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In the Matter of Delaware River Basin Commission Consolidated Administrative Adjudicatory Hearing on Natural Gas Exploratory Wells

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Overview

The Delaware River is a high quality water source which provides roughly 15,000,000 people, 5% of the United States population, with water from ground or surface water sources in the basin. The Delaware River watershed is also maintained to support aquatic and terrestrial life – plant, animal and microbial species – which also provide ecosystem services for human health but are a major consideration in their own right. Clean and plentiful water resources are necessary to maintain public health, economic activity, recreational and esthetic values, and social and emotional health. Ecosystem health is also predicated on sufficient water quality and quantity to support the web of life. Exploratory Marcellus Shale drilling impacts present water management problems that can threaten both human and ecological health.

This testimony is in two parts. Part I describes the potential impacts to surface and groundwater from exploratory well drilling. Also presented in Part 1 is a peer-reviewed chain of causation model, which is used to support the contention that development of natural gas from the Marcellus Shale has the potential to result in substantial adverse effects on water quality, the environment and public health. Ground-surface disturbances associated with well drilling, including site clearing, and the construction of access roads, drill pads and impoundments, can produce impacts associated with stormwater, erosion and sedimentation of surface waterways, which in turn may lead to higher levels of water turbidity, total dissolved solids, conductivity and salinity. Increases in water turbidity are associated with increases in gastro-intestinal illnesses, even if water is treated to US EPA Safe Drinking Water Act (SDWA) standards. In addition to the impacts associated with surface activities are those associated with deep well drilling. Wells drilled to depths of 7,000 to 8,000 feet to reach the Marcellus formation create pathways for the migration of naturally-occurring contaminants into usable quality aquifers, and involve the disposition on the surface of drill cuttings and formation waters that also may contaminate ground and surface water. Contaminants associated with natural gas drilling in the Marcellus include toxic heavy metals and elements, organic compounds, radionuclides and acid producing sulfide minerals, and natural gases and sulfide producing gases, which can threaten surface and groundwater sources.

The cumulative environmental and pollution impacts from oil and gas drilling operations are significant in areas of oil and gas exploration across the country. Exploration for and production of oil and gas have caused detrimental impacts to soils, surface and groundwaters, and ecosystems in the 36 producing states in the United States and thus, in my view, pose a threat to public and ecological health.

A number of the impacts associated with oil and gas development generally are also associated with exploratory wells. Although it is unclear that even a strong regulatory program can prevent these adverse effects, in my view, the risk of damage to water resources and the environment should be reduced to the extent possible through mandatory use of best practices; ground and surface water quality monitoring to facilitate the detection and measurement of adverse effects; and the mandatory remediation by operators of any environmental damage caused by spills or other releases of contaminants from drilling sites.

Part II of this testimony is a presentation and analysis of violations of state oil and gas act regulations for the States of Pennsylvania, West Virginia and Utah. Violations data are important indicators of spills, leaks, erosion and sedimentation problems, incidents and accidents, and intentional and unintentional waste scattering and pollution problems associated with gas and oil drilling and extraction activities. Patterns of violations from oil and gas drilling operations include encroachment on wetlands and sensitive habitat, failure to restore sites following drilling and construction activities, improper erosion and sedimentation controls, improper well casing, inadequate pollution prevention, spills of drill cuttings/sediments/wastewater/and “unspecified materials” (a term used by regulators in describing spills and other violations), and failure to plug wells. These violations are frequent in Pennsylvania and the other states analyzed. All of these violations may occur in connection with the development of exploratory wells. These data and their analysis strongly suggest that exploratory drilling in the Marcellus Shale formation is likely to be accompanied by some degree of contamination of surface and/or groundwater and that regulatory controls to protect water resources and the public health are warranted, not only to minimize the risks of surface and ground water contamination, but to ensure that adverse impacts from exploratory drilling, when they occur, are measured and remediated. The fact that the Commonwealth of Pennsylvania makes no distinction between exploratory and production wells in applying a multitude of state oil and gas regulatory requirements supports this contention.

Part I. Public Health and Ecosystem Impacts of Exploratory Marcellus Shale Formation Well Drilling and Analysis

The drilling of exploratory wells into the Marcellus formation at depths of 7000 – 8000 feet below the surface of the earth, is a highly industrialized process with numerous sub-operations. Risks to water resources are associated with ground-surface aspects of the activity as well as with the well drilling itself, including disposition of drill cuttings and formation fluids. These risks are discussed in turn below.

Potential impacts associated with surface activities. The cumulative environmental and pollution impacts from oil and gas operations are significant in oil and gas exploration regions across the country (Otton et al., 2002). Pollution impacts to soils, surface and groundwaters, and ecosystems in the 36 producing states in the United States have been caused by exploration for and production of oil and gas (Richter and Kreitler, 1993; Kharaka and Hanor, 2003).

Ground surface disturbances associated with drilling of natural gas exploratory wells include but are not limited to site clearance of several acres per well, construction of access roads, and other land modifications (Kharaka, Y.K. and Dorsey, N.S., 2005). Generally, a driller needs to develop or improve access roads for transporting heavy drilling equipment, power supplies, fuel, cement and strings of well pipe and casings to the drilling site. Additionally a pad area is created, generally 3 to 5 acres in size, to accommodate one or more wellheads; and pits are constructed for holding fresh water, drill cuttings, formation water and drilling muds. Site preparation involves clearing the land of trees, shrubs and other vegetation and laying gravel over the surface of the roads and well pad. Site clearance and truck traffic combine to promote erosion. This puts soil sediments into water that runs off as stormwater. Increased sediment in water increases water turbidity, which has been shown to be associated with increases in gastrointestinal disorders (Egorv A. et al., 2003; Gaffield et al., 2003; Monis, RD et al., 1996; Schwartz et al., 1997).

Heavy metals, oils, other toxic substances and debris from drilling area traffic and spillage also may be absorbed by soil and depending on their solubility, transported into the groundwater or vadose zone horizons (unsaturated soils between the ground surface and the water table) (Hemond, H. and E. Fechner-Levy. 2000). Pesticides and fertilizers used along roadway rights-of-way and adjoining land may pollute surface waters and ground water when they filter into the soil or are blown by wind from the area where they are applied (US EPA, 1995).

Part II of this report on violations shows that erosion and sedimentation violations on both Marcellus and non-Marcellus well sites are a common occurrence. Accordingly, not only are construction and post-construction stormwater and sediment and erosion controls necessary to prevent the transport of soil and contaminants from drilling sites to surface waters (Viel, 2010), but in my view monitoring and remediation requirements are also essential to detect and prevent lasting damage to the environment, including water resources, in the event that precautionary practices fail.

Potential impacts associated with drilling. The wellbore can be a conduit for the migration of natural gas and contaminants to usable-water-bearing zones. Oil and gas wells can develop leaks of natural gases and sulfide contaminants along the casing, either during production or years after production has ceased and a well has been plugged and abandoned (Dusseault, M.B. et al., 2000). Some of the gas may enter shallow aquifers, where traces of sulfurous compounds, organic compounds and heavy metals, including toxicants, can make groundwater non-potable, or where the methane itself can cause effects in well systems and tap water, including gas locking of household wells, and gas entering household systems that can be released when the tap is turned on (Dusseault, M.B. et al., 2000). Methane gas in water can be an explosion hazard, especially for households that rely on private wells. In “Why Oilwells Leak: Cement Behavior and Long-Term Consequences” Dusseault and co-authors state that there are certainly tens of thousands of abandoned, inactive, or active oil and gas wells that currently leak gas to the surface in North America (Dusseault, M.B. et al., 2000). These authors demonstrated that leaks occur because of cement shrinkage at depth with subsequent gas and fluid migration outside of the casing. Gas and fluids are transported up the string into groundwater aquifers. The authors further state that once this phenomenon occurs it is not likely to attenuate. Rather, methane migration will become worse over time, with more and more gas and fluids accumulating in the ground water aquifer.

Drilling to depths of as much as 8000 feet to tap the Marcellus shale requires employment of numerous casing strings that must be cemented to form hydraulic seals that isolate deep strata from the atmosphere and groundwater. Because of the great depth of these wells, the potential for cement shrinkage and cracking, accompanied by transfer of gases and fluids upwards is greater than in shallow wells.

Disposal of drill cuttings and muds from Marcellus shale wells also poses concerns for water resources. The Marcellus Shale is a Middle Devonian, carbonaceous black shale (Faill, 1998). Black shales have long been known to contain levels of trace elements and metals above levels found in the crustal earth. A summary report published in 1970 of sedimentary provinces in the United States and Canada examined beds of metal-rich black shale, including Devonian shales (Vine, J.D. and Tourtelot, E.B., 1970).

The investigators analyzed for trace elements 20 sets of samples (comprising 779 individual samples) selected as representative of a wide variety of geologic environments of black shale deposition. These samples include black shale and associated organic-rich rocks transitional with black shale. Statistical methods were used to determine the composition of the average black shale and the normal range in composition of black shale and to provide a definition of metal-rich black shale for any one of 21 trace elements. A black shale sample was defined as metal-rich if any minor element was found to occur in excess of the 90th percentile as determined from the sum of the percent frequency distribution of elements in the 20 sets of black shale samples.

Statistical analysis of chemical data indicate that the detrital mineral fraction of most black shale deposits is characterized by the elements aluminum, titanium, gallium, zirconium, and scandium and may also include any of the following elements: beryllium, boron, barium, sodium, potassium, magnesium, and iron. The carbonate fraction of black shale deposits commonly includes calcium plus magnesium, manganese, or strontium. These elements are readily available from solution and are regarded as mobile. The organic fractions of black shale deposits are locally enriched in other mobile elements including silver, molybdenum, zinc, nickel, copper, chromium, vanadium, and, less commonly cobalt, lead, lanthanum yttrium, selenium, uranium, and thallium.

Elemental and metal contaminants in drill cuttings and debris can be moved as soluble dissolved constituents in runoff water or by entrainment of cutting/debris particles in runoff water. Since drilling sites are cleared of vegetation, fewer plants are available to take-up potentially toxic elements and metals, increasing their likelihood of entering both surface and groundwater. These elements and metals can have varying toxic impacts on human and ecological health, depending on exposure and dose.

Certainly gas-bearing shales also contain numerous organic hydrocarbons. We know, for example, that the Marcellus contains from 3-12% organic carbon (OC), the Barnett: 4.5% OC, and the Fayetteville: 4-9.8% OC (Arthur et al, 2008). We also know that produced waters (formation waters) from gas production contain low molecular-weight aromatic hydrocarbons such as benzene, toluene, ethyl benzene, and xylene at higher levels than do produced waters from oil operations. Produced water from oil and gas operations contains: aliphatic and aromatic carboxylic acids, phenols, and aliphatic and aromatic hydrocarbons. While the quantity of formation fluid flowback from an exploratory well may be considered to be minor compared to that from a production well, drill cuttings from the Marcellus layer itself will necessarily be enriched with organic compounds that could be released into surface and groundwater. These organic hydrocarbons can have varying toxic impacts on human and ecological health, depending on exposure and dose.

Elevated concentrations of naturally occurring radioactive materials (NORM), including 238U, 232Th and their progeny, are found in underground geologic deposits and are often encountered during drilling for oil and gas deposits (Rajaretnam G, and Spitz HB., 2000). Drill cuttings from the Marcellus may be enriched in radium radionuclides and off-gas the radioelement radon. Also, the activity levels and/or availability of naturally occurring radionuclides can be significantly altered by processes in the oil, gas and mineral mining industries (B. Heaton and J. Lambley, 2000)**.** Scales in drilling and process equipment may become enriched in radionuclides producing technologically enhanced naturally occurring radioactive materials (TENORM). Exposure to TENORM in drilling equipment may exceed OSHA and other regulatory authority standards for the protection of both human and ecological health. The occurrence of TENORM concentrated through anthropogenic processes in soils at oil and gas wells and facilities represents one of the most challenging issues facing the Canadian and

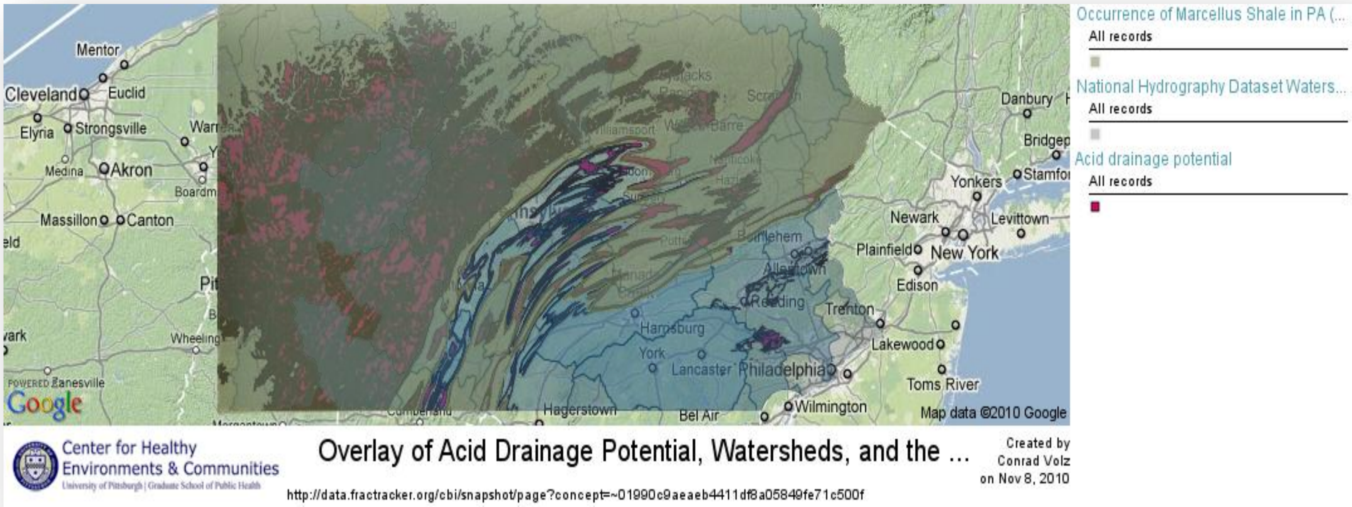
US oil and gas industry today (Saint-Fort et al., 2007). The risk of contamination of surface water and ground water by TENORM accompanies the risk of soil contamination, as TENORM generated may runoff of drilling equipment during rain events or if on the soil surface into surface water sources and/or enter groundwater by transport through the unsaturated zone.

Drilling through numerous layers of geologic formations will necessarily increase the likelihood of contacting sulfide-containing rocks. Drill cuttings and debris open to the environment, including rain and wind dispersion, have the potential to form sulfuric acid in a process that is analogous to the formation of acid mine drainage, if on a localized and smaller scale. A similar phenomenon is predicted in connection with exposure of natural gas well drill cuttings. Sulfides within the rock extracted from the borehole can create sulfuric acid after reacting with air and water, and further mobilize toxic elements and metals, which may then be transported to both surface water sources and ground water.

Documentation of this type of non-traditional acid drainage effect was demonstrated in a paper entitled “Evaluation of acid-producing sulfidic materials in Virginia highway corridors” (Orndorff, Z.W. and Lee, E.W., 2004). The authors found that road construction through sulfidic materials in Virginia has resulted in localized acid rock drainage (ARD) that threatens water quality, sedimentation, integrity of building materials, and vegetation management. Geologic formations associated with acid roadcuts were characterized by potential peroxide acidity (PPA), expressed as calcium carbonate equivalence (CCE), and total sulfur (total-S) in order to develop a statewide sulfide hazard rating map. They found that the Marcellus Shale had PPA<60 Mg CCE/1000 Mg; total sulfur < 2.6% similar to the Millsboro Shale, thus placing it near the high end of PPA among geologic formations that could be disturbed by roadcuts (the formations with the highest PPA were the Chattanooga shale and Quantico slate at PPA<99 Mg CCE/1000 Mg; S<3.9%, followed by the Chesapeake Group, Lower Tertiary deposits, Millboro shale, Marcellus shale, and Needmore Formation at PPA<60 Mg CCE/1000 Mg; S<2.6%, followed by the Ashe formation at PPA<18 Mg CCE/1000 Mg; S<2.0% , and the Tabb formation at PPA CCE/1000 Mg; S<0.2%). The authors conclude that sulfide hazard analysis should be an essential step in the pre-design phase of highway construction and other earth-disturbing activities. Based on this report, and given that drill cuttings stored on the ground surface or buried on site may be exposed to weathering, the risk of localized acid formation leading to increased mobilization of toxic elements and heavy metals cannot be overlooked. Once mobilized by acid waters these elements and heavy metals may enter both ground and surface waters.

A map entitled "Geologic Units Containing Potentially Significant Acid-Producing Sulfide Minerals" was produced by the Bureau of Topographic and Geologic Survey of the Department of Conservation and Natural Resources, the Department of Environmental Protection, and the Pennsylvania Department of Transportation (PennDOT) in 2005, and revised in 2006 (Open-File Miscellaneous Investigation (OFMI) Report 05–01.1: Geologic Units Containing Potentially Significant Acid-Producing Sulfide Minerals (2005; rev. 3/2006). This map was put onto the fractracker.org web-based system and overlaid with watersheds in the Marcellus Shale region, including Pennsylvania. A map visualizing this relationship is shown in Map 1, Overlay of Acid Drainage Potential, Watersheds and the Marcellus Shale Layer. Acid producing strata are outlined in red, the Marcellus in yellow overlay and watersheds in blue.

The creators of "Geologic Units Containing Potentially Significant Acid-Producing Sulfide Minerals" stress that this map is meant to provide a general reference for the extent of acid mine drainage risk and should not be read to assert that rock-cutting or drilling activities within the designated areas will necessarily lead to acid mine drainage while similar activities undertaken outside such areas will not. Sulfide-containing rock is found throughout the Commonwealth and is thus a potential problem for any shale drilling operation.



Map 1, Overlay of Acid Drainage Potential, Watersheds and the Marcellus Shale

Chain of Causation Model

I have developed a Chain of Causation Model to understand and predict how water-related issues can lead to significant human and ecological consequences of numerous types. This model is peer reviewed and has been used as a:

- Basis for an integrated water management plan by the Regional Water Task Force planning group for the Southwestern Pennsylvania area and Upper Ohio River Watershed, which includes portions of the States of Pennsylvania, Ohio, New York, West Virginia, Maryland and Virginia (Miller, T. Editor, Volz, C. D., Author; 2007).
- Conceptual model to help environmental health professionals, public health officials and occupational – environmental physicians understand how water, land management, ecological and contamination issues interact to produce tertiary public health, ecological, medical, social and economic problems (Volz, C. D.; 2007a).
- Planning tool for NATO efforts at peacekeeping. Inter- and intrastate conflicts and political problems often have as their proximal causes issues related to water management, including quality, quantity, erosion and sedimentation and flooding (Volz, C.D., 2007b)

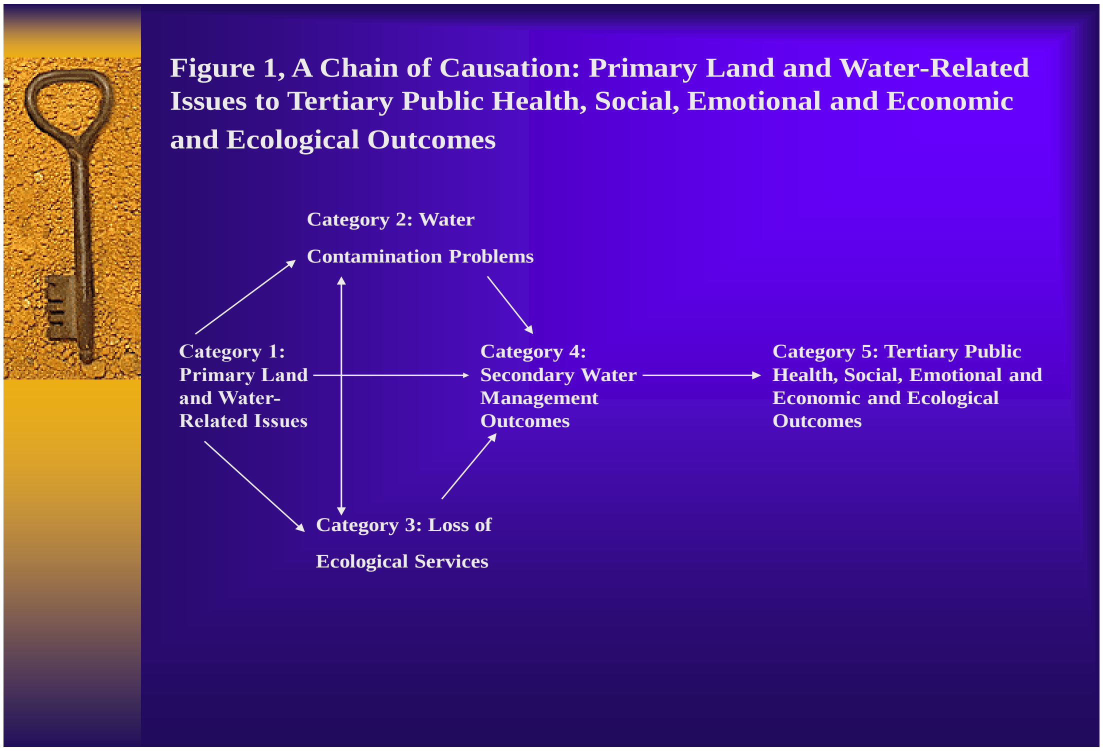


Figure 1, A Chain of Causation: Primary Land and Water-Related Issues to Tertiary Public Health, Social, Emotional and Economic and Ecological Outcomes

The model is presented in Figure 1, above, "A Chain of Causation: Primary Land and Water-Related Issues to Tertiary Public Health, Social, Emotional, Economic and Ecological Outcomes." Succinctly, Category 1, Primary Water-Related Problems either cause or exacerbate Category 2, Water Contamination Problems, and Category 3, Loss of Ecological Services. Categories 2 and 3 may combine to exacerbate Category 1 issues. A feedback loop exists from Category 3 to Category 2 as well, in that ecological degradation hinders natural purification of water, so that contaminants in the water build up over time, in turn further eroding the ecosystem's ability to purify water. The problems in Categories 1, 2, and 3, alone or in combination, result in Category 4, Secondary Water Management Outcomes, such as decreased production of clean surface water and groundwater, increased stormwater/snowmelt runoff, and increased contaminant loads in surface water and groundwater. Finally, these secondary outcomes result in Category 5, Tertiary Environmental and Ecological, Public Health, Medical, Social, Emotional, and Economic Outcomes. These can include increased stormwater management costs, increased cost of water purification, decreased recreational and aesthetic value, decreased economic growth, loss of aquatic and terrestrial species, increased cost of flood insurance, and increased risk of cancer and waterborne diseases.

In this model I have borrowed the classifications of primary, secondary, and tertiary from the field of public health to show where interventions can most successfully be applied to break the chain of causation. In public health, primary care (e.g., immunization) is always ethically and economically better than secondary care (e.g., treating the infected), which in turn is better than relying on tertiary care (e.g., hospitalizing very sick individuals for extremely intrusive and costly treatment).

It is my contention that exploratory drilling in the Marcellus formation in the Delaware River basin is a primary threat to the production of clean and adequate water resources. Regulatory measures are appropriate and necessary at this very early stage in the natural gas development process in my view to reduce the risk of degradation of water resources and prevent the far-reaching consequences, including contamination and loss of ecosystem services, that accompany such degradation in the long-term.

Part II Violations

Violations data are important indicators of spills, leaks, erosion and sedimentation problems, and intentional and unintentional waste scattering and pollution problems associated with oil and gas drilling activities. The issuance of a violation is of course dependant on direct inspection of the operator's process and/or paperwork by agency enforcement staff. Therefore, violation data indicate patterns of environmental and pollution violations but should be regarded as a subset of the total universe of violations of state oil and gas act regulations.

Violations data for oil and gas drilling and extraction operations were analyzed for Pennsylvania, West Virginia and Utah pertaining to both "conventional" and "unconventional" extraction activities. Activities involving stimulation techniques such as hydraulic fracturing of horizontal wells are deemed to be "unconventional."

In Pennsylvania violations history exists for three types of gas and oil wells: shallow oil and gas wells, vertical Marcellus wells (primarily gas wells, but oil may also be generated) that have been hydrofractured, and horizontal Marcellus wells that have been hydrofractured. Pennsylvania does not distinguish "exploratory wells" from production wells. Due to the depth of the Marcellus wells, the need for more casing strings and cement, longer drilling times, the penetration of more geologic layers, and the generation of commensurately more drilling waste, the potential for violations in connection with vertical exploratory wells is greater than for shallow gas and oil wells, though less than for Marcellus production wells. Violations data from all wells drilled, however, demonstrate patterns of violation that can be expected to accompany drilling activity generally, including exploratory drilling, in the Marcellus Shale.

Whether considered in sub-categories or in combination, conventional, unconventional, stimulated and non-stimulated oil and gas well development activities generate significant numbers of violations and high ratios of violations to wells drilled in the three states analyzed.

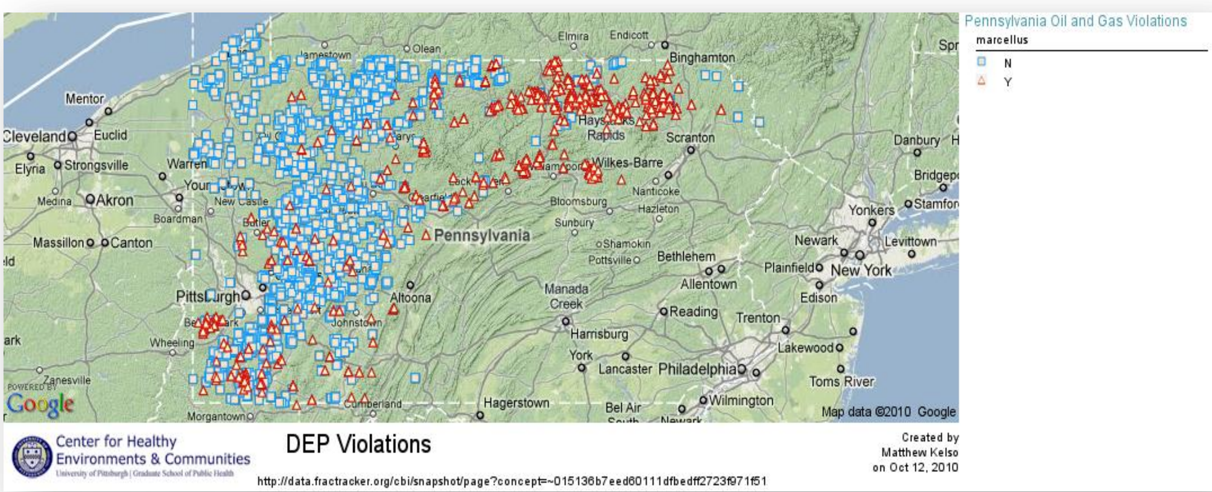
Pollution-related violations in Pennsylvania for all wells include encroachment on wetlands and sensitive habitat, failure to restore the site following drilling and construction activities, improper erosion and sedimentation controls, improper well casing, inadequate pollution prevention, spills of drill cuttings/sediments/ wastewater/and or unspecified materials, and failure to plug wells. These categories of violations are frequent in Pennsylvania as well as in the other two states analyzed. All of these types of violations may occur during the construction of exploratory wells. Violations in each of the three states are considered below.

Pennsylvania

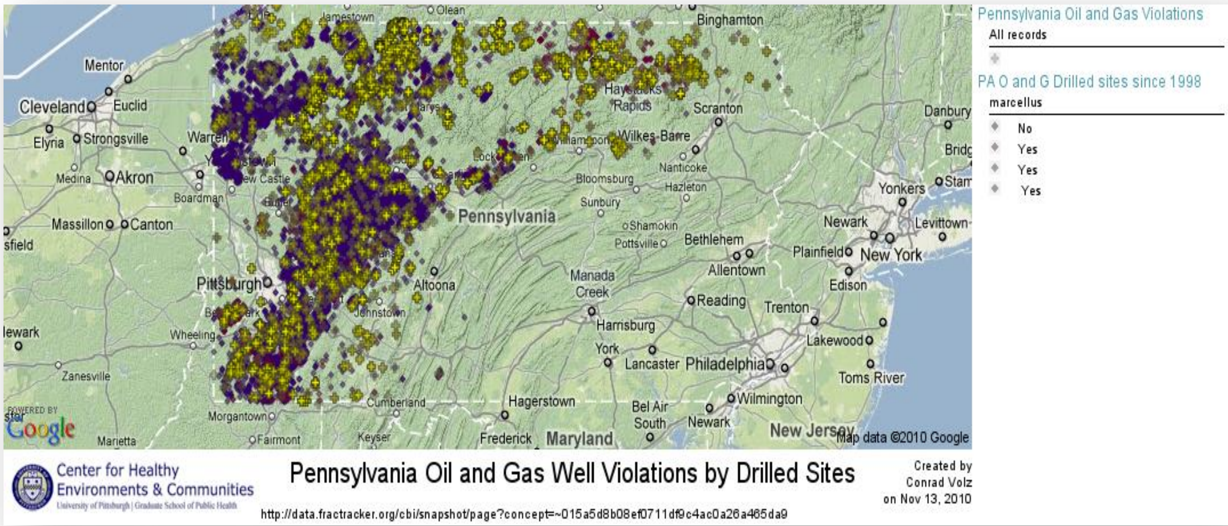
Datasets of wells drilled from 1998 to 9/30/2010 and violations of the Pennsylvania Oil and Gas Act from 2007 to 9/30/2010 were provided by the Pennsylvania Department of Environmental Protection (PADEP) Oil and Gas Bureau in response to the request of CHEC researcher Mr. Matt Kelso on 9/15/2010. These datasets were uploaded onto CHEC's fractracker.org web-based information system by Mr. Kelso, who added and verified location coordinates based on address information. These datasets were visualized on CHEC's web-based fractracker.org program by the author on 11/13/2010. Map 2, entitled "All PA DEP Violations," shows all recorded violations of the Pennsylvania Oil and Gas Act from 2008 through 9/30/2010 at Marcellus and non-Marcellus wells. This visualization shows violations over the entire geographical range of oil and gas extraction activities, which is confirmed by Map 3, "Violations of Pennsylvania Oil and Gas Act Regulations by Wells Drilled from 1998 through 9/30/2010." Map 3 shows non-Marcellus wells as blue diamonds, Marcellus wells as red diamonds and violations as yellow crosses. Again, these violations cover all oil and gas extraction areas of Pennsylvania, including the Marcellus "greenway".

Some violations correspond to oil and gas wells that were drilled prior to 1998. These are denoted on Map 3 by yellow crosses without corresponding diamonds indicating wells drilled. The Pennsylvania Spatial Data Access (PASDA) system maintains a list of over 123,000 oil and gas locations in the state, based on Department of Environmental Protection (DEP) data, and CHEC has found over 6,000 more locations from permit information available on the DEP website, bringing the total number of oil and gas drilling locations known to exist in the Commonwealth to over 129,000. The significance of this number increases when one considers that in Pennsylvania wells continue to produce pollution violations long after they have been drilled. Moreover, large amounts of salts and organics can be found in soils and groundwater after more than 65 years of natural attenuation, following cessation of oil and gas extraction activities (Kharaka, Y.K. and Dorsey, N.S., 2005). Exploration for and production of oil and gas have caused local pollution impacts to soils, surface and groundwaters, and ecosystems in the 36 producing states in the United States (Richter and Kreitler, 1993; Kharaka and Hanor, 2003).

Map 2, All PA DEP Violations



Map 3, Violations of Pennsylvania Oil and Gas Act Regulations by Wells Drilled from 1998 through 9/30/2010.



The violation dataset provided by the Pennsylvania Department of Environmental Protection for violations from 2007 to the present contained 9,370 violations associated with 3,661 discrete wells. The original dataset included 109 violation categories, which were collapsed into 12 categories for ease of analysis. I note that some of these categories were relatively simple to collapse. For example, wastewater spills and brine spills clearly belong together. Other examples were less clear. One of the original categories was "Improper storage of residual waste," which does not explain whether or not a spill occurred. For that reason, this category was included with, "Inadequate pollution prevention," although the violation might well have been issued after a spill of drilling debris or the overflow of an impoundment.

Figure 2, "Categories of Violations Issued by the PA DEP from 2008 to Present," shows the 12 collapsed categories of violations by "all Marcellus wells" (that is, both vertical and horizontal Marcellus wells), "non-Marcellus wells" and "total wells". Focus here will be on violations for total wells because exploratory wells do not exist as a category in the PA DEP database, and for the purpose of violations data, Marcellus exploratory wells were considered to resemble both "all Marcellus wells" and "non-Marcellus wells" to some extent. Of the 9,370 violations, 106 were for permit problems; 3,073 were administrative and paperwork problems; 119 were related to encroachment onto wetlands, stream and river borders of the Commonwealth, and other ecologically sensitive areas; 1,111 were for failure to plug wells; 22 were for improper erosion control procedures and events; 439 related to failure to restore the drill site (which may result in long-term erosion and sedimentation problems); 180 specified improper well casings; 2,938 violations were for inadequate pollution prevention techniques and precautions; 9 pertained to safety regulations; 24 concerned spills of drill cuttings or sediments; 1,043 were for unspecified spills; and 306 violations were for spills of oil and gas wastewater.

Figure 2, Categories of Violations Issued by the PA DEP from 2008 to Present

Violation Type	Horizontal Marcellus	Vertical Marcellus	Non-Marcellus	Total
Activity requires permit	4	0	102	**106**
Administrative	538	212	2323	**3073**
Encroachment	40	11	68	**119**
Failure to plug well	1	4	1106	**1111**
Failure to restore site	13	19	407	**439**
Improper erosion control	3	0	19	**22**
Improper well casing	49	14	117	**180**
Inadequate pollution prevention	595	260	2083	**2938**
Safety violation	6	0	3	**9**
Spill, drill cuttings or sediments	0	0	24	**24**
Spill, material not specified	188	78	777	**1043**
Spill, wastewater	30	10	266	**306**
Grand Total	1467	608	7295	9370

Violation Type by Well Type, 1-1-2007 through 9-30-2010

Collapsed categories of violations that can have a direct effect on surface and groundwater quality, including additions of toxic heavy metals and elements, organic compounds, radionuclides, turbidity, and total dissolved solids include: encroachment; failure to plug a well; failure to restore a site; improper erosion control; improper well casing; inadequate pollution prevention; and spills of drill cuttings and sediments, wastewater, and unspecified materials. The total of the spill categories was 1,373 violations, which accounted for 14.7% of all violations reported in this time-period. Serious pollution related violations that could affect surface and groundwater quality accounted for 6,182 of the 9,370 total violations or 70% of all violations in the time-period.

The number of violations per well type was calculated for wells with any violations. Figure 3, Violations per Well for any Well with at Least One Violation, shows by well type the number of violations for wells with at least one violation, and the average frequency of violations for any well with at least one violation. There were a total of 3,661 wells with violations from 2007 to the present and a total of 9,370 violations concerning those wells, for a rate of 2.56 violations per well for all wells with at least one violation. There were 7,295 violations at 3,069 distinct non-Marcellus wells for a rate of 2.38 violations per well with any violations.

Figure 3, Violations per Well for any Well with at Least One Violation

Well Type	Violations	Wells	Frequency
Marcellus, Horizontal	1497	399	3.75188
Marcellus, Vertical	578	193	2.994819
Total Marcellus	2075	592	3.505068
Non Marcellus	7295	3069	2.376996
Total Wells	9370	3661	2.55941

Violations per Offending Well by Well Type Table, 1-1-2007 Through 9-30-2010

Figure 4, "Chart of Average Frequencies of Violations for Any Well with a Violation," shows the relationship between violation rates of types of wells with at least one violation. Horizontal Marcellus wells have the highest average frequency of violations per well with a violation (3.36), followed by all Marcellus wells (3.51), Vertical Marcellus wells (2.99), all wells including Marcellus and non-Marcellus (2.56), and all non-Marcellus wells (2.38). To be clear the analysis presented in Figure 4 does not suggest that an average of 2.56 violations per well is occurring in Pennsylvania. Information as to the number of wells drilled—that is, denominator data – are needed to calculate a violations rate per well, and such data are not currently available in Pennsylvania, as I explain at greater length below. The data do show, however, that when a PA DEP inspector determines that a notice of violation must be issued, he or she typically cites the operator for more than one problem.

Figure 4, Chart of Average Frequencies of Violations for Any Well with a Violation

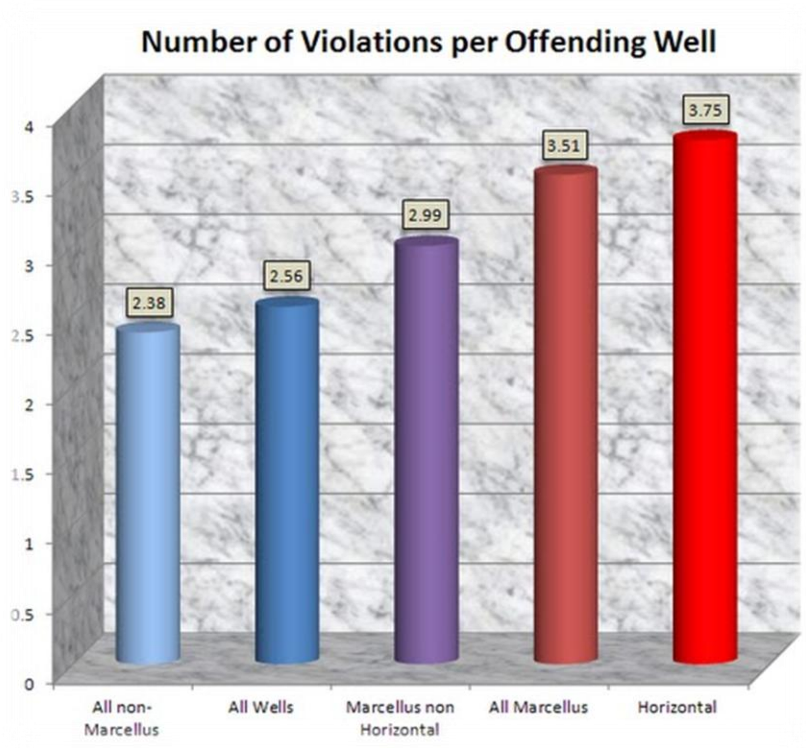


Figure 5, Total PA DEP Violations by County by Type of Well, shows by county the number of violations by well type and the total number of violations in that county from 2007 to present. Violations are seen across all counties where oil and gas extraction activities occur. The three contiguous counties in the north central/east quadrant of the Commonwealth—Bradford, Susquehanna, and Tioga—account for a majority of the Marcellus Shale violations. Two northwestern counties—McKean and Venango—have noticeably more violations than the rest of the counties in terms of oil and gas operations that are drilled into other formations.

Analysis of violations per total wells drilled is difficult because oil and gas activity has been ongoing in Pennsylvania since before the turn of the 20th Century PA DEP databases do not contain data on oil and gas wells drilled before 1998, . let alone those drilled in the early part of the 20th century.

County	Horizontal Marcellus	Vertical Marcellus	Non-Marcellus	Total
Allegheny	0	2	128	130
Armstrong	15	10	289	314
Beaver	0	0	2	2
Bedford	0	0	2	2
Blair	9	0	0	9
Bradford	453	48	59	560
Butler	5	10	37	52
Cambria	0	1	68	69
Cameron	42	12	4	58
Centre	9	8	11	28
Clarion	0	2	486	488
Clearfield	54	23	193	270
Clinton	20	6	14	40
Columbia	0	1	0	1
Crawford	0	0	54	54
Elk	10	8	122	140
Erie	0	0	201	201
Fayette	3	41	124	168
Forest	4	4	741	749
Greene	21	22	216	259
Indiana	1	6	255	262
Jefferson	0	1	154	155
Lycoming	167	54	19	240
McKean	4	2	1452	1458
Mercer	0	0	56	56
Potter	51	46	279	376
Somerset	12	13	52	77
Sullivan	1	0	0	1
Susquehanna	225	139	23	387
Tioga	257	51	64	372
Venango	0	0	1199	1199
Warren	0	6	474	480
Washington	47	66	187	300
Wayne	0	5	10	15
Westmoreland	13	7	320	340
Wyoming	44	14	0	58
Grand Total	1467	608	7295	9370

Number of Violations by Well Type by County, 1-1-2007 thorugh 9-30-2010

Figure 5, Total PA DEP Violations by County by Type of Well

CHEC estimates there have been over 129,000 wells drilled for oil and gas in the Commonwealth of Pennsylvania since recordkeeping began. Using this denominator would dilute the number of violations per drilled well, however, because many of the 129,000 wells have been plugged and are no longer actively inspected. However, CHEC was able to obtain from the PA DEP a database of all wells drilled from 1/1/1998 through 10/21/2010. These data were compared to the database of all violations from 1/1/2007 to 9/30/2010 and results are presented in Figure 6, "Number of Violations by Well Type for Wells Drilled Between 1/1/1998 and 10/21/2010."

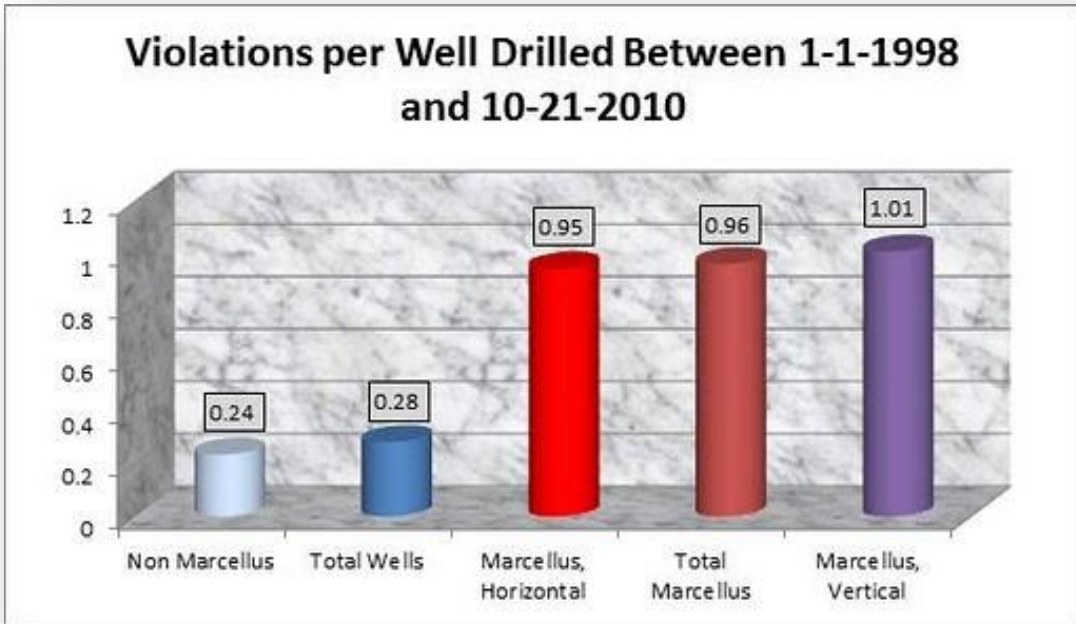
A total of 33,109 wells of various types were drilled between 1/1/1998 and 9/30/2010. For these wells, 9,370 violations were reported between 1/1/2007 and 9/30/2010. This corresponds to an arithmetic mean of 0.28 violations per well drilled. Non-Marcellus wells had 0.24 violations per well on average; and vertical Marcellus wells had 1.01 violations on average.

Well Type	Violations	Number of Wells	Violations per Well
Marcellus, Horizontal	1497	1584	0.9450758
Marcellus, Vertical	578	572	1.0104895
Total Marcellus	2075	2156	0.9624304
Non Marcellus	7295	30953	0.2356799
Total Wells	9370	33109	0.2830046

Figure 6, Number of Violations by Well Type for Wells Drilled Between 1/1/1998 and 10/21/2010; Violations Filed Between 1/1/2007 and 9/30/2010

Fgure 7, "Chart of Average Violations per Well for Wells Drilled Between 1/1/1998 and 10/21/2010; Violations Filed Between 1/1/2007 and 9/30/ 2010," compares average violations by well type in Pennsylvania. It is not possible to establish violation rates for exploratory Marcellus wells, since there are no data explicitly covering them. In my opinion, vertical Marcellus wells that are not hydrofractured could be expected to have a violation rate above that for Non-Marcellus wells and below that for Vertical Marcellus wells (Range 0.24 – 1.01 violations per well). There is certainly a strong probability that any well drilled will have a pollution violation, and that probability increases with additional exploratory wells drilled into the Marcellus Shale.

Figure 7, Chart of Average Violations per Well for Wells Drilled Between 1/1/1998 and 10/21/2010; Violations Filed Between 1/1/2007 and 9/30/ 2010



West Virginia Violations

Unlike other states in which violation data has had to be requested, the West Virginia DEP provides access to separate spills and violation databases on the WV DEP website. The spills database includes 488 records between the dates of January 1, 2000 and September 30, 2010, and the violation database includes an additional 245 records from the same time-frame. Figure 8, "Spill Type by Year of Incident and Total Spills" shows the details for spills of drill cuttings, drilling additives, crude oil, contaminants related to operations, and wastewater as well as gas leaks from the years 2000 through 2009.

Figure 8, Spill Type by Year of Incident and Total Spills

	YEAR OF INCIDENT										Total
Spill Type	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Spills
Drill Cuttings	1			1	2	1	1	2	1		9
Drilling Additives		2	5	2	4	4	2	8	3		30
Gas Leak		3	3	5	2	3	4	14	14	12	60
Crude Oil	31	21	33	43	29	30	20	32	21	18	278
Operations Contaminants	2		2	1	2	3	2	1	3	4	20
Wastewater	6	6	7	11	9	8	5	25	8	6	91
Total Spills	40	32	50	63	48	49	34	82	50	40	488

West Virginia Spills Incidents by County from 1-1-2000 through 9-30-2010.

It should be noted that the six different spill types in Figure 8 were condensed from an original list of 134. Most of the category combinations were straightforward. For example, brine spills and wastewater spills clearly belong together and were combined as “Wastewater.” A few, such as “Substance From Gas Well” required some degree of interpretation and were combined with “Operations Contaminants,” which included other materials, such as hydraulic fluids and sewage. According to the website, the West Virginia Department of Environmental Protection, Office of Oil and Gas is responsible for over 55,000 active and 12,000 inactive oil and gas wells in the state. The author does not have a detailed dataset for wells drilled in West Virginia or documentation of the inspection frequency of active wells, although these data have been requested. Still, these data indicate that any wells drilled have the potential to generate pollution problems, and if observed by inspectors, violations.

The 245 violations records are broken out by various legal codes, explanations for which have been requested from the West Virginia authorities.

Utah Oil and Gas Industry Overview

Utah’s Oil and Gas Permitting Manager and Petroleum Geologist Brad Hill provided CHEC with data concerning Utah’s new oil and gas industry. From Mr. Hill, we learned that while there has been discussion of shale gas extraction in the state, no wells in Utah currently are producing natural gas from shale. Mr. Hill did indicate that most of the wells in the state had been stimulated to some degree with hydraulic fracturing.

Well Type	Horizontal	Total	Percentage
Gas	17	2096	0.81%
Oil	45	1485	3.03%
Water Disposal	1	14	7.14%
Unspecified	1	1	100.00%
Grand Total	64	3596	1.78%

Frequency of Horizontal Wells in Utah by Type, 2003 through 9/29/2010

There were 4,499 oil and gas wells drilled in Utah from 2003 through 9/29/2010. A breakdown of these wells by well type is shown in Figure 9, "Oil and Gas Wells by Type Drilled in Utah from 2003 through 9/29/2010."

Figure 9, Oil and Gas Wells by Type Drilled in Utah from 2003 through 9/29/2010

Well Types	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
Total Gas Wells	1	1	1	415	393	917	789	479	2996
Directional				76	80	206	334	363	1059
Horizontal				3	4	4	3	3	17
Vertical	1	1	1	336	309	707	452	113	1920
Total Oil Wells				146	160	435	373	371	1485
Directional				17	74	219	59	96	465
Horizontal					3	15	11	16	45
Vertical				129	83	201	303	259	975
Total Test Wells						1			1
Vertical						1			1
Total Water Disposal Wells						6	7	1	16
Directional						1			1
Horizontal						1			1
Vertical						4	8	2	14
Total Unspecified Wells								1	1
Horizontal								1	1
Grand Total	1	1	1	561	553	1359	1170	853	4499

Directional, Horizontal, and Vertical Oil and Gas Permits in Utah, 2003 through 9/29/2010

The Utah data are relevant insofar as the great majority of gas and oil wells in the state are vertical wells, not horizontal wells, and reportedly, the newer wells are exploratory in nature.

Figure 10, “Frequency of Horizontal Wells in Utah by Type, 2003 through 9/29/2010,” shows that only 0.81% of gas and 3.03% of oil wells are horizontal wells—the remainder are vertical wells.

Figure 11, “Oil and Gas Violations in Utah by County, 2003 through 9/29/2010,” shows a breakdown of all oil and gas violations into 8 collapsed categories. There were a total of 518 violations over this time-period, including 32 fires, which can have serious impacts on water quality as a result of pyrolysis of site materials, including impoundment liners and petrochemicals. Other pollution-related violations included gas leaks, oil spills, sediment spills, other unspecified spills, and wastewater spills. The violation rate in Utah is .12 violations per well drilled, which is 12 violations per hundred wells drilled.

Figure 11, Oil and Gas Violations in Utah by County; 2003 through 9/29/2010

County	Fatality	Fire	Injury	Gas Leak	Oil Spill	Other Spill	Sediment Spill	Wastewater Spill	Total Violations
Carbon	1	1		1	2	1		28	34
Duchesne		9		13	77	6		60	167
Emery				8	6		1	2	17
Garfield									1
Grand		1		2	9			5	19
Salt Lake		5							10
San Juan		1		1	8	2		9	23
Sanpete			2						2
Sevier								1	1
Summit						1		4	5
Uintah		15	8	11	68	9	1	126	238
Wayne					1				1
Grand Total	1	32	0	36	171	19	2	235	518

Oil and Gas Violations in Utah by County, 2003 through 9/29/2010

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