aquifers with fugitive hydrocarbon gases (i.e., stray gas contamination); 2) the contamination of surface water and shallow groundwater from spills, leaks, 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.”[8] Gas wells constructed improperly with problematic cementing or casing can allow shale gas from production or intermediate layers to migrate to shallow aquifers.[5,23–26] Flowback and produced waters arrive at the surface from deep underground.[8] They contain metals, naturally occurring radionuclides, chemicals used in the hydraulic fracturing process, and high concentrations of salts.[9] Spills on well pads or during transportation, leaks, and overflows from containment pits and improper treatment of wastewater can lead to the contamination of surface water, groundwater, and soil.[5,27,28]

UGD has contributed to several documented cases of water contamination. Wastewater sent to publicly owned treatment works that were not equipped to treat such waste contributed to high loads of total dissolved solids in PA rivers in 2008–2009.[5] Awareness of this contamination by regulators, scientists, and the public helped end this practice. Thirty-two cases of large spills (> 400 gallons) have been reported between 2005 and 2013, which impact soil, surface, and groundwater.[7] In August 2014, the DEP revealed that since 2007, 243 private water wells have been contaminated by natural gas drilling, with approximately half caused by “unconventional or horizontal drilling.”[29,30] Contamination included high levels of methane in the well water and surface spills of wastewater and chemicals.[29] The analysis of 161 positive determination letters (PDLs) issued to both conventional and unconventional oil and gas wells between 2008 and 2012 found 90 cases that report methane contamination.[7]

A few wells have experienced blowouts during hydraulic-fracturing operations, which led to the uncontrolled release of fracturing fluids and required emergency response to shut the well.[5] Studies examining other US states have reported that surface spills from storage and production facilities at well sites have led to groundwater contamination, including high levels of benzene,[31] and that UGD operations failed to implement accepted engineering practices, such as impoundment construction, liner installation, and institutional controls.[32]

3. Unresolved Debates on Water Contamination and Information Gaps

The unresolved debate on the role of UGD in water contamination centers on three issues: first, the extent of water contamination that has been caused by UGD; second, the role of UGD in specific cases of contamination; and third, the role and extent of UGD in specific types of contamination, such as methane contamination in drinking water. These issues remain unsolved because of information gaps.

3.1. Systematic baseline data

This data is critical to assess whether new UGD, or alternatively, natural processes or historical industrial activity contribute to observed water contamination. [5,7] PA government agencies have not collected systematic baseline predrilling water quality data. Independent researchers do not have access to the database of predrilling water quality data that has been collected by industry.[33]

3.2. Number of contamination incidents

The number of contamination incidents is not fully known. The DEP may not issue positive determination letters for contamination incidents if operators and landowners agree to private settlements.[34] Act 13 is silent on the duty of the
3.3. Causes of contamination

The DEP, in its correspondence with complainants, has not provided a detailed explanation for its conclusion that the oil and gas industry did or did not contribute to water contamination. Moreover, nondisclosure clauses in settlements between complainants and gas-well operators may conceal information on the operators’ performance and details about contamination incidents, which are relevant to public health assessments.

3.4. Chemicals in hydraulic fracturing fluids

Oil and gas service companies have not disclosed the entire list of chemicals in hydraulic fracturing fluids, asserting that it is a trade secret. Recently, though, one company announced its plans to report the full list of chemicals.

3.5. Monitoring data for surface waters

Present data is inadequate to document the short- and long-term impacts of UGD. Gaps include the low density of sampling and sensors near headwaters or watersheds with high levels of UGD and the inadequate collection of parameters appropriate to capture the impact of UGD. Baseline data for benchmarking, and long-term monitoring to detect cumulative impacts.

3.6. Wastewater

Act 13 exempts the disclosure of compounds that arrive at the surface in flowback or produced waters. PA regulates UGD wastewater as nonhazardous waste even if the waste meets the technical definition of hazardous waste. The DEP’s waste-tracking system falls short of the Department of Energy’s recommendation of cradle-to-grave tracking. At present, shale gas companies’ reports of waste shipments to landfills fall far short of landfills’ reports of waste received from these companies. Chemical analyses of waste streams, which well operators are required to submit to the DEP, are not published online or in a digital database by the DEP. To obtain this information through state open-record requests requires a significant amount of time, effort, and funds, which can be prohibitive for individuals and small research institutions.

4. Role of Information Collection, Access, and Dissemination in Improving Risk Management

Disclosure policies—data collection, access, and information—generate knowledge about the risks of industrial activity and incentivize the innovation of mitigation strategies. These policies work in tandem with other policy instruments, such as regulation, legal liability, and performance bonds, to incentivize companies to reduce their environmental footprint.

Armed with information, the public can debate the appropriate trade-off between the benefits and costs of UGD. Current PA legislation falls short of the recommendations of scientists and suffers from several gaps. The public can debate the benefits of averted environmental damage with stricter regulations versus the financial cost of such regulations. Access to information also enables the public to participate in discussions on the internalization of environmental costs from UGD by increasing performance bonds, impact fees, charges for water withdrawal, and charges for wastewater treatment and disposal.

The publication of data by the DEP on its website on some aspects of shale wells and its regulatory activities has enabled nongovernment organizations, researchers, and members of the public to complement the DEP’s oversight activity. As in the case of the Toxic Release Inventory (TRI), the most well-known federal data disclosure program, nonprofit organizations and researchers have undertaken the task to make DEP data more accessible to the public and conducted systematic data analyses. As discussed in Section 5.5, nonprofit organizations, such as Fracktracker.org and the Carnegie Museum of Natural History, have presented data in a manner comprehensible to the public. Researchers have analyzed data to identify cement, casing, and well-construction violations and spills at well pads and to examine factors correlated with inspections and violations.

The DEP initially regulated UGD under PA’s existing oil and gas regulations, even though the rapid growth of UGD posed unique or greater challenges in wastewater management and water withdrawal compared to the conventional oil and gas industry. Access to information has been crucial to enable scientists to undertake independent research. Despite gaps in data access, scientists have assembled robust evidence to strengthen regulations. The 2012 Act 13 mandated several improvements such as restricting drilling within 1000 feet (1 ft = 0.3 m) of a public water supply, doubling the distance of separation between a gas well and private well to 500 feet, and more than doubling the distance for the operator’s presumptive liability for water contamination to 2500 feet.

Information on the environmental impact of UGD and the compliance record of operators enables reasoned decision-making by landowners who contemplate leasing their land to shale gas companies. Similarly, this information enables reasoned decision-making by investors, who take into account expected environmental liabilities, in choosing their level of investments in the shale gas industry and among shale gas companies. The disclosure of environmental liabilities is required in the annual filings of publicly traded companies to the Security and Exchange Commission (SEC). In 2011, on reviewing the filings of oil and gas companies, the SEC sent letters to several companies to inquire about the chemicals injected into the ground and actions undertaken to mini-
mize water usage and environmental impact. The SEC requested for this information “to ensure that investors are being told about risks a company may face related to its operations, such as lawsuits, compliance costs or other uncertainties.” Nevertheless, companies are reported not to have responded with specific information on these chemicals as they regard them as proprietary.

Public disclosure of pollution release incentivizes companies to take into account the environmental costs that may otherwise be outside their narrow profit-maximizing calculus and thus reduce their environmental footprint. The potent role for information disclosure is illustrated by companies’ pollution reduction in response to the TRI. Following the first publication of TRI data on pollution releases, publicly traded companies with large releases experienced negative abnormal returns. Subsequently, the companies with large declines in their stock market values reduced their TRI releases by a greater amount relative to the industry average. Coincident with the inception of the TRI program, worker exposure to chemicals in factories declined. Case studies indicate that some companies reduced emissions in response to requests from concerned citizens and because of the threat of public scrutiny.

The shale industry, as a collective, benefits from information collection, analysis, and dissemination. The industry’s operation of activities that pose non-negligible risks depends crucially on their social license to operate. The social license to operate is the fourth most important business risk for the mining industry in 2013–2014. Poor performance by any one company can tarnish the reputation of the entire industry, for example, the stock market value of the entire chemical and nuclear industries fell in response to the Bhopal and Three Mile Island accidents, respectively. The failure to provide information and to maintain transparency can contribute to the loss of public trust in an industrial activity and to the amplification of the perceived risks from that activity. Industries’ recognition of their need to maintain their social license to operate is one of the reasons for their adoption of industry-sponsored self-regulation programs. These programs, with government regulations and legal liability as a backstop, have improved some, though not all, aspects of environmental health and safety.

5. Case Studies on Disclosure Policies

The cases below describe limitations in data collection, access, and dissemination in the shale industry, a subset of shale companies, and PA. However, counterexamples from other industries, other shale companies, and other US states illustrate the successful implementation of disclosure policies that reveal information for health and environmental protection, yet protect the privacy of individuals and companies’ trade secrets.

5.1. Case 1: Noninclusion or exemptions from provisions in federal statutes

The US legislature, through federal statutes, has imposed baseline regulations and reporting requirements for industries that operate in the US. The legislature recognizes correctly the need to mitigate environmental risks from industrial activities. However, the oil and gas industry, which share the characteristics of other industrial activities in imposing environmental risks, has not been included or has received exemptions from several provisions in federal statutes that apply to other industries. Provisions in federal statutes that apply to industries other than oil and gas are listed below.

5.1.1. Resource Conservation and Recovery Act Subtitle C

The Safe Drinking Water Act (SDWA) protects drinking water by regulating the underground injection of fluids, solids, and gases. The 2005 Energy Policy Act excluded “hydraulic fracturing” from the definition of “underground injection” as regulated by the SDWA, except if diesel fuel is used.

5.1.2. Emergency Planning and Community Right-to-Know Act

The act requires the reporting of chemical emissions into air, water, land, or offsite for recycling, treatment, or disposal to the TRI. UGD is not on the list of reporting industries, which includes petroleum refining, coal, metal and nonmetallic minerals, petroleum bulk terminals, electric utilities that combust coal or oil, and hazardous waste treatment and disposal facilities. The Environmental Integrity Project and 16 other environmental organizations have requested that the EPA reconsider its 1997 decision not to include oil and gas extraction activities on this list of TRI-reportable industries.

5.1.3. Comprehensive Environmental Response, Compensation, and Liability Act

Based on this act companies can be liable for the cost of remediating contamination. The oil and gas industry is exempt from this liability provision.

5.1.4. Comprehensive Environmental Response, Compensation, and Liability Act
The need to protect trade secrets is the main argument used to justify nondisclosure by companies that operate in the shale industry. Companies’ proprietary information is a valuable asset across industries, including the pharmaceutical and biotechnology industries. The nondisclosure of trade secrets maintains companies’ competitive edge and incentivizes companies to innovate new technologies and knowledge. Nevertheless, the economic justification for protecting trade secrets to incentivize innovation applies to only a narrow set of cases. Even in those cases, disclosure policies can be designed to provide information only to regulatory agencies and not to the public at large, thus maintaining the companies’ incentives to innovate new technologies and knowledge. Several federal statutes require companies to submit information to regulatory agencies, and the agencies would not make the information available to the public if the company makes a trade secret claim. Similarly, the federal Freedom of Information Act (FOIA) and many state open-record statutes exempt trade secrets from the rule that government records be made available to the public.

The greater willingness of a subset of companies to disclose the chemicals used in hydraulic fracturing fluids indicates that the disclosure policies can be designed to reveal information pertinent to public health without compromising trade secrets. Oil and gas service companies have claimed the formulations of chemicals used in hydraulic fracturing fluids, which may vary by each well, as trade secrets. Several states, which made the reporting of these chemicals mandatory, require companies to report these chemicals to the FracFocus website. A task force of the Secretary of Energy Advisory Board reported that at least one chemical ingredient was omitted for 84% of the wells listed on FracFocus. The task force recommended that companies report raw chemicals separately from the additive products of which they are constituents. The analogy for such disclosure is the Coca-Cola Co. that reports its ingredients on every can and yet keeps the recipe secret. Baker Hughes, Schlumberger, and Halliburton, which are the three largest oil and gas service companies, have taken contrasting positions on this recommendation. Halliburton argued that the suggested disclosure approach would not protect trade secrets because competitors could reverse-engineer patented processes. In contrast, Baker Hughes announced its plans to begin to disclose all chemicals without asserting trade secret claims and noted that their new disclosure policy would strike “a balance that increases public trust while encouraging commercial innovation.” Schlumberger reported that it had followed this reporting strategy since 2010 whereas Halliburton reported that it would examine the approach of Baker Hughes.

Baker Hughes’s stated plans to provide a complete list of their chemicals would go farther towards transparency than PA’s legislation. Act 13 Section 3221.1(b) requires companies to disclose the contents of hydraulic fracturing fluids to a health professional, but the health professional must also execute a confidentiality agreement to obtain the information. Public health specialists argue that this provision prohibits them from sharing information about the chemicals with others who are at risk of exposure, other healthcare providers whose patients are at risk of exposure, and researchers who undertake health impact assessments. In December 2013, a case that challenged this provision was sent by the Supreme Court of Pennsylvania back to the lower court for adjudication on its merits. In May 2014, the EPA published an advanced notice of proposed rulemaking under the Toxic Substance Control Act pertaining to hydraulic fracturing chemicals and mixtures.

Despite these initiatives, efforts to enhance disclosure in the shale industry have omitted the more critical parameters—chemicals that arrive at the surface in flowback or produced waters. PA’s Act 13 exempts the disclosure of these compounds despite their potentially significant health and environmental impacts. The primary rationale to label and protect information as trade secrets is to incentivize innovation. The disclosure of a wide range of activities in UGD, relevant to assess environmental and health impacts, does not raise trade secret issues. These include 1) emissions of pollutants into the environment from each well, 2) wastewater composition, production, and management, 3) the chemical signature of gases from each gas well and the list of chemicals used in the hydraulic fracturing process at each gas well, 4) performance at well pads, which includes the structural integrity of wells and storage pits, as well as the incidence of leaks, overflows, and spills at the well pads or during transportation, 5) inspection, violation, and enforcement data at each well, and 6) full information on contamination incidents that are linked to UGD.

Baseline predrilling data is critical to assess whether new UGD activity or, alternatively, natural processes or historical industrial activity contribute to observed water contamination. Unfortunately, researchers and the public do not have access to predrilling well-water data in PA. PA law does not require the DEP to collect water-quality data pre- or postdrilling or to make such information publicly available. The Marcellus Shale Coalition, a gas industry trade group, has built an electronic database to compile information that the industry has collected on water quality at private water wells. It has been reported that tens of thousands of water tests were completed by natural gas drilling companies across PA. However, industry has not made this data available to independent researchers. To my knowledge, only one team of researchers from GSI Environmental Inc. and Cabot Oil and Gas Corporation, that is, Molofsky et al., has published studies using this database.

Companies that own and operate gas wells have the incentive to collect pre- and postdrilling water data and they have done so. These companies face a rebuttable presumption of
liability for the contamination of water supply within 2500 feet of their drilling operation for up to a year after a gas well is drilled.\textsuperscript{[79]} They must restore or replace any private or public water supply deemed impaired by the DEP.\textsuperscript{[79]} Pre- and postdrilling water quality data are valid in court only if they are reported to the DEP and landowners.\textsuperscript{[80]} The DEP recommendations of parameters for testing\textsuperscript{[81]} omit several parameters required by Colorado’s Rule 609, such as total petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylenes (BTEX) compounds. STRONGER has recommended that the DEP should provide greater guidance on sampling procedures and testing of indicator parameters.\textsuperscript{[26]}

In contrast to PA, other states, which include Colorado, Ohio, and Wyoming, require baseline water testing before the commencement of drilling.\textsuperscript{[82]} Colorado takes the most transparent approach in the publication of water quality data.\textsuperscript{[83]} Colorado’s Rule 609 applies to oil and gas wells whose permits to drill are submitted after May 1, 2013.\textsuperscript{[83]} Rule 609 requires shale-well operators to collect 1) baseline water samples within 12 months prior to any drilling activity within a half-mile radius (1 mile \(\approx 1.6 \text{ km}\)) of any proposed oil and gas well and 2) two postdrilling water samples and additional samples if changes in water quality are observed.\textsuperscript{[80]} The sample is to be taken from a water source whose owner “has given consent for sampling and testing and has consented to having the sample data obtained made available to the public, including without limitation, being posted on the Colorado Oil and Gas Conservation Commission (COGCC) website.”\textsuperscript{[83]}

Baseline and subsequent testing of specific parameters help researchers and regulators to identify the nature and the source of contamination.\textsuperscript{[26,42]} If methane is detected, gas composition and stable isotope analysis of the methane are required.\textsuperscript{[83]} The operator has reporting responsibilities to the COGCC director and water-well owners, while the COGCC director has reporting responsibilities to the public, such as posting the information to the COGCC website. The data\textsuperscript{[84]} includes the identifier for the water sample, the latitude and longitude of the sampling location [to six decimal points displayed with Universal Transverse Mercator (UTM) projection], the unique American Petroleum Institute (API) number of the associated gas well, the name of the gas-well operator, the status of the gas well, and various water quality parameters.

The privacy of landowners is one reason that has been cited for not making well-water data available to researchers and the public. New information on poor water quality would lower property prices. The decision of a state legislature to require or, conversely, not to require disclosure allocates the financial risks that stem from poor water quality among classes of homeowners. States such as PA that do not require disclosure allocate the risks to potential buyers. In contrast, states such as New Jersey allocate the risks to the seller by requiring the testing of private wells upon the sale of a property.\textsuperscript{[82]}

Privacy concerns can be respected and, at the same time, information can be disclosed for the investigation of public health hazards. First, several landowners have sought media attention to pressure regulatory agencies to undertake more detailed investigations in cases of contamination.\textsuperscript{[85,86]} In these cases, the identities and locations of landowners are already public information. Second, some landowners, as seen in Colorado,\textsuperscript{[83]} have been willing to allow the publication of water quality data sampled from their lands and the geo-coordinates of sampling locations. Third, before the publication of the data, the location of the water sample can be masked by using fuzzy algorithms. This strategy would balance the need of researchers for spatial accuracy to study links between UGD and water contamination and the desire of landowners for privacy.\textsuperscript{[93]} Similar algorithms have been used successfully in medical research that examines patients’ locations and sensitive medical records.\textsuperscript{[93]}

5.4. Case 4: Baseline predrilling groundwater data collected by industry

The scientific debate on the contribution of UGD to methane contamination of well water underscores the importance of scientists’ access to baseline predrilling data. A research team composed of Jackson, Osborn, Darrah, Vengosh, and others, based on multiple lines of evidence, found that UGD contributes to methane contamination in drinking water in the Marcellus Shale.\textsuperscript{[23–25]} Beyond reporting a statistical association of the co-location of groundwater contamination and UGD, Osborn et al.\textsuperscript{[23]} and Jackson et al.\textsuperscript{[24]} applied forensic techniques\textsuperscript{[87]} to identify the likely source of the stray gas. Without access to predrilling baseline data, however, they were not able to examine changes between pre- and postdrilling water-quality data in the areas with UGD relative to control areas.

In an earlier study, Boyer et al. found no statistical increase in dissolved methane concentration in 48 water samples from the pre- and postdrilling periods, but the authors note the limitation of their small sample size.\textsuperscript{[90]} In contrast, Molofsky et al., a team of researchers from GSI Environmental Inc. and Cabot Oil and Gas Corporation, examined data from 1701 water wells, collected by Cabot Oil and Gas, from northeastern PA. They report that methane concentrations are correlated to topographic and hydrogeological features rather than shale-gas extraction activities.\textsuperscript{[99]} Access to the chemical signatures of gas from individual gas wells\textsuperscript{[73]} and to industry’s predrilling data\textsuperscript{[5,33]} can help to clarify this debate. Given the rapid growth of UGD in PA, predrilling data collected by industry is often the only predrilling water data. Researchers, the DEP, industry, and landowners need to work together to make this data accessible to researchers. As noted, the application of fuzzy algorithms to the location data can strike a balance between the need of researchers for spatial accuracy and the desire of landowners for privacy. To date, researchers have assembled multiple lines of evidence on the contribution of UGD to methane contamination in well water. Osborn et al.\textsuperscript{[23]} and Jackson et al.\textsuperscript{[24]} found
statistically higher methane concentrations in areas close to UGD (gas wells present within 1 km) than in areas further away. They also conducted analyses of isotopes, gas composition (ratio of methane to other gases such as ethane and propane), and geochemistry. Accounting for hydrology and geology, they interpret that these results as indicating that the gas came from the deep shale reservoirs\cite{23,24} and intermediate layers.\cite{24} They suggest that poorly constructed gas wells allow gas to migrate from deeper shale reservoirs or intermediate layers to shallow aquifers and into drinking water.\cite{8,23,24} Well-integrity failures are often caused by cement and casing failures.\cite{43}

Darrah et al. examined eight clusters of groundwater wells that experienced stray gas contamination, seven of which were in the Marcellus Shale and one in the Barnett Shale.\cite{25} Based on analyses of noble gas and hydrocarbon tracers, they attribute the stray gas contamination to UGD. In investigating the mechanism for stray gas contamination, they report that gas leaked into the aquifers from shale gas wells through the annulus cement in four cases, through the production casings in three cases, and from underground well failure in one case.\cite{30} Although well integrity failures do not necessarily result in gas leaks into the environment, the estimate of the nontrivial rates of these failures in PA by Ingraffea et al.\cite{43} provide complementary evidence to the findings of Osborn et al.\cite{25} Jackson et al.\cite{24} and Darrah et al.\cite{25} These studies, Osborn et al.\cite{25} and Jackson et al.\cite{24}, have limitations, including a small, nonrandom dataset,\cite{89,90} a lack of pre-hydraulic-fracturing baseline data,\cite{91} and the similarity of the average value of methane\cite{25} and the US Geological Survey (USGS) baseline predrilling water data.\cite{9}

Another study by Fontenot et al.\cite{92} examined 100 private water-wells in the Barnett Shale, including predrilling data. They found higher concentrations of heavy metals in wells located within 3 km of active gas wells, and these concentrations exceeded predrilling historical data. They suggest that these spatial patterns could be related to various factors associated with UGD, which include “mobilization of natural constituents, hydrogeochemical changes from lowering of the water table, or industrial accidents such as faulty gas well casings.” Differences in well integrity and geology are the likely explanation for stray gas contamination that occurs in some shale plays, such as the Marcellus Shale\cite{23,24} and the Barnett Shale,\cite{92} but not in the Fayetteville Shale.\cite{90}

5.5. Case 5: The DEP public e-database

The DEP uses its Environment Facility Application Compliance Tracking System (eFACTS) database to manage information in its regulatory programs, including those in the shale gas sector. It makes a subset of this data, including information on wells, inspections, and compliance, available on its website in comma-separated-values files, a format that can be easily analyzed by researchers. Despite gaps in the information, the DEP’s efforts to place data online have enabled nonprofit organizations and researchers to gain a better understanding of the DEP’s regulatory program and the performance of well operators. In addition, conversations between the DEP staff and data users have fostered a reiterative process to improve the data quality. Data users have also assisted the DEP to enhance the public’s understanding of the DEP’s regulatory program. Fracktracker Alliance is a nonprofit organization that “aims to increase transparency of and access to data and information relating to unconventional oil and gas development.”\cite{94} It has created an electronic interface that is more accessible to the general public and clarified how to interpret the data. For example, the prevalence of violations based on this database provides counts of violations as a fraction of the counts of inspected wells, and not as a fraction of all wells. Moreover, counts of administrative violation do not merely indicate errors in paperwork, but have included violations that can have significant environmental impacts.\cite{95} The Carnegie Museum of Natural History Unconventional Natural Gas Wells Geodatabase project has posted data along with metadata to facilitate researchers’ understanding of this data.\cite{96} As noted earlier, researchers have used the DEP data to identify cement, casing, and well-construction violations\cite{5,49} and spills at well pads\cite{7} and to examine factors correlated with inspections and violations at well pads.\cite{46}

Knowledge of the impact of UGD would be enhanced if the DEP had a more complete record of the violations and environmental impacts at these wells. At present, violations are detected only if the DEP undertakes inspections or if operators self-report violations. Automated continuous monitoring technologies that can better detect potential problems and provide a more complete record of operations at well pads\cite{26,77} should be investigated. The implementation by companies of such automated technologies is regarded as a standard operating procedure in many industries.

Knowledge of the impact of UGD would also be enhanced if the DEP released more electronic information to the public on violations at these wells and the environmental impact of such violations. In contrast to PA, Colorado reports information online on environmental impairments that result from faulty gas-well construction or surface spills and the results of remedial efforts.\cite{31} With these details, researchers can undertake statistical analyses\cite{31} to estimate how specific well, operator, or geographical characteristics, on average, influence violation rates and environmental impacts. Such statistical findings, along with the first-hand knowledge of inspectors, can assist the DEP to prioritize their limited inspection resources to riskier wells.

STRONGER has recommended that the DEP standardize its data to track its inspections and enforcement actions.\cite{21} To improve its e-database, the DEP needs to design standardized entries to accurately capture inspectors’ observations, operator violations, and environmental impacts in UGD. In the present e-database, violation codes alone may not provide a full picture of the nature and severity of the violations.\cite{43} Extensive comments on violations at well pads have been made by some inspectors in their reports, but only an incomplete subset of these comments have been entered into...
the e-database.\textsuperscript{[22]} In future, it would be useful for the DEP to scan the original paper reports and to post them on the website with inspection identifiers that link each report to the inspection record in the eFACTS database. With a greater understanding of the diversity and extent of violations and environmental impacts, researchers and the DEP can work jointly to propose standardized entries to accurately capture DEP inspections and enforcement actions and companies’ violations. These standardized entries would facilitate the DEP’s shift towards a more complete e-database for UGD. Inspectors would enter data directly into electronic devices, which are linked to the e-database. They can select well-defined categories to record fairly detailed observations on the well, operators’ violations, and environmental impacts and they would only need to use the text comment section sparingly to record additional information. This way, the inspectors can record their inspections efficiently, and regulators, researchers, and the public can access the data without delay in a format that is readily analyzable.

5.6. Case 6: DEP investigations

The public does not have full information on the extent to which UGD has contributed to water contamination in PA. The DEP has released very limited information on its investigations, in part, because of PA legislation. First, Act 13 is silent on the duty of the DEP to inform private water-well users if it has information about spills by the oil and gas industry; though Act 13 does require the DEP to notify public water systems. Lawyers filed a brief in Robinson versus Commonwealth of Pennsylvania, arguing that the act should require the DEP to notify private well-water users.\textsuperscript{[34]} In a deposition, a DEP oil and gas program manager noted that a neighbor is not likely to know about contamination suffered by another neighbor who reaches a private settlement with a well operator.\textsuperscript{[34]} Yet, neighbors who live in close proximity are likely to be similarly affected by contamination incidents.

Second, PDLs, which are public record, have not been easily accessible.\textsuperscript{[34]} In an important move to enhance transparency, in August 2014, the DEP posted information on 243 contamination incidents that occurred since 2007, half of which were caused by unconventional or horizontal drilling, and its letters to landowners with identifying information redacted.\textsuperscript{[38]} Previously, the media had to seek legal intervention to compel the DEP to publish the PDLs. In 2012, the Commonwealth Court ordered the DEP to search for and to release the PDLs to Laura Legere of the Scranton Times Tribune.\textsuperscript{[97]} The Scranton Times Tribune collaborated with Fracktracker Alliance to place these letters online with a map that shows the municipality location for each of these PDLs with the names of landowners redacted.\textsuperscript{[98]}

Third, the numbers of PDLs may underestimate the counts of cases in which the oil and gas industry has contributed to the contamination of water supplies. It has been reported that “it is the practice of DEP regulators not to issue a violation notice, fines, or formal determinations of contamination where shale gas development companies reach private settlements with water well owners.”\textsuperscript{[94]} The Auditor General of PA argues that the DEP must issue violation notices for all cases of contamination, but the DEP does not agree with this interpretation of PA law.\textsuperscript{[22]}

Fourth, the DEP’s correspondence with landowners who lodged complaints do not provide sufficient information for landowners to determine if or how their water sources have been impacted.\textsuperscript{[22,35]} In particular, the DEP does not explain in detail the water sample analyses or how it reached its conclusion.\textsuperscript{[22,35]}

Fifth, a DEP spokesperson has argued that its investigative reports, even at the conclusion of the investigation, are not required to be produced to the public, under PA’s Right-to-Know laws.\textsuperscript{[39]} In practice, the Environmental Integrity Project has successfully used these laws to compile documents from the DEP’s investigative files.\textsuperscript{[99]}

In contrast to PA’s approach, Colorado’s COGCC has posted information on their website pertaining to its investigations of alleged contamination by the oil and gas industry. They include scanned documents of COGCC’s correspondence with operators, landowners, and other complainants, which includes the names of recipients, the location of the alleged contamination, including maps, actions undertaken to investigate the alleged contamination, water sample analyses, and operators’ responses to mitigate the contamination.

5.7. Case 7: Nondisclosure clauses in private settlements

Settlements between operators and claimants who allege health impairments and environmental contamination from UGD have included nondisclosure clauses.\textsuperscript{[35,73]} These clauses limit public knowledge about company practices and the resolution of these alleged cases of contamination.\textsuperscript{[36,73]} The compliance record of operators is relevant to PA regulators, who must consider the operators’ records in the approval of new permits.\textsuperscript{[100]} Landowners who contemplate leasing their lands to operators, investors who assess the potential liability of operators, and citizen groups that scrutinize companies’ environmental records to exert social pressure on them to improve.

The concern that nondisclosure clauses in settlements may conceal public hazards is a challenge in broader cases of environmental contamination, product liability, and professional malpractice.\textsuperscript{[101–105]} In several states, courts require strong countervailing reasons that outweigh the interests of public health in disclosure, such as personal safety or psychological or emotional harm to minors.\textsuperscript{[73]} To protect personal privacy, courts have proceeded by requiring the selective disclosure of information relevant to the understanding of public health while concealing private information that is not relevant.\textsuperscript{[106]}

Companies can benefit from ensuring that agreements remain open. The Southwestern Energy Co. of Houston agreed to settle a class-action complaint of water contamination in Arkansas only if the agreement remained open, so that the company would not be tainted by unfounded suspicion.\textsuperscript{[96]} In contrast, it has been reported that the Encana...
Corporation of Calgary’s threat of legal action for breach of contract discouraged a complainant in a settled case from testifying for the COGCC.\[36\]

6. Conclusions

Disclosure policies—the collection, access, and dissemination of information—entail costs but yield social benefits to incentivize industry to internalize environmental costs and improve risk management. A robust information infrastructure ensures that industrial activity proceeds in a manner that mitigates health and environmental impacts. Thus the expense for the construction and enhancement of this framework constitutes part of the cost of doing business. The Pennsylvania (PA) legislature has allocated only a small percentage of the impact fee imposed on the shale industry to environment protection initiatives, that is, only $10 million of the $225 million of impact fees in 2013. The impact fee is in turn only a small fraction of the revenues from industry’s estimated revenues from unconventional natural gas production, that is, approximately $15 billion in 2013.\[107\] It is critical to ensure that the costs to mitigate environmental damage are internalized in the costs of undertaking unconventional gas development (UGD) to achieve a level of UGD that is commensurate with its net social benefits.

Specific actions are required to improve disclosure policies in PA, particularly, from the PA legislature, which sets the legal framework and funding for the operation of the Department of Environmental Protection (DEP).

For the PA legislators:

- Increase staff and funding for the DEP’s information infrastructure, to improve the quality and coverage of the DEP’s public e-database.
- Pass legislation to require the collection of pre- and post-drilling water samples, which includes specific parameters that can help to identify the source of contaminants, and make this data available for researchers, in a manner that balances the need for spatial accuracy for research and the privacy of landowners or tenants.
- Impose a duty on the DEP to inform private well-water users of spills by the oil and gas industry.
- Require the disclosure of chemicals that arrive at the surface in flowback and produced waters by wells.
- Require the DEP to implement cradle-to-grave measurement, characterization, and tracking of waste in the shale industry, as recommended by the Secretary of Energy Advisory Board.
- Require the DEP to post online investigative reports on cases of contamination, if appropriate, with the landowners’ information redacted.

For the DEP:

- Post more detailed information on its inspections, violations, and environmental impact of violations to the web.
- Provide detailed public information on all cases of contamination caused by the oil and gas industry, if appropriate, with landowners’ information redacted.

Researchers, DEP, and industry:

- Work together to provide researchers with access to pre-drilling data that the industry has collected in a way that fulfills researchers’ need for spatial accuracy to study links between UGD and water contamination and landowners’ desire for privacy.

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