Damascus Citizens for Sustainability

Dangers of Vertical oil gas Wells - the 2010 Reports - part 1 of 3

These expert reports were commissioned by Damascus Citizens for Sustainability and Delaware Riverkeeper Network.� These reports were submitted as direct testimony in a consolidated administrative hearing before a hearing officer appointed by the Delaware River Basin Commission.�

DCS' attorney, Jeff Zimmerman's explanation of the hearing:
At issue in this hearing were two determinations regarding so-called exploratory or test wells by the executive director of DRBC, one known as the SEDD and the other as the ASEDD.� SEDD stands for "Supplemental Executive Director Determination" and ASEDD for "Amended Supplemental Executive Director Determination.� The SEDD subjects almost all exploratory wells in the Basin to full Commission review thus reversing an exception for exploratory wells in a prior executive director determination that made all shale gas production wells subject to full Commission review.� The application of the SEDD to exploratory wells was challenged by an alliance of property owners who have all leased land to the gas companies.� Another part of the SEDD gave an exception to allow approximately 15 wells permitted by Pennsylvania over the period from the production well determination to the SEDD to proceed without any review by the Commission.� The ASEDD allowed 2 additional exploratory wells that had not obtained final permits from Pennsylvania to also proceed without any Commission review. This Reservation Provision (aka Grandfathered Wells) of the SEDD and the ASEDD was challenged by DCS and DRN.�
The hearing was aborted by the industry wanting to trade cancelling the hearing in exchange for them agreeing to no additional 'exploratory' wells to be permitted and those permitted but not started would not be developed in the DRB. I and others feel strongly that they were very impressed by the information in the reports on what damage has been caused or could be caused by the vertical and not hydraulically fractured wells they were labelling 'test' wells and did not want that information to be publicized. It is on the strength of that recommendation that I offer them in this comment and the following comments to stress that NO gas or oil drilling should be allowed in the Delaware Basin. The proposed prohibition of high volume hydraulic fracturing is good and should be adopted, but additionally all - even low volume, vertical wells should also be prohibited.

These reports were submitted in December of 2010 and a lot of additional research and exploration has been done of the damages caused by oil and gas drilling and all the processes involved in fracking the information in these reports is still viable and must be paid attention to. For newer material see, e.g., the fifth edition of the Compendium, http://concernedhealthny.org Additionally according to the federal EIA "up to 95% of all new wells" since 2013 are fracked - US Dept. of Energy, How is shale gas produced?, Apr. 2013 � https://energy.gov/sites/prod/files/2013/04/f0/how_is_shale_gas_produced.pdf
This means that by only prohibiting the high volume process the Commission is leaving the DRB open to damage by these other activities.

As a result of the number of and size of some of the reports this is PART 1 of 3
This comment has the 5 reports commissioned by the DRBC

Anderson-Kreeger
O'Dell
Silldorff
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Volz

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

Filed November 23, 2011

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

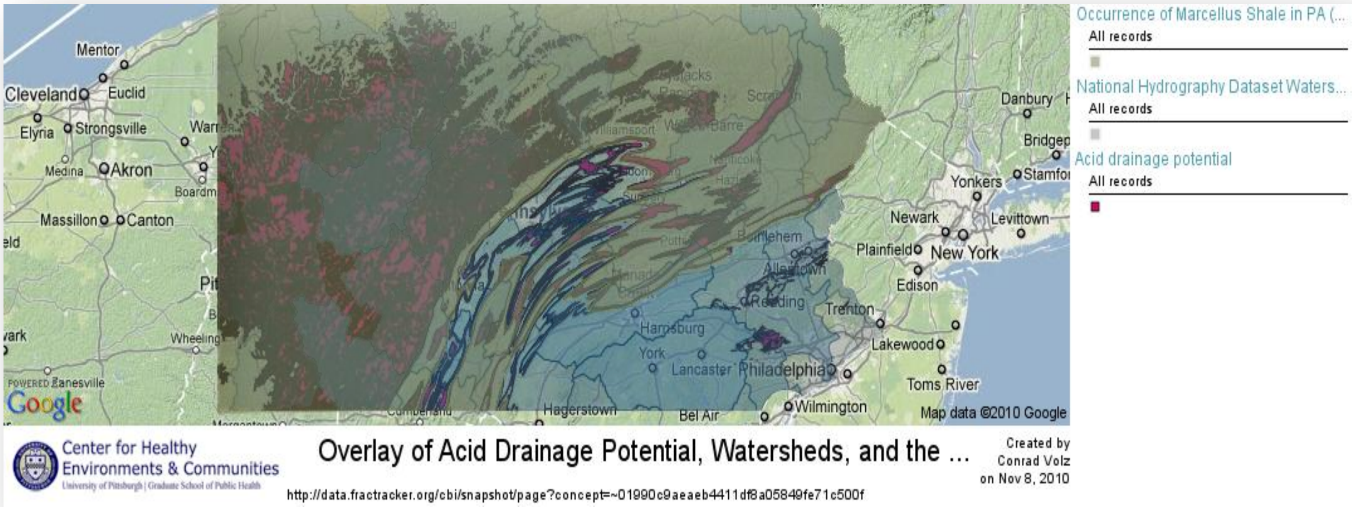
US oil and gas industry today (Saint-Fort et al., 2007). The risk of contamination of surface water and ground water by TENORM accompanies the risk of soil contamination, as TENORM generated may runoff of drilling equipment during rain events or if on the soil surface into surface water sources and/or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

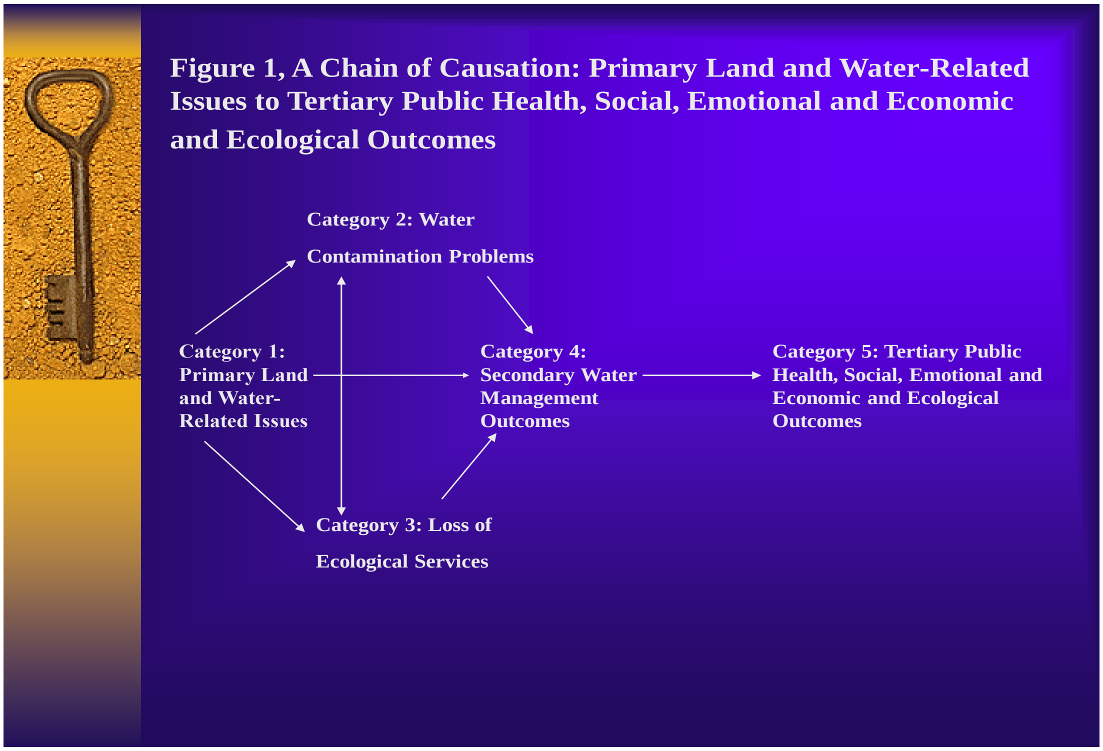


Map 1, Overlay of Acid Drainage Potential, Watersheds and the Marcellus Shale

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)



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.

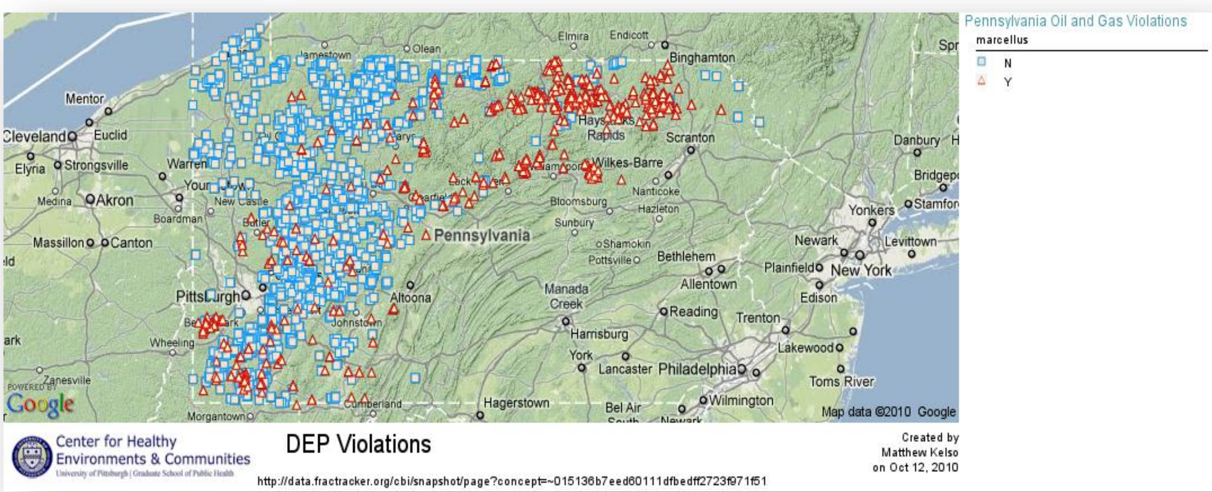
Pollution-related violations in Pennsylvania for all wells include encroachment on wetlands and sensitive habitat, failure to restore the site following drilling and construction activities, improper erosion and sedimentation controls, improper well casing, inadequate pollution prevention, spills of 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

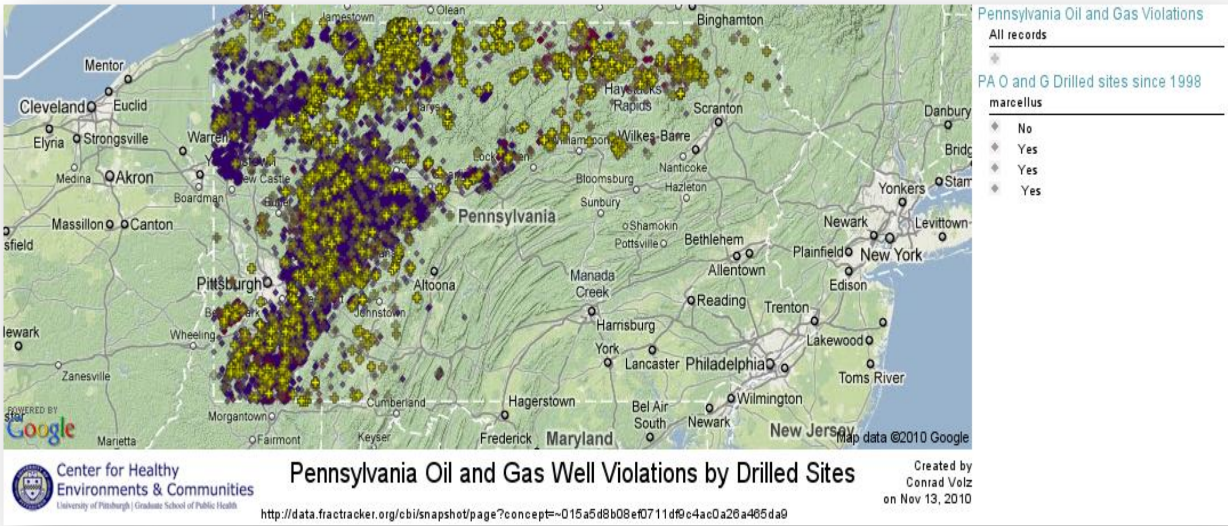
Datasets of wells drilled from 1998 to 9/30/2010 and violations of the Pennsylvania Oil and Gas Act from 2007 to 9/30/2010 were provided by the Pennsylvania Department of Environmental Protection (PADEP) Oil and Gas Bureau in response to the request of CHEC researcher Mr. Matt Kelso on 9/15/2010. These 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

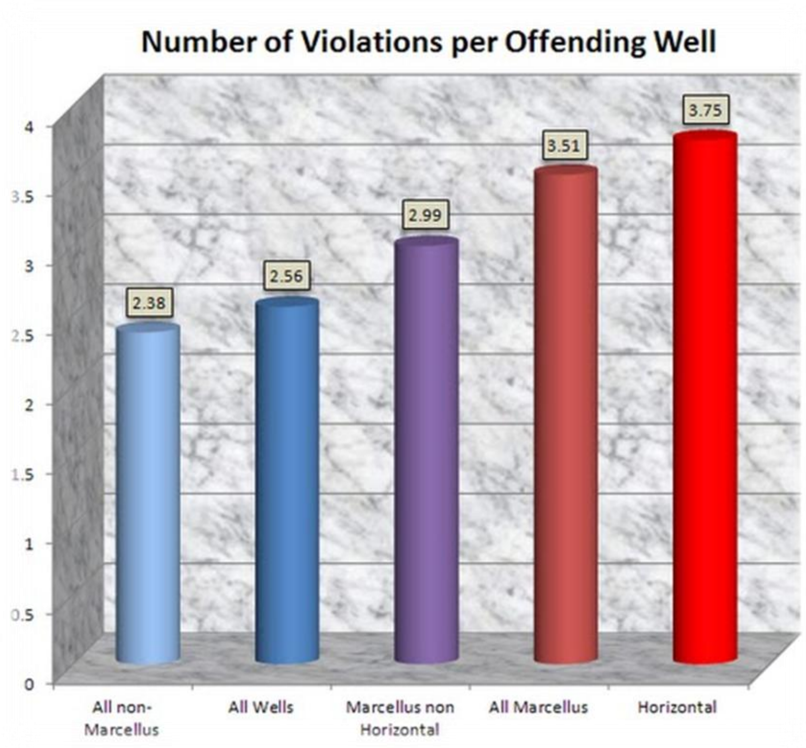


Figure 5, Total PA DEP Violations by County by Type of Well, shows by county the number of violations by well type and the total number of violations in that county from 2007 to present. Violations are seen across all counties where oil and gas extraction activities occur. The three contiguous counties 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.

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

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

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."

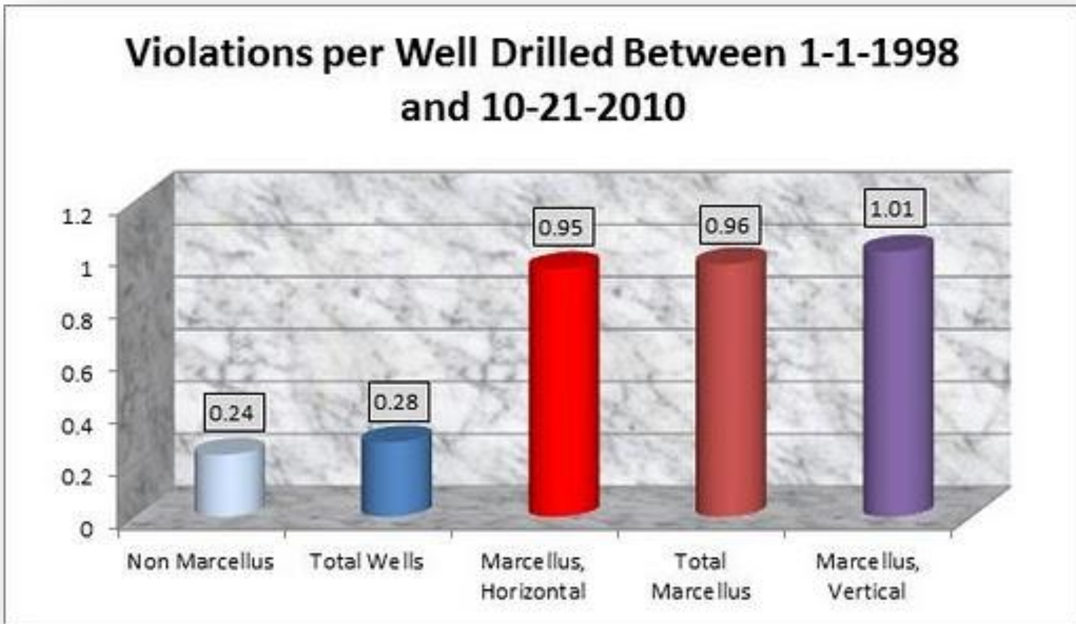
A total of 33,109 wells of various types were drilled between 1/1/1998 and 9/30/2010. For these wells, 9,370 violations were reported between 1/1/2007 and 9/30/2010. This corresponds to an arithmetic mean of 0.28 violations per well drilled. Non-Marcellus wells had 0.24 violations per well on average; 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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Potential for Development of Natural Gas Exploratory Wells to Adversely Affect Water Resources of the Delaware River Basin

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State of California Certificate #1529

National Park Service
Geologic Resources Division

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

November 23, 2010

Author Background

Patrick M. O’Dell, P.E., Petroleum Engineering, National Park Service
Area of Expertise – Management of Oil and Gas Operations for the Protection of National Park Resources and Values

Mr. Patrick O'Dell has a BS in petroleum engineering from Montana College of Mineral Science and Technology (1982). He is a registered professional petroleum engineer in the State of California (Certificate No. 1529) and has been employed in both the private and public sector.

Mr. O'Dell worked for Marathon Oil Company in Bakersfield, California as a production engineer, where he was responsible for maintaining production and controlling expenses in older oil and gas fields undergoing secondary recovery (e.g., waterflooding and gas cycling). In 1986, he relocated to Anchorage, Alaska with Marathon. In Anchorage, he worked as a reservoir engineer responsible for field development planning, reserve determination, and property evaluation for purchase or sale. While in Alaska, Mr. O'Dell became accountable for the region’s new well completions, major workover projects, and the Alaska Region's hydraulic fracture stimulation program. Environmental and safety compliance was a significant part of project design and execution. He also worked on drilling and abandonment operations.

Mr. O'Dell joined the National Park Service in 1992 as a petroleum engineer. He functions as the Service’s nationwide technical specialist and authority in the application of best available fluid mineral exploration and development technology to ensure protection of park resources and values. Mr. O’Dell is responsible for assessing impacts of oil and gas activity in and around parks, and developing measures to minimize or remove such impacts via site-specific recommendations and through development of minerals management and training programs.

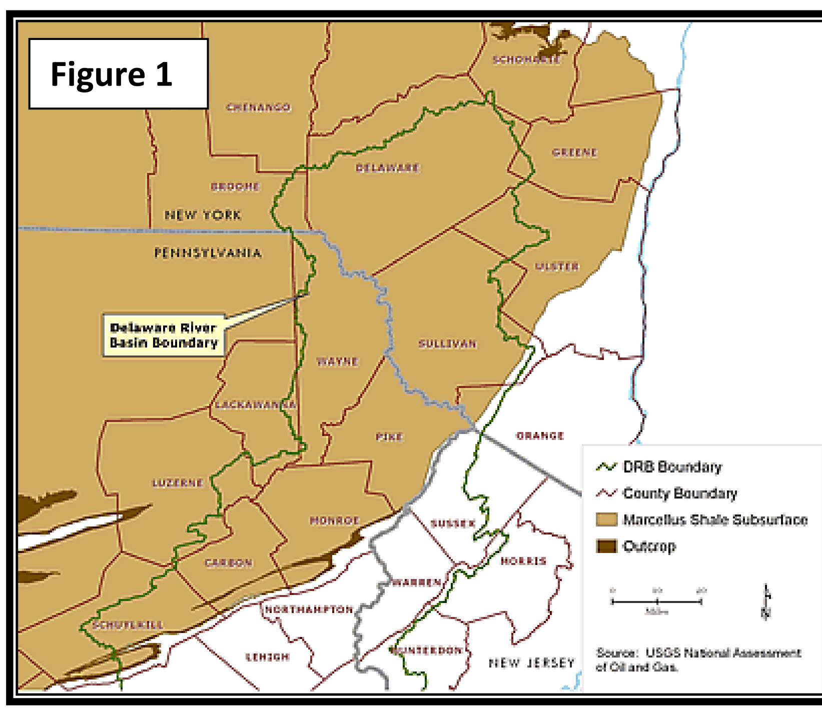
Overview

The Marcellus Shale underlies a significant part of the Delaware River Basin that drains to Special Protection Waters (*also* "SPW"), waters for which the policy is "no measurable change to water quality except toward natural conditions." *See* DRBC Water Quality Regulations, sec. 3.10.3 A.2. It is inconceivable that Marcellus Shale exploration and production will improve water quality in the Special Protection Waters of the Delaware River Basin. It is also improbable that such a widespread and water resource-intensive industrial activity in a rural setting will never adversely affect water quality. The question is whether focused attention by both industry and regulatory agencies can keep water quality and quantity degradation to localized and intermittent events – as opposed to a broad and long-term adverse impact.

The focus of this report is whether "exploration wells" have the potential, either individually or cumulatively, to have a substantial effect on water resources of the basin, and in particular, whether these projects have the potential to cause "measurable change" to the exceptionally high quality of the basin's Special Protection Waters. This report provides support for the conclusion that exploration wells do indeed have such potential.

Background

Natural gas exploration and production is an industrial activity. Shale gas exploration and production is proving to be very extensive industrial activity with a network of well pads, access roads, compressor stations, and gas transportation lines often dispersed over thousands of square miles.



The Marcellus Shale is a vast, natural gas-bearing formation extending 50,000 square miles from southern New York across Pennsylvania and through West Virginia. USGS Fact Sheets acknowledge that over 300 trillion cubic feet (TCF) of natural gas could ultimately be produced – enough gas to supply the entire United States for about 15 years. Economic and environmental stakes are high.

The horizontal drilling and large multi-stage hydraulic fracturing stimulations being used to tap the shale require large drilling locations and millions of gallons of water per well. Development in the coming years and decades will vary across the play but could ultimately be 4, 8, or even 16 wells per square mile. Infrastructure build out (roads, transmission pipelines, compressor stations, etc.) will be substantial. Today, there are about 100 active rigs drilling the Marcellus. (Baker Hughes, Nov 2010)

The Marcellus Shale formation in northeastern Pennsylvania and southern New York underlies about 5,000 square miles or one-third of the 13,500 square-mile Delaware River Basin (Figure 1). Over 15 million people (approximately five percent of the nation's population) rely on the waters of the Delaware Basin for drinking, agricultural, energy and industrial use, but the watershed drains only four-tenths of one percent of the total continental U.S. land area. (DRBC)

Figure 2 (Photo by Soete)

The 5,000 square-mile area common to the Marcellus Shale and the Delaware River Basin includes a 73.4-mile stretch of the Upper Delaware Scenic and Recreational River, which snakes gracefully through the rural countryside of green rolling hills (Figure 2). Within this same area, The Marcellus Shale includes some of the most promising sections in terms of the thickness of organic-rich shale. Figure 3 is a map of Pennsylvania showing the net feet of organic-rich shale in the Marcellus Formation. John Harper of the Pennsylvania Geological Survey believes that the thickness of organic-rich shale may be more important than the total Marcellus thickness in assessing the production potential of a well site.

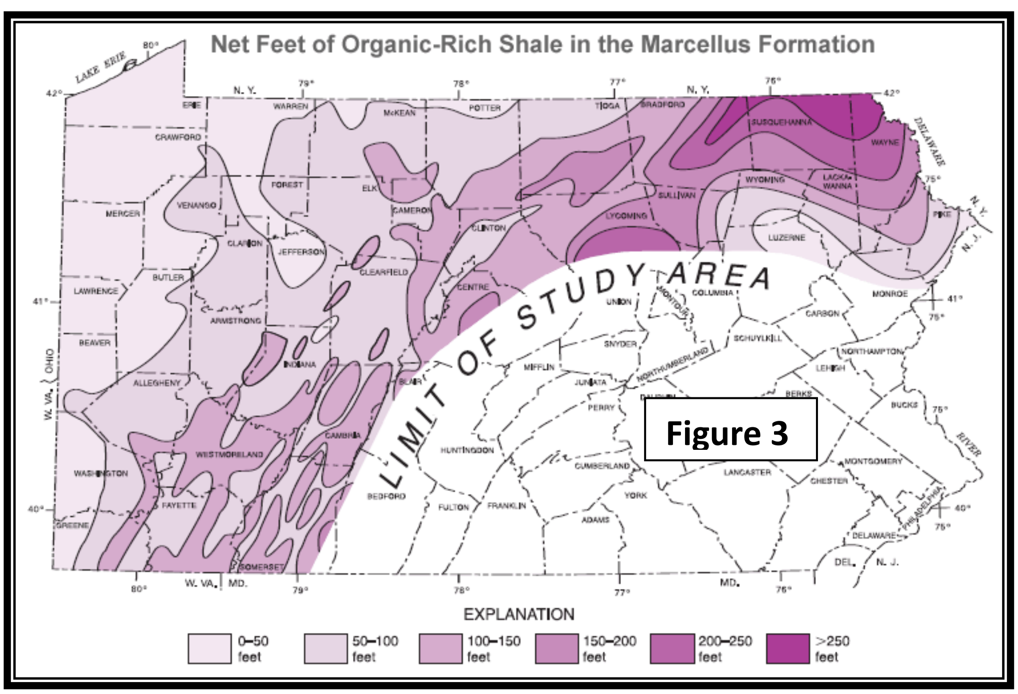


Figure 3

Figure 4 shows a map ranking Pennsylvania counties based on depth, thickness, and thermal maturity of the Marcellus Shale. Note the core area that includes a substantial area within the Upper Delaware River Basin including all of Wayne County, PA and portions of Broome, Delaware, and Sullivan Counties, NY.

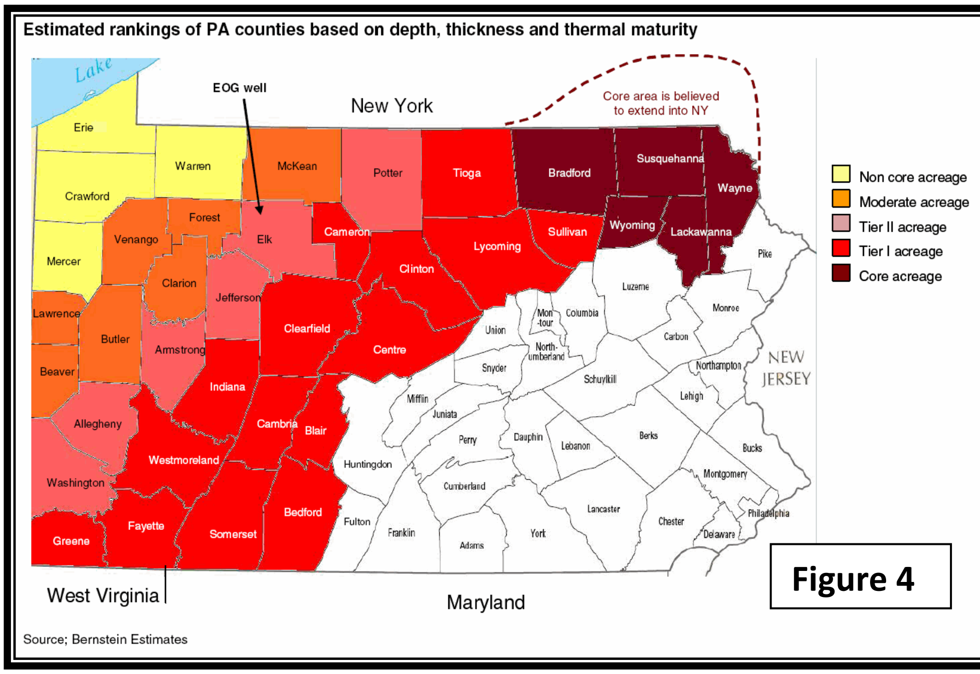
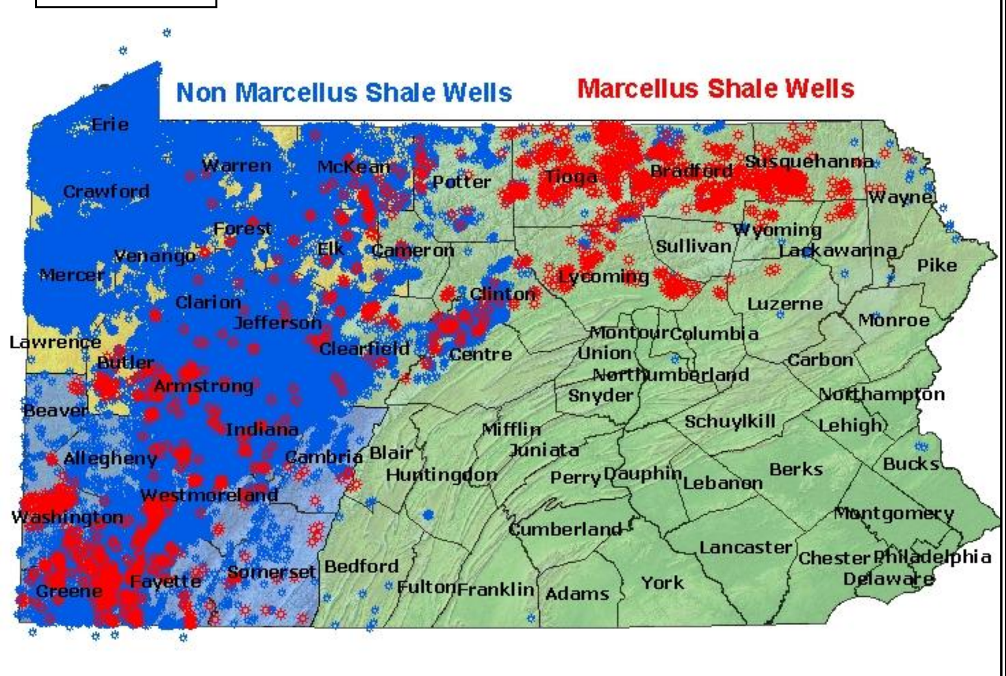


Figure 4

Figures 3 and 4 present the most promising areas of the Marcellus Shale in a slightly different manner, but based on the same geological information.

Figure 5 is a map of Marcellus wells drilled to date in Pennsylvania. Note the concentration of wells in the northeastern counties of Tioga, Bradford, and Susquehanna that correspond to an area mapped in Figures 3 and 4 as having high net feet of organic rich shale. This appears to be industry's confirmation of the focus on net feet of organic-rich shale.

Figure 5


It is reasonable to conclude (and the extent of lease holdings of parties to this hearing confirm) that areas within the Delaware River Basin are of primary interest to the industry.

Federal legislation established the Upper and Middle Delaware River as part of the National Wild & Scenic River Management program in 1978 in recognition of the scenic and recreational values and uses and exceptionally high water quality of these reaches. DRBC's SPW program, established in 1992 and modified in 1994, 2005 and 2008, created an anti-degradation management regime – the SPW program – to implement the objective established by the Upper Delaware Scenic and Recreational River Management Plan (Conference 1986), and the General Management Plan for the Delaware Water Gap National Recreation Area/ Middle Delaware Scenic and Recreational River (DWGNRA 1987) of preserving and protecting the exceptionally high quality of these waters. For more than three decades, the water resources of the upper and middle Delaware River have been accorded special status and protections by agencies of federal and state government. In my opinion, if the quality of these water resources is to be protected, then natural gas development activity within the Delaware Basin must be undertaken – from start to finish – with this goal as an industry and regulatory agency priority.

The Role of Exploration Wells in Shale Development

In the Delaware River Basin, there is a strong likelihood that a well labeled as an "exploration well" will become a producer. Further, the well site and access road that supports the initial "exploration well" could very likely support additional wells and all the related activities and associated production/transportation facilities. An explanation follows.

In a conventional sense, wells drilled for oil and gas are classified as either exploration or development wells. An exploration well is drilled either in search of an as-yet-undiscovered pool of oil or gas (a wildcat well) or to extend greatly the limits of a known pool. Exploration wells may be classified as (1) wildcat, drilled in an unproven area; (2) field extension or step-out, drilled in an unproven area to extend the proved limits of a field; or (3) deep test, drilled within a field area but to unproven deeper zones.

Development wells are wells drilled in proven territory in a field to complete a pattern of production.

With a continuous or unconventional resource play such as the Marcellus Shale, the "exploration drilling" phase is focused on determining if the shale can be stimulated in such a manner as to obtain gas in sufficient rates and volumes to make the endeavor economical. More importantly, the "exploration" phase is designed to ascertain whether the formation is receptive to a process that is economical (e.g., horizontal wellbores with multi-stage hydraulic fracture treatments) and repeatable. Basically, the driller is seeking to determine whether a technical and financial "assembly line" can be applied to the geology of the shale to make a reasonable rate of return.

Figure X shows the geological differences between the "conventional" oil and gas pools historically sought by the industry and the emerging "unconventional" or "continuous resource" plays now garnering so much attention. In conventional plays, much of the risk is geological. Is there good reservoir rock? Is there a geologic trapping mechanism? Have hydrocarbons migrated into and become trapped in sufficient volumes within the reservoir rock? As to these conventional pools, the exploration well's primary purpose is to address the geologic risk.

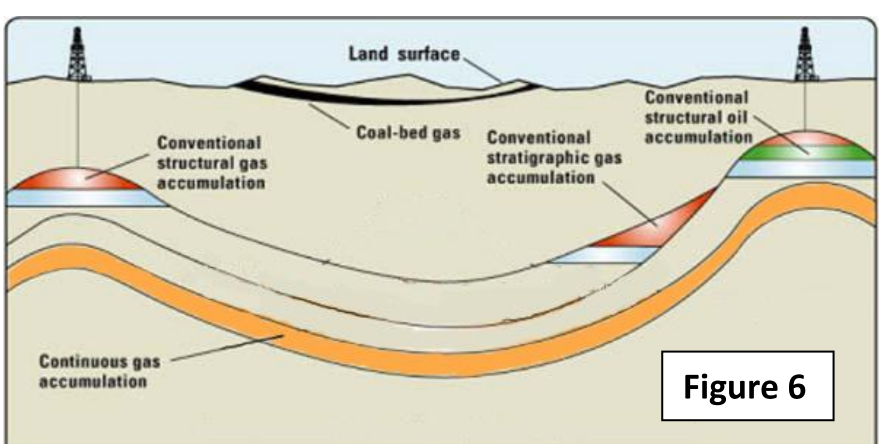


Figure 6

In unconventional plays, the geological risk is exceedingly lower than for conventional targets. For example, the depth and areal extent of the Marcellus is well known. Enough geologic information is already available to have mapped the net feet of organic rich shale for the Marcellus. True, additional drilling will hone the accuracy of existing maps, but industry activity demonstrates that the primary risks have already shifted from geological to technical and financial. Companies are leasing large acreages at highly competitive prices far from the nearest Marcellus well because, in practice, there is little need for a "discovery" well.

While the "intent" of a well as exploration or development in the Delaware River Basin is inarguable, there can be little doubt that the "first" well establishes the access route and operational location of perhaps decades of drilling and production activity.

Environmental protection from the adverse impacts of an activity hinges on best management practices that consider time, place, and manner. Distance between an activity and the resource at risk is fundamental to that resource's protection. Eliminating the "place" consideration is perhaps the most serious handicap that could be put upon an environmental protection regulatory scheme.

Scope of Anticipated Marcellus Shale Development

Development of the Marcellus is currently following the pattern of other continuous gas shale plays, but at a faster pace.

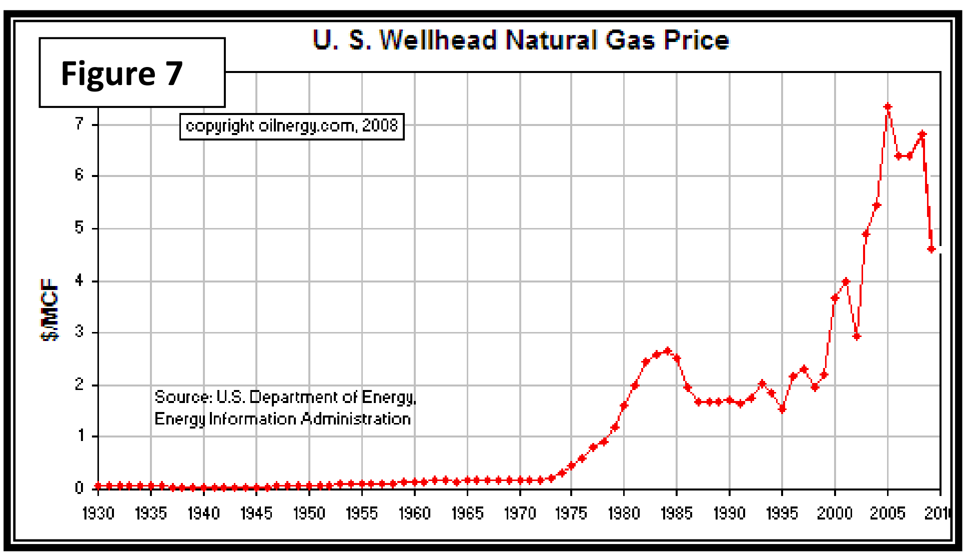


Figure 7

With natural gas prices off the peaks of the last few years (Figure 7), drilling has generally slowed in gas shales. However, the Marcellus Shale drilling activity has bucked the trends of others. This probably has much to do with the stage of development.

During the early phase of leasing and drilling, holding leases by production has a strong influence on drilling activity. Drillers have an incentive to begin production before a lease expires in order to avoid additional transaction costs and the potential for less favorable terms under a re-negotiated agreement. Once leases are secured by production, supply and demand (natural gas wellhead prices) will have a more profound influence on the rate of development.

The moratorium on production well approvals in the Delaware Basin imposed by the Commission in May of 2010 pending promulgation of new DRBC regulations, no doubt has raised concerns among some lessors (landowners) and their lessee operators that leases will expire before DRBC approvals are issued. It is certainly likely that the existence of an exploration well in the ground and capable of conversion to production may provide both landowner and operator with some comfort that they are in a position to proceed as soon as rules are adopted and approvals can be processed. It is also possible that the Commission's moratorium might inadvertently create an incentive for project sponsors to classify their wells as exploratory in order to meet lease obligations and be poised to produce when the regulations are in place. By allowing only a limited number of exploration wells to proceed, the Executive Director appears to have balanced the interests of those who had relied on a previous exemption to advance their exploratory well projects. Importantly, she also closed off the potential for a wave of exploratory wells to be drilled without any DRBC review as to their placement vis `a vis valued water resources.

Spacing of oil and gas wells ordinarily is dictated not by environmental concerns but by the extent of the area from which a single well can extract the maximum amount of commercially recoverable oil or gas. The spacing histories of the Barnett, Fayetteville, Antrim, New Albany, Ohio, and Woodford shales as shown in Table 1 all trend from larger to smaller spacing units over time. For the Marcellus Shale, it is reasonable to expect 320-acre or 160-acre spacing initially, and eventually some areas experiencing infill drilling to 80-acre or even 40-acre spacing should infill drilling produce an economic return.

Table 1 – Sample of Well Spacing in Gas Shale Plays

Gas Shale Name	States	Well Spacing
Barnett Shale	TX	• 40- to 160-acre spacing typical • 20-acre spacing being tested
Fayetteville Shale	AR	• 40-acre spacing by rule (Arkansas Oil and Gas Commission Rule B-43) • 80- to 160-acre spacing in practice • 60-acre spacing being tested
New Albany Shale	IL, IN, KY	• 160-acre spacing initially • 80-acre spacing now common
Antrim Shale	MI	• 40- to 80-acre spacing
Ohio Shale	OH	• 40- to 160-acre spacing
Woodford Shale	OK	• 640-acre spacing initially • 160-acre spacing now common • 80-acre spacing proving effective • 40-acre spacing being tested
Marcellus Shale	NY, PA, OH, WV	• 160- to 320-acre spacing initially • 40- to 80-acre spacing can be expected

Source: Modified from Sumi 2008.

Using 80% of the 5,000 square mile Marcellus area in the Delaware River Basin developed at 160-acre spacing yields 16,000 wells. An 80-acre spacing pattern would result in doubling the number to 32,000 wells. Of course, voluntary restrictions by private agreement may limit this number. For example, NWPOA's current lease with Newfield Appalachia PA, LLC provides for an 80-acre spacing equivalent by means of a single 8-well drilling pad per each square mile. Such private agreements of course are subject to change by contracting parties.

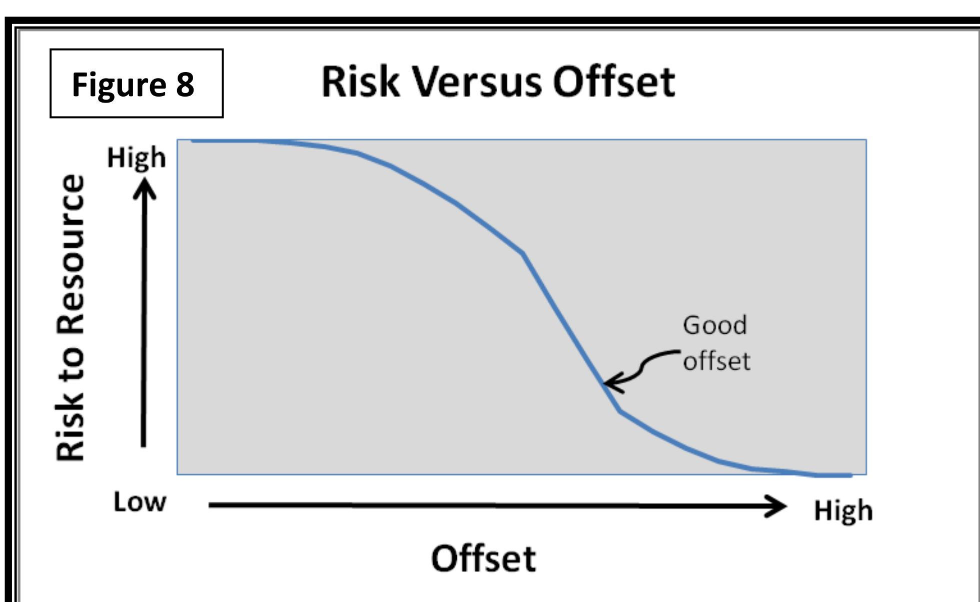
One of the benefits of horizontal well completions is the ability to site multiple wells on one location. So while each multi-well pad constructed for a group of six or eight or ten horizontal wells may occupy a much larger land area than the pad for a single vertical well, the overall disturbance on an acres/well basis could ultimately be much less than for a traditional vertical well build-out. Also, with the capability to drill horizontal sections ranging up to 5,000 feet, there may be opportunities to site surface operations away from sensitive areas, such as the basin's Special Protection Waters, without losing the ability to recover the gas. However, if the Commission intends to implement its Special Protection Waters program, it will need to find ways to incentivize or compel the industry to develop at a pace and manner that allows for natural gas extraction while simultaneously optimizing water resource protection. Otherwise, my experience indicates that water resources will not be a priority in the industry's rate-of-development, well spacing, and siting equations.

In addition to the Marcellus Shale, the Utica Shale may be targeted for natural gas production within the Delaware River Basin. One shale play on top of another could in theory double the environmental impacts, in particular those related to water resource demands and surface disposal of waste streams to surface waters. In practice however, technical innovation and economic constraints would produce impacts less than double, but certainly greater than one.

Risks to the Water Resource from Surface Operations of Natural Gas Exploratory Well Drilling

For purposes of this report, "exploration" drilling consists of access road and well pad construction followed by drilling and casing of a vertical well through the Marcellus Shale. The effects on and risks to surface and groundwater from well completion, hydraulic fracture stimulation, development well drilling on the same site, installation of gas handling facilities, gathering lines, compressors and waste handling areas, and long-term production and maintenance of wells are directly proportional to the activities' proximity to the water resources. That proximity of drilling is key to water resource protection is acknowledged by the many federal and state oil and gas regulatory agencies that include minimum setbacks in their policies and regulations. It is reasonable to conclude that site selection for both well pads and access roads is a crucial component of mitigating risks and effects on water resources. As noted above, the locations of the exploration well and its access road set the stage for the location of the activities that follow.

Figure 8 is a graphical representation of a minimum offset being used to reduce the risk



to a resource. At some point the incremental offset begins to accelerate the rate of risk reduction to the resource. This is typically the area where site specific environmental conditions begin to provide time and space to react to accidents or spills so as to prevent or minimize impacts to the resource. Finally, offsets become great enough that incremental offset distance provides very little additional risk reduction. Each site is unique. Environmental conditions may provide natural or human-made barriers that would justify a reduced setback. Site conditions such as steep slopes or annually high precipitation can enhance pathways between the activity and resource, and thus justify greater setbacks. Regulatory establishment of a “good offset” that considers both the activities and the average environmental conditions provides a beginning point for site location considerations. Additionally, having a regulatory process for adjusting site-specific setbacks – either lower or higher – based on project and environmental conditions is the key to successful use of setbacks.

The remainder of this section highlights the primary risks to water resources from Marcellus Shale exploration well drilling. Perfect execution by industry and regulatory agencies is necessary to lower these risks to a level that will not result in measurable impacts to water resources – at least on a localized and short-term basis. Since it is unrealistic to expect perfection over the course of time, it is reasonable to conclude that not only is there a potential for measurable impacts to water resources, but that measurable impacts will occur.

Erosion and Sedimentation

Erosion is a natural process by which the surface of the land is worn away by water, wind or chemical action. Erosion and subsequent deposition of eroded materials to surface waters (sedimentation) are a primary threat to water quality associated with road and well pad construction activities. Realizing the potential for erosion and sedimentation associated with oil and gas development to adversely impact water resources, state and federal oil and gas management agencies have developed best management practices and require operators to use them.

Road and pad construction for an exploration well often involves extensive earth disturbance that can speed erosion. For a vertical Marcellus well, the pad size will most likely be between 2 and 3 acres of level, usable space just to support the drilling operations. Construction on sloped areas can substantially increase the area of disturbance when considering cut and fill requirements.

Vegetation is a significant check on natural erosion rates. Accelerated erosion occurs when human activities increase the rate of erosion above the natural processes.

Road and well pad construction necessitate removal of the vegetation that serves to check the natural rates of erosion. A well pad and half-mile access road may require a footprint of approximately 4 acres on level ground. Placement of roads and pads in the hilly terrain of the Upper Delaware River Basin will involve some degree of cut and fill construction techniques on most, if not all, projects. This increases both the area of disturbance (by up to 50% on slopes exceeding 15 degrees) and the efforts required to mitigate erosion and sedimentation.

In general, the proximity of roads and well pads to surface waters increases the risk that erosion and sedimentation will cause measureable impacts on water quality. Stream crossings will be unavoidable for some projects.

Materials Used or Generated Onsite Create a Potential Source of Water Contamination

In well drilling, sources of potential contamination to surface and ground water include spills of fuels, lubricants, and chemicals used in mud systems or air drilling systems, as well as fluid (or “brine”) returned from deep rock formations. While amounts vary, it would not be uncommon to have several thousand gallons of diesel fuel stored on site at any given time, and 4 or 5 fuel deliveries each week. For an 8,500-foot vertical Marcellus Shale well, that could be 20 fuel deliveries. Chemicals such as pH buffers, water loss agents, friction reducers, corrosion inhibitors, biocides, foaming agents, and others are typically used in very low concentrations within mud or air drilling systems. However, these chemicals are stored in concentrated liquid or solid form on location, and if handled improperly, are sources of potential contamination of surface and ground water.

Drill cuttings from an 8,500-foot Marcellus Shale well can amount to approximately 200 cubic yards of material. A portion of the drill cuttings may come from formations bearing heavy metals and elevated levels of naturally occurring radioactive materials (NORM). Shales are also known to contain minerals such as pyrite and sulfides, which when brought to the surface and exposed to air can break down to form sulfuric acid and iron hydroxide. The acid in turn can mobilize metals in the cuttings, creating a potential source of contamination to both surface and ground waters.

If air drilling is utilized, as compressed air and additives (the “air system”) are pumped down the hole, water, additives, drill cuttings and formation fluid are returned to the surface. The formation fluid, or “brine” consists of water into which salts and other minerals have leached from the surrounding rock for millennia. Formation fluid from the Marcellus formation tends to be extremely high in total dissolved solids (TDS). With concentrations of as much as 300,000 mg/l of TDS, Marcellus brine is five times as salty as ocean water (35,000 mg/l TDS) (PA EQB 2010). In addition to chlorides, this solution carries high concentrations of barium and strontium and may be radioactive due to the presence of naturally-occurring radium. Although quantities produced during construction of a vertical exploration well will be much smaller than for a horizontal or production well, if not carefully contained, brines or oily water can be sources of contamination to both surface and ground water.

Water Needs

Well drilling requires the use of water. The volume of water varies depending on well depth and the mud system used to drill the well. A typical Marcellus Shale well drilled vertically to 8,500 feet in depth may require 50,000 to 300,000 gallons of water, the lesser volume being associated with air drilling operations. The source of water and the withdrawal methods used may cause or accelerate bank erosion, diminish streamflow, elevate water temperature, and introduce invasive species, all of which may potentially adversely affect water quality and aquatic biota.

Mitigation of Risks to Water Resources

A comprehensive regulatory system helps to ensure that each of the identified risks to water resources is reduced by mandatory use of established protective management practices. The idea that regulation is a necessary means of protecting water (and other resources) from the adverse effects of oil and gas development activities is virtually uncontested, as evidenced by existing state regulatory regimes.

For Marcellus Shale "exploration" well drilling in the Delaware River Basin, examples of best management practices that in my view should be applied in the land development aspects of drilling to protect water resources include, but are not limited to:

- Use and upgrade of existing roads, rather than construction of new roads
- Implementation of strong erosion and sedimentation control plans
- Seasonal or other timing restrictions to avoid construction during periods of high precipitation
- Avoidance of steep slopes
- Well site construction that conforms to the landscape in lieu of insistence on rectangular sites for all locations
- Appropriate setbacks from surface waters, including wetlands
- Minimization of stream crossings
- Stormwater management that ensures discharges are uncontaminated and do not exacerbate erosion
- Strong spill prevention, containment, and response equipment, structures, and methods, designed and implemented throughout the construction and drilling process (for example, bermed locations, with appropriate placement of impermeable liners beneath potential spill sources)
- Closed-loop drilling systems in lieu of earthen (including lined) pits
- Offsite disposal of drilling wastes for sites in close proximity to surface waters or with near-surface groundwater
- Exotic species control
- Establishment of adequate performance bonding and liability insurance standards to ensure that remediation will be provided in the event of accidents or poor operator performance that results in impacts to water resources

In the experience of the National Park Service, it can be fairly said that the most environmentally conscientious operators willingly, but only minimally, comply with those regulatory requirements that serve only to protect a natural, cultural, or recreational resource. [Note: There are many actions taken by industry that serve operational or financial purposes and coincidentally serve to reduce environmental impacts. For example, drilling multiple wells from a single well pad has both operational/financial and environmental benefits.] Any regulatory agency can and reasonably should expect no more from an operator than full compliance with its regulations. The point being that if the public depends on operators in general to voluntarily use measures such as "best management practices" to meet an agency's standards of resource protection, the public will be disappointed. This is because operators are sometimes willing to assume more environmental risk in exchange for a reduction in expense or acceleration of project completion (i.e., time to production).

The recent British Petroleum Mississippi Canyon Well #252 blowout is a spectacular example of a company making choices that increase the risk of an incident in an effort to reduce expenses or speed the time to production. While incidents of the scope experienced in the Gulf are not expected in the Marcellus, the Punxsutawney Hunting Club 36H well incident in Clearfield County, Pennsylvania, is a closer-to-home example of an operator's willingness to take on environmental and human health and safety risk in order to decrease costs or speed the time to production, while at the same time staying within, but perhaps testing the envelope, of regulatory requirements. This incident involved loss of well control during post stimulation cleanout activities. The Pennsylvania Department of Environmental Protection's (PA DEP) July 12, 2010 letter to operators states, "Over a period of 17 hours, gas and hydraulic fracturing wastewater flowed uncontrolled into the environment and impacted nearby waters." As a result of the post-incident investigation, PA DEP determined the operator used inadequate equipment and practices to maintain control of the well. The PA DEP issued further direction to the Marcellus Shale industry in Pennsylvania that mandated specific equipment and practices necessary to meet regulatory requirements of well control (PADEP July 2010).

Although the Punxsutawney Hunting Club incident occurred during operations associated with a production well, not an exploratory well, the incident illustrates that accidents will occur in development of natural gas, whether as a result of equipment failure, human error, or simply by miscalculations of human safety and environmental risk by project managers. Risk is the probability of an incident occurring multiplied by the consequences of the incident. Reducing the consequences of an incident can and should receive appropriate weighting when selecting the location of roads and well pads. The importance of selecting a well site in full consideration of distance and pathway between the well and the water resource cannot be overstated – particularly when the inevitable accident such as the Punxsutawney blowout occurs.

Simultaneous Regulation by NPS and Other Agencies

Oil and gas operators in units of the National Park System must comply with both NPS regulations and state oil and gas regulations. The National Park Service regulations are generally more restrictive than state regulations on surface use requirements. This does not mean some states may have lax environmental standards, but rather that states typically leave the bulk of surface use issues to be settled between the private landowners and the operators. It has never been the experience of the National Park Service that its rules and state rules contradict each other. Rather, they supplement each other with respect to various environmental issues.

Most states' oil and gas regulations include some provisions that serve to protect the environment and human health. For example, all states' rules contain provisions for the protection of fresh water and for public and worker safety. However, a primary focus of state regulations generally is the conservation of the oil and gas resource and protection of the associated ownership interests.

In contrast, the National Park Service's mission is to prevent or minimize damage to the environment and other resource values and insure that parks are left unimpaired for the enjoyment of future generations. To that end, the NPS controls nonfederal oil and gas development in parks under regulations codified at 36 CFR, Part 9, Subpart B (the "9B" regulations). These regulations oversee an activity that in large part also is regulated by the states – but with a different focus.

The NPS 9B regulations focus on surface use and groundwater issues and require that operators apply methods that will avoid or minimize impacts to park resources and values, as well as public health and safety. These priorities and constraints may also be addressed by state regulations, but they are the sole focus of the NPS program.

Reasonable time, place, and manner considerations are fundamental to the 9B regulation program.

Place. One of the strongest regulatory tools in the 9B regulations is establishment of a 500-foot setback of operations from surface waters (36 CFR §9.41(a)). This requirement gives the operator and the park resource manager a starting point in locating drilling or other operational sites. The regulations provide a process for increasing or easing the 500-foot setback requirement if the particular conditions of the project warrant an adjustment.

The National Park Service has undergone five park-specific planning efforts to furnish operators and park managers with guidance on implementing the 9B regulations, given the local environments, park uses, and the scope of operations – either ongoing or forecast. The planning effort in each case focused most intensively on identifying sensitive resource areas (e.g., surface waters, wetlands, endangered species habitat, high visitor use areas, etc.) and considering the level of expected impacts for various setbacks. These efforts have resulted in park-specific setbacks ranging from zero to 1,500 feet. For example, short-term foot-traffic-only recording operations for a seismic survey may occur within a wetland with negligible post-operational effects. Conversely, a full-scale drilling operation may require a much more substantial setback from a nature trail to retain a high quality visitor experience.

Manner. An example of how the natural gas drilling requirements imposed by most states and those required by the National Park Service differ relates to the handling of drilling muds and drill cuttings. Drilling muds and well cuttings may contain chemical and material contaminants, including petroleum products. Most states allow the use of earthen pits for storing muds during operations, and for ultimate disposal of drilling waste solids. The NPS requires the use of above ground tanks ("containerized mud systems"). Earthen pits are prone to leaks, which can go undetected for long periods of time and lead to costly cleanup. Above ground tanks provide a higher degree of environmental protection because leaks from the tanks are readily apparent, and the tanks are removed from the site upon completion of the drilling phase of operations. Many companies have voluntarily adopted the NPS approach outside of parks. However, the State of Texas, for example, does not require the use of tanks. Instead, it has developed guidance for Texas Statewide Rule No. 8 (TAC), Protection of Water, which regulates the use of earthen pits through a permitting system. As soil permeability and proximity to water increase, state rules "recommend" but do not require more stringent construction methods for such pits, including the use of leak detection.

Timing. The regulations adopted by most states do not include timing restrictions, though operators may necessarily have to time their operations to meet compliance with other federal laws such as the Endangered Species Act. The National Park Service uses daily, weekly, and seasonal timing restrictions to augment resource protection and visitor experience. For example, limiting oil/fuel hauling to daylight hours has been found to reduce accidental spills. Scheduling mobilization of equipment for a drilling operation to avoid times of heavy visitor use on weekends may serve an operator and park visitors by avoiding conditions adverse to both. Where water resources are of high value, additional protection may be afforded by avoiding construction of roads and pads during seasonally wet periods.

Overlapping NPS authority is sometimes used to back up state resources where the staff of state agencies, charged with a broad range of responsibilities and concerns, are spread thin. For instance, on the day that the surface casing for a well in Padre Island National Seashore is run and cemented, state inspectors for the area may have a dozen or more other active drilling sites, compliance responsibilities for several thousand well sites, and so on. The National Park Service wants 100 per cent monitoring/ inspection of casing and cementing activities. Although state inspectors may be unable to be present, the National Park Service can commit staff resources to ensure that the casing and cementing are completed to NPS standards.

Conclusion

My opinion based on some 18 years of experience with oil and gas development activities on lands managed by the National Park Service is that "exploration wells" have the potential, either individually or cumulatively, to have a substantial effect on water resources of the Delaware River Basin, and in particular, that these projects have the potential to cause "measurable change" to the exceptionally high quality of the basin's Special Protection Waters.

The "place" factor in the "time, place, and manner" equation is most important in terms of ability to protect an environmental resource such as water. The risks created by a poorly selected location cannot easily be overcome with even the best operational methods or timing. Conversely, proper site selection can do much to mitigate the effects of accidents or environmentally unsound practices.

Reverences

36 CFR §9.41. Code of Federal Regulations, Title 36 Chapter 1, Part 9, Subpart b: National Park Service, Minerals Management, Non-Federal Oil and Gas Rights, Operating standards.

36 CFR §9.41(a). Ibid. Section 9.41(a)

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Potential for Impairment of Freshwater Mussel Populations
in DRBC Special Protection Waters as a Consequence of
Natural Gas Exploratory Well Development

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November 23, 2010

Our testimony addresses the question of whether natural gas exploratory wells have the potential for a substantial effect on the quality of waters classified by the Delaware River Basin Commission (DRBC or "Commission") as Special Protection Waters (SPW), for which the Commission has established a policy of "no measurable change except towards natural conditions . . . ." *DRBC Water Quality Regulations* § 3.10.3 A.2. We focus on the water quality value and susceptibility to impairment of freshwater mussel populations, which both depend upon and contribute to the exceptional water quality of the main stem upper and middle Delaware River. We also highlight characteristics of the dwarf wedgemussel, a federally listed endangered species found in portions of the main stem upper Delaware River and its tributaries underlain by the Marcellus shale. The dwarf wedgemussel is particularly susceptible to siltation, hydrologic changes, exposure to contaminants, and losses of population caused by invasive species, all of which are likely to accompany the development of natural gas in the region, including the construction of exploratory wells. We contend that in light of the potential for adverse effects on water quality and aquatic resources as a result of natural gas exploratory well development, regulation by the Delaware River Basin Commission is warranted. Such regulation may help to prevent impairment, ensure that any water resource impacts, should they occur, are measured, and require that those responsible for causing damage to water quality and aquatic resources have the means and legal obligation to perform restoration.

I. Freshwater Mussel Status and Trends in the Delaware Basin

Freshwater mussels include abundant species that are vital for ecosystem function. These are also the most imperiled of all animals and plants in the Delaware River Basin, as elsewhere in North America (Williams et al. 1993.) This otherwise highly successful and diverse group has specific life history characteristics that contribute to their apparent sensitivity and have resulted in substantial declines in range and abundance of some species. These characteristics include a dependence upon populations of an unrelated species of fish for successful reproduction, low annual recruitment balanced by a long reproductive life-span, relative immobility, and filtering of water to extract food.

II. Mussel Assemblages in the Delaware River System

Population Abundance and Biodiversity

As a result of being undammed and well managed, the upper mainstem Delaware River retains healthy numbers of several native species of freshwater mussels (Lellis 2001, Lellis 2002). Although there are numerous state and federal listed imperiled species in the basin (e.g. dwarf wedgemussels), the numerical health of the collective mussel assemblage is sizeable in the river itself, extending down even into the tidal areas of the Delaware River.

Approximately 60 species of bivalve mollusks live in headwater streams and lakes of the Delaware basin as well as in the non-tidal main stem and other large tributaries, freshwater tidal areas, and in the brackish and saline portions of the Estuary (Kreeger and Kraeuter 2010).

Approximately 12-14 species are native freshwater mussels (Unionidae, Table 1) based on historical accounts (e.g., Ortmann 1919.) Numerous species of special concern to PA and NJ are known to remain in portions of the basin (Table 1) including the Upper Delaware. Although the status terminology varies among states, nine of the twelve remaining native species are deemed imperiled by New York, New Jersey, Pennsylvania, and/or the Federal Government, or are deemed to be globally imperiled (Table 1.)

Scientific Name	**Common Name**	**Conservation Status**			
		NY Status	**NJ Status**	**PA Status**	**Global/ Federal Status**
Alasmidonta heterodon	Dwarf wedgemussel	Critically imperiled/ **Endangered**	Critically imperiled/ **Endangered**	Critically imperiled/ **Endangered**	Critically imperiled/ **Endangered**
Alasmidonta undulata	Triangle floater	Apparently secure	Imperiled/ **Threatened**	Vulnerable	Apparently secure
Alasmidonta varicosa	Brook floater	Critically imperiled/ **Threatened**	Critically imperiled/ **Endangered**	Imperiled	Vulnerable/ **Species of concern**
Anodonta implicata	Alewife floater	Critically imperiled	Secure	Not ranked	Secure
Elliptio complanata	Eastern Elliptio	Secure	Secure	Secure	Secure
Lampsilis cariosa	Yellow lampmussel	Vulnerable	Imperiled/ **Threatened**	Vulnerable	Vulnerable
Lampsilis radiata	Eastern lampmussel	Apparently secure	Imperiled/ **Threatened**	Critically imperiled	Secure
Leptodea ochracea	Tidewater mucket	Critically imperiled	Imperiled/ **Threatened**	Critically imperiled/ extirpated	Vulnerable
Ligumia nasuta	Eastern pondmussel	Vulnerable	Critically imperiled/ **Threatened**	Critically imperiled	Apparently secure
Maragatifera maragatifera	Eastern pearlshell	Imperiled	Not ranked Proposed	Critically imperiled/ **Endangered**	Apparently secure

			Endangered		
Pyganodon cataracta	Eastern floater	Apparently secure	Secure	Vulnerable	Secure
Strophitus undulatus	Creeper	Apparently secure	Vulnerable/ **Species of concern**	Apparently secure	Secure

Table 1. Conservation status of native freshwater mussel species of the Delaware River watershed. Bold text indicates legally protected species status by state. Natural Heritage status accessed on NatureServe (www.natureserve.org) on November 16, 2010.

Within the Delaware basin, colonies of dwarf wedgemussels, a federally listed endangered species, currently are found only in portions of the main stem upper Delaware River and in four tributaries – the Neversink River, within the drainage area of DRBC Special Protection Waters in New York State, and the Flat Brook/Little Flat Brook, Paulins Kill River and Pequest River in New Jersey. The distribution of dwarf wedgemussels was once much wider across the mid-Atlantic watersheds than it is today.

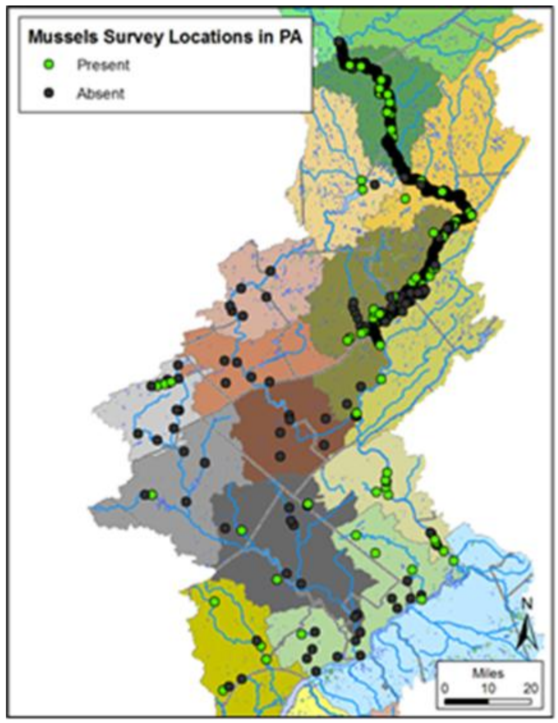

Figure 1. Presence and absence of freshwater mussels in Pennsylvania locations where they were historically reported as surveyed by various researchers since 1980.

The natural mixed-species assemblage of mussels would have consisted of aggregated populations of numerous species, occupying different niches (benthic habitats) within the stream, and collectively filtering a tremendous amount of water. Today, only one of our native 12+ mussel species can be readily found (*Elliptio complanata*). Unfortunately, mussel abundance appears greatly reduced in virtually all tributary streams and rivers in the Delaware River Basin. (PDE 2008.)

Based on the limited current distribution of mussels of any species in tributary streams (<10% in southeast PA, limited surveys elsewhere, Fig. 1), and the patchiness and low mussel abundance (<1 m^2) within streams where they are found (often only in wooded reaches), the healthy assemblages that exist in the main stem and tributaries of the Upper Delaware are particularly valuable and require protection.

Preservation of Existing Colonies is Critical to Stemming Mussel Declines

A number of factors make it critically important that existing colonies be preserved to serve as broodstock for restoring populations to streams from which they have been lost.

Mussels likely become extirpated from streams because of either: 1) general impaired water or habitat quality, 2) specific incidents (i.e. spills) that cause acute mortality in a single event, 3) overharvesting/predation, or 4) loss of fish host species to support larval growth and distribution.

Once extirpated from a stream or reach, mussels are not able to recolonize easily, particularly if there is no longer broodstock nearby. In some tributaries, dams and other impediments to fish passage may block dispersal of juveniles (via fish hosts, see life history below) back into the stream (McMahon 1991). Most mussels have a long lifespan (30-100 years) and don't reproduce until at least 8 years old. Therefore, even if conditions permit redistribution via fish hosts, recolonization and recovery can take decades.

Remaining mussel beds in the Delaware River are vulnerable to spills and land-based development. Protection of the existing metapopulation includes ensuring that it does not become further fragmented, less able to disperse and exchange genes, and as a result, less resilient.

III. Importance of Freshwater Mussels

There are societal and ecological reasons for maintaining large populations of filter feeders in aquatic ecosystems. Where abundant, they help to maintain water quality, stabilize substrates, decrease erosion, and create beneficial habitat complexity. Some species are also commercially and historically important. Filter-feeders are effective at accumulating many classes of contaminants and so are useful in assessing water and sediment contamination in specific areas and for specific time periods. The health of individual bivalves and assemblages of bivalves can directly indicate the health of the aquatic ecosystem.

Ecosystem Function Values

Freshwater mussels, like most bivalves, are considered "ecosystem engineers" because they modify habitat complexity and improve water quality, often dominating the ecology of rivers and streams where they are still abundant. Similar to oyster and coral reefs, these animals form dense assemblages that create habitat conditions beneficial for other organisms. The habitat benefits are myriad, including physical, chemical, and biological modifications. They help to stabilize stream channels and decrease bed transport during high flow events (physical). The vertical structure of large-bodied mussels also furnishes stable microhabitats for benthic macroinvertebrates and fish (physical). Mussel shells protruding from the bottom increase turbulent mixing in the benthic boundary layer and provide refugia for other fauna.

Through their biodeposits (agglutinated mussel feces and pseudofeces), mussels enrich sediments (Vanni 2002, Howard and Cuffey 2005) with organic materials and biochemical compounds (chemical) providing for enhanced benthic algal production and greater food resources for other benthic fauna (biological).

Although mussel beds provide many ecosystem services such as streambed stabilization and enrichment of sediments for other animals and plants, they are most valued for their water processing ability. Mussels improve water quality by removing suspended particulates through filter-feeding. Each adult mussel filters liters of water per day during the growing season, and the combined biofiltration by beds of mussels in healthy streams may exceed the system's downstream flushing volume. For instance, Dr. Kreeger estimated that a relic population of 500,000 mussels on the lower Brandywine River in Pennsylvania still filters more than 1 billion liters and removes 26 metric tons of dry total suspended solids (TSS) each summer season. This population is old, may not be reproducing, and represents a fraction of the system's carrying capacity for mussels. Approximately 4 billion *E. complanata* are estimated to reside in the Delaware River Basin today and they collectively filter about 10 billion liters of water per hour in the summer (Kreeger, unpublished).

Water quality and mussel abundance in the main stem and tributaries affect the ecosystem health of the Delaware Estuary. Kreeger and Kraeuter (2010) estimated that populations of all bivalve species in the Delaware Estuary watershed collectively filter more than 100 billion liters of water every hour during warmer seasons (10^8 m^3 hr^{-1}). If true, this represents about 2500 times the volume of freshwater entering the tidal estuary every hour (Kreeger and Kraeuter 2010.) Still, many streams contain no mussels at all, and others, such as the lower Brandywine, host older populations that may not be reproducing.

Biofiltration by mussels has direct implications for reduction of impacts of stormwater runoff and particulate nutrient control. Since much of the material filtered from the water column (e.g. particle bound nutrients, phytoplankton) is metabolized and then either used by the mussels or transformed into usable materials by other organisms, mussels facilitate nutrient control in streams and rivers.

Other important ecosystem functions include serving as prey for wildlife, biogeochemical cycling and remineralization, and in some areas facilitation of microbial denitrification. Freshwater mussels are eaten by many mammals and birds (van Tets 1994, Tyrrell and Hornbach 1998). Mussels therefore represent important links in aquatic food webs by feeding on microscopic matter at the base of the food chain and in turn being eaten by secondary consumers such as vertebrates.

In healthy rivers such as the main stem upper Delaware River where mussels are numerous, base-of–food-web conditions are richer and ecological turnover rates higher, compared to streams with few mussels.

In summary, healthy beds of mussels provide a multitude of structural and functional services including nutrient sequestration and cycling, substrate stabilization, suspended sediment removal, and the transfer of particulate matter from the water column and into easily assimilated foods for other aquatic species, including fish (Bauer and Wächtler 2001, Pusch et al. 2001, Kreeger 2004).

Bioindicator Value

Mussels are long-lived "sentinel bioindicators", meaning their abundance, biodiversity, and physiological health can tell us a great deal about overall environmental conditions (Kreeger et al. 2002; Martel et al. 2003, PDE 2008). Being relatively sessile, long-lived (up to 100 years), and sensitive to environmental conditions, freshwater mussels are excellent bioindicators of long-term changes in watershed condition. Due to their limited mobility that prohibits their movement to escape suboptimal environmental conditions, mussel fitness and population vigor is therefore directly indicative of local conditions. In addition, they are indicators of long-term habitat stability because their riverbed habitat is dependent on channel hydraulics and sediment transport.

Internationally, suspension-feeding bivalves have long been considered to be among the best bioindicators of aquatic ecosystems (Dame 1996). For example, in 1976 the U.S. instituted the “Mussel Watch Monitoring Program” to examine the environmental impact of pollution in aquatic ecosystems. Although initially conceived as including bivalves in marine, estuarine and freshwater habitats, the concept was embraced primarily by scientists and resource managers in marine habitats, and the program thereafter focused on marine species such as oysters and blue mussels. The program has been extended to the United Kingdom, France, Canada, Australia, Japan, Taiwan, India, South Africa and the Soviet Republic. In 1986, the U.S. program evolved into the National Status and Trends Mussel Watch Project. Today, a diverse array of chemical and biological contaminants is uniformly analyzed in bivalve tissue from more than 280 coastal sites in the U.S. Mussel Watch.

A comparable, bivalve-based biological monitoring program for freshwater systems is technically feasible but not yet developed, although many studies are now using caged mussels to monitor water quality (e.g., Kreeger et al. 2002).

Due to their unparalleled ability to filter water and improve water quality, suspension-feeding bivalves such as mussels are also perceived as top restoration targets, because enhanced mussel populations will promote positive feedbacks for water and habitat quality, which then benefit mussels. Again, where we are fortunate to have healthy mussel colonies, it is essential that they be preserved.

IV. Potential for Impairment of Freshwater Mussels as a Result of Activities Associated with Development of Natural Gas Exploratory Wells

The greatest diversity and abundance of mussels are associated with clean-swept sand and gravel substrates, but as largely sessile organisms, the complex life history traits of mussels make it possible for populations to thrive in a highly dynamic environment where rapid changes in flow and water quality can occur at each rain event. These same adaptations, however, limit the ability of freshwater mussels to withstand, or recover from, lethal and chronic impacts to which these animals are sensitive, such as increased siltation, water quality alteration, hydrologic alteration, and introduced species. These factors are discussed in greater detail below.

Sedimentation

Mortality, injury and stress to mussels from siltation and other types of sedimentation caused by onshore construction (*i.e.*, staging areas and access road use) is more likely to occur near the source, but erosion and siltation in tributaries at distant locations in the watershed can cause damage when this material is flushed downstream. Silt in the form of increased turbidity and suspended sediment transport is detrimental to mussel health and habitat because it reduces the depth of light penetration leading to alteration of primary productivity, decreases oxygen levels, increases water temperature, irritates or clogs mussel gills, and deposits silt on the substrate.

High turbidity may also interfere with sight lures, such as conglutinates, which attract host fish. Silt that settles from the water column can smother, bury and/or clog the gills of freshwater mussels unable to avoid these effects due to the extent of siltation or particular phase of the animals' annual life history (for example, gravid female mussels hold eggs and young within a specialized gill structure for weeks to months of a year).

Silt deposition also affects mussels by smothering the eggs or larvae of the fish host populations and by reducing food availability for either the fish or the mussels themselves. Siltation also may result in reduced dissolved oxygen and increased organic material at the substrate level (Ellis 1936, Harman 1974) even when it does not blanket the substrate due to quantity or local water velocity. Silt that settles between sand and gravel particles alters water flow, food and oxygen through the gravel. The interstitial space between sand and gravel is vital for spawning habitat and survival of young host fish and juvenile mussels. When this area becomes unsuitable for juvenile mussels, the population may be unable to reproduction even when the adults continue to survive. Finally, alteration of sediment grain size or excessive volumes of highly mobile soft sediments can increase the risk of scour and hinder the sediment-stabilization benefits of mussels

Excessive sedimentation reduces suitable bottom habitat for mussels, leading to reduced populations and reduced ecosystem services.

Excessive sedimentation can smother mussels, causing acute mortality, reduced populations and reduced ecosystem services.

Suspended Sediments

As filter feeders on microscopic food items, mussels are very susceptible to not only acute mortality due to smothering by silt but also high sediment loads in the water. High turbidity can directly hinder or prevent filter-feeding and respiration when mussels close their valves to avoid intake of silt. At sublethal levels, silt interferes with feeding and metabolism in general (Aldrige *et al*. 1987) because the mussels must divert more energy to sort silt particles from food, again resulting in starvation. Over time, this will reduce an animal's fitness through starvation and, at the population scale, decreases biofiltration services.

Finally, chemicals and compounds are often bound to, and mixed with, fine silts due to their high surface area-to -volume ratio and positive charge. While mussels have some ability to select particular particle sizes, they indiscriminately feed on vast numbers of these small particles, both organic and inorganic. Since particle capture is achieved on the soft tissue gills, which are also used for gas exchange (countercurrent), they have a high degree of exposure to any particle-associated chemicals. Furthermore, particle sorting is inefficient on the gills and labial palps prior to ingestion, so these animals unavoidably consume a variety of non-food particles. Although the chemical conditions in the digestive tract of the mussel can metabolize or mobilize some of the particle-associated contaminants, the high surface area-to -volume ratio of the very small particles exposes the animal to higher levels of toxic compounds than non-filter feeding species that consume larger prey.

In summary, filter feeding bivalves such as freshwater mussels are typically exposed to greater amounts of both waterborne dissolved contaminants and particle-associated contaminants than other aquatic organisms. Although some classes of contaminants can be broken down through metabolism, most tend to be bioaccumulated within the tissues of the animals, leading to either acute mortality, chronic stress, or mediation into the food web as other animals prey on mussels. For these reasons, bivalves are regarded as sentinel bioindicators around the world; e.g. by International Mussel Watch.

Excessive suspended sediments can impair feeding processes of mussels, leading to acute or chronic stress, reduced fitness and populations, and reduced ecosystem services.

Excessive suspended sediments that include contaminants can be efficiently captured and often efficiently bioaccumulated by mussels, leading to acute or chronic stress, reduced fitness and populations, and reduced ecosystem services, as well as facilitating contaminant entry to aquatic food webs.

<u>Brines, Contaminants, Water Quality</u>

Freshwater mussels are very sensitive to water quality and most classes of contaminants. Contaminant exposure can be particle-mediated (discussed above) or direct via dissolved compounds or attributes associated with the water (discussed here.) Because freshwater mussels feed and respire by filtering large volumes of water across many thin tissue layers (e.g., mantel, gills) they are highly exposed to changes in water quality. Therefore, dissolved toxins (e.g. heavy metals, TDS, biocides) are rapidly taken up by direct absorption (Russell and Gobas 1989, Metcalfe Smith et al. 1996, Riedel et al. 1998) and indirectly via the food (Wikfors et al. 1994).

Mussels can temporarily (hours to days) avoid some contaminants or poor water quality (e.g. low dissolved oxygen) by closing their shells, if the contaminant is of a type and at a concentration that the animal can detect.

Suboptimal water quality (e.g. high conductivity) or the presence of waterborne (dissolved) contaminants might cause acute toxicity and mortality by exceeding mussel tolerance levels.

Suboptimal water quality or the presence of contaminants will impart chronic toxicity to mussels, leading to decreased productivity or reproductive output due to stress or bioaccumulation of contaminants in soft tissues.

Stressed mussels consume more oxygen, especially at higher temperatures, potentially contributing to low DO in some deeper areas.

Physiological impairment due to acute or chronic toxicity from chemical or high solute exposure will reduce population-level ecosystem services, especially biofiltration services.

<u>Ecological Flows</u>

As aquatic organisms, freshwater mussels can survive only brief exposure to the atmosphere, particularly when high temperatures rapidly desiccate exposed mussels or when low air temperatures quickly freeze exposed mussels. Very low water can buffer temperature changes to some extent but low water velocity also allows for greater solar exposure in the summer and increased temperature (and decreases in dissolved oxygen) resulting in stress and mortality.

Similarly, low water during colder periods can result in the formation of ice, which in shallow water can reach the substrate, killing any mussels that freeze.

Riverine mussel species depend upon flow for not only food and oxygen but also to maintain water quality and shape the physical habitat. For example, reduced flow increases the likelihood of silt deposition in areas that may typically have velocity that precludes deposition, and contaminants in the water are increasingly concentrated during low flow events.

Sustained low flows, which could result from unregulated withdrawals from headwater streams, can alter quality and quantity of food, causing stress and reproductive failure for mussels.

Low flows can interfere with mussel reproduction if fish hosts are unavailable for mussel larvae, depending on seasonality.

Any physiological impairment due to extreme low or high temperatures associated with low flows or reduced habitable bottom will reduce population-level ecosystem services, especially biofiltration services.

<u>Invasive Species</u>

Activities that result in transfer of water between watersheds have also resulted in the transfer of exotic or invasive species that can cause direct mortality of freshwater mussels through predation, toxicity, and disease or through competition for food or habitat. Resource management agencies have taken great pains in recent years to educate the public and institute practices to prevent the accidental spread of invasive species by anglers, boaters and other recreationists.

Once established in a waterway, zebra mussel populations can become extremely abundant, directly competing with native mussels for food and rapidly covering any exposed surface of a mussel shell. In some locations, populations of native freshwater mussels have been severely reduced, or eliminated, after zebra mussel colonization that altered substrate, flow, and food availability.

In the fall of 2009, Dunkard Creek, a tributary of the Monongahela River located along the border of southwestern Pennsylvania and West Virginia experienced a massive aquatic kill affecting native freshwater mussels, fish and salamanders in a 43-mile reach of the Creek. The kill was associated with a spike in conductivity that may have caused direct mortality of freshwater mussels, but which also contributed to the bloom of an invasive marine alga *Prymnesium parvum* or "golden alga", a species that proliferates in saline waters more typical of coastal Texas than the Appalachian Mountains of Pennsylvania. Golden algae produce a toxin fatal to other aquatic organisms. The species had never been observed in Pennsylvania waters before the Dunkard Creek aquatic kill but is known to thrive at the higher TDS concentrations that are often associated with mining and drilling activity. Its presence in state waters makes spread of the species to other surface waters of the state highly likely. Transfer of water between basins increases the risk that invasive species like golden algae and zebra mussel will also be inadvertently introduced to the Delaware Basin. Once established, invasive species are very difficult or impossible to remove.

Loss of Forest Cover

Some mussel species depend on leaf litter inputs for their nutrition. Forest loss or fragmentation, especially in areas near streams and rivers, has the potential to significantly impair food quality and quantity as well as degrade stream habitats for mussels by altering nutritional conditions as well as physical and chemical habitat conditions. In streams of southeast Pennsylvania, for example, the only remaining mussel beds are found within heavily forested areas of watersheds such as the Brandywine and Ridley Creeks – mussel abundance decreases dramatically in stream reaches above and below forested segments.

Loss or fragmentation of forests near streams and rivers can impair mussels by altering nutrition support and degrading habitats, thereby reducing mussel populations and ecosystem services.

V. Special Considerations – Dwarf Wedgemussels

The federal endangered dwarf wedgemussel (*Alasmidonta heterodon*) is sensitive to many of the same threats described above for other native species of freshwater mussels. Siltation, hydrologic changes, and contaminants are among the threats to the species survival cited at the time it was listed in 1990 (55 FR 9447 9451; U.S. Fish and Wildlife Service 1993).

Dwarf wedgemussels have characteristics that likely increase their susceptibility to these factors. First, the species is small compared to most other freshwater mussel species, (in the range of about an inch in length); therefore, relatively minor siltation events can deposit a smothering silt layer that reaches a depth that animals cannot push above.

Second, although they require flowing water and occur in a diversity of habitats from small streams to large rivers, dwarf wedgemussel are a thin shelled species that could be easily transported during a scour event. Like many freshwater mussels, dwarf wedgemussel populations tend to occur in areas protected from high-flow events, such as side channels of larger rivers and lower gradient streams. These low to medium velocity areas tend to have finer particle size substrates. Infiltration of relatively smaller amounts of silt between sands and smaller gravel particles can quickly hinder interstitial flow.

In the Delaware River this microhabitat preferred by dwarf wedgemussels tends to be away from the main channel, and therefore it is very susceptible to low flow exposure and associated changes in temperature. The seasonality of low flow and temperature rise may also be critical for dwarf wedgemussel reproduction and nutrition since freshwater mussels require specific food conditions for reproductive conditioning.

Dwarf wedgemussels are sensitive to all of the factors listed in Sections I-IV and potentially more susceptible than other mussel species to sedimentation, low flow, and temperature extremes.

VI. Management Implications for Natural Gas Development

It is our opinion that natural gas drilling activities, including the construction of natural gas exploratory wells, pose a substantial risk to mussel populations in the Special Protection Waters of the Delaware River Basin but that this risk can be reduced through the mandatory use of protective management practices of the types set forth below:

A. Consistent use of avoidance and minimization measures across the supporting watershed in three states to reduce the risks that siltation, spills or other releases of contaminants, flow changes and the spread of invasive species could adversely affect mussel populations, including the federally listed dwarf wedgemussels that inhabit the upper Delaware River.

B. Implementation of stormwater management and erosion and sedimentation control practices to help minimize sources of sediment during and after construction of natural gas well pads, wells and impoundments.

C. Monitoring of water quality, flow conditions, and invasive species in potentially affected areas before, during and after project construction in order to identify where preventive measures may have failed, where they were effective, and where mitigation or restoration measures are warranted.

D. Monitoring of the diversity, fitness and abundance of freshwater mussel assemblages in potentially affected areas.

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Testimony of Erik Silldorff, Ph.D., Aquatic Biologist, Delaware River Basin Commission
Areas of Expertise: Aquatic Ecology, Ecological & Water Quality Assessment, Statistics

In the Matter of Delaware River Basin Commission Adjudicatory Administrative Hearing on Natural Gas Exploratory Wells
November 23, 2010

Overview

As a Ph.D. biologist with 18 years of professional experience, it is my view that exploratory well drilling projects within the drainage area of Delaware River Basin Special Protection Waters pose a substantial risk to the water quality and ecological condition of these waterways; this risk is expected to increase commensurately with the number of exploratory well projects. In this testimony, I describe many of the unique and sensitive attributes found within the Special Protection Waters region, including the high water quality which motivated the anti-degradation protections for the Delaware River and a number of its tributaries. I then review the multiple mechanisms by which exploratory well projects elevate the risks from environmental damage to these Special Protection Waters, and how the combined risks could lead to substantial effects on the resources, particularly when expanded in scale above the current level of activity. The juxtaposition of highly sensitive resources in an area that could see unprecedented industrial activity through exploratory well projects highlights the need for appropriate environmental safeguards, including review by the DRBC. Such safeguards provide a means to minimize the risks from exploratory wells, risks that could undermine the considerable efforts across the preceding decades to prevent degradation of these resources.

A. Physical Geography and Regulatory Context

The Delaware Basin covers an area of approximately 13,600 mi^2 across five states (NY, PA, NJ, DE, and MD). Within this area, the Marcellus Shale spans the drainages of the upper Schuylkill River, the upper Lehigh River, and the Lackawaxen River in PA; the Neversink River, the Mongaup River, and both the East and West Branches of the Delaware River in NY; as well as numerous direct tributaries to the Delaware River within this region of the basin (see Map 1). Among these drainages overlapping the Marcellus Shale, only the Schuylkill River falls outside of the area subject to DRBC's Special Protection Waters regulations. All other regions where the Marcellus Shale and the Delaware Basin overlap are included in the DRBC's Special Protection Waters jurisdiction, with an areal overlap of 4,669 mi^2 (69% of the total Special

Protection Waters drainage area of 6780 mi^2). Thus, the Marcellus formation underlies the large majority of the Special Protection Waters drainage for the DRBC. Other natural gas bearing formations that could be targeted for development (e.g., the Utica shale) extend beyond the Marcellus within the drainage area of the Special Protection Waters.

Within the Delaware River Basin's Water Quality Regulations, the Special Protection Program (§ 3.10.3 A.2) serves as the dominant component of DRBC's antidegradation program. Under these regulations, the quantitative measurement of water quality for both tributaries and the mainstem Delaware River at the time of designation is established as the benchmark for water quality regulations and assessments. These "existing" water quality conditions, codified in the regulations, are typically more protective of water quality and ecological conditions than the traditional effects-based water quality criteria promulgated by the DRBC, the states, and the federal government. For instance, DRBC's effects-based criterion in Zone 1D for in-stream Fecal Coliform is 200 cells/100 mL while Special Protection Waters benchmarks range from 20 to 100 cells/100 mL (*see* § 3.20.5 C.8 and Tables 2C, 2E, and 2I). Likewise, DRBC's effects-based criterion in Zone 1D for in-stream Dissolved Oxygen ranges from 4.0 to 5.0 mg/L while the Special Protection Waters benchmarks range from 7.9 to 8.5 mg/L (§ 3.20.5 C.1 and Tables 2C, 2E, and 2I). Furthermore, the intent and function of the Special Protection Waters regulation is to maintain water quality at the levels measured at the time of designation, unlike typical water quality programs operated through DRBC or the states where water quality is allowed to decline to the point where ambient or forecasted water quality simply attains the numeric criteria. Thus, the DRBC's Special Protection Waters regulations operate in a manner similar to the state and federal antidegradation programs under the Clean Water Act.

B. Delaware River Conditions

The Delaware River is an exceptional river within the eastern United States. The Delaware remains un-dammed on its mainstem for the 330 miles from the Atlantic Ocean to the confluence of its East Branch and West Branch at Hancock, NY, with free-flowing access to the principal headwaters extending an additional 60 miles via the East Branch Delaware and Beaver Kill rivers. As such, it is among the largest un-dammed rivers east of the Mississippi and one of the only large river systems draining to the Atlantic seaboard of the United States without a dam on its mainstem (Benke and Cushing 2005).

The free-flowing condition of the Delaware provides critical functions for the ecology of this large river. The most fundamental of these functions is the free access for migratory fish. The non-tidal Delaware River currently maintains strong populations or runs of many declining migratory fishes, including American eel, American shad, alewife, and blueback herring. The Delaware thus serves as an important component in the overall maintenance of these economic fisheries as well as the conservation of these fish species (ASMFC 2007, ASMFC 2009). Through the maintenance of these migratory fishes, the undammed river provides further indirect benefits to the ecosystem, as well. For example, recent evidence suggests the most dominant species of freshwater mussel in the Delaware River (*Elliptio complanata*) prefers American eels as its obligate host for juvenile glochidia (W.A. Lellis, USGS, *personal communication*). The free-flowing condition of the Delaware River, through its abundant eel population, therefore likely contributes to the Delaware's high densities of freshwater mussels, further maintaining the function and composition of the river's ecosystem in a form similar to what existed hundreds of year ago (Lellis 2001, Lellis 2002).

Lellis's surveys have also documented the persistence of 9 native mussel species in the mainstem Delaware River, indicating the Delaware remains a northeastern Atlantic slope stronghold for native mussels that are largely declining regionally and nationally (Bogan 1997, Strayer and Jirka 1997, Strayer et al. 2004, Nadeau 2008). These recent surveys on the Delaware River identified previously undiscovered populations of the dwarf wedgemussel (*Alasmidonta heterodon*) in the mainstem river between Hancock, NY, and Callicoon, NY, thus expanding the range of known populations of this Federally Endangered species within the Delaware Basin (Lellis 2001, Lellis 2002). It is significant to note that one of the largest remaining populations of *A.heterodon* lies within the Neversink River (USFWS 2007), located within the drainage area of the Special Protection Waters and underlain by the Marcellus Shale. The upper mainstem populations also lie in the region where the Special Protection Waters overlaps the Marcellus Shale. Thus, a diverse and imperiled mussel fauna occupies the central area within Special Protection Waters and could be affected by any negative environmental impacts from exploratory natural gas development projects in shale formations underlying the area.

High densities of freshwater bivalves can strongly affect water clarity and suspended materials (Caraco et al. 2006, Strayer et al. 2008). Thus, while the diversity and abundance of mussels benefits from the intact ecological conditions of the mainstem Delaware River and its headwater tributaries, the high water quality in the river likely is also enhanced by the high density of these large-bodied filter-feeding mussels.

The extraordinary quality of water within Special Protection Waters streams and rivers can readily be understood through a comparison of water quality data to surface water quality criteria. For instance, total dissolved solids (TDS) is a broad measure of the solid material contained in water but which passes through a standard filter (Eaton et al. 2005). Because of aesthetic issues with drinking water, water quality criteria for TDS have been recommended at 500 mg/L (USEPA 1986). Recent research and monitoring results indicate that high TDS likewise can negatively affect aquatic organisms (Pond et al. 2008), with states such as

Pennsylvania moving to protect both drinking water supplies and aquatic life with revised TDS requirements and criteria that closely match the 500 mg/L criteria recommended by the USEPA (PA Bulletin 2010). Current DRBC regulations likewise include a TDS water quality standard of 500 mg/L basin-wide, and also provide for a maximum increase in TDS of 33% over background by any proposed discharge (or group of discharges) as a means of minimizing effects on aquatic biota and keeping TDS at the more dilute levels seen through much of the basin (DRBC 2008a). Both the existing water quality defined by Special Protection Waters regulations and recent unpublished data (DRBC 2006-2009) indicate that TDS in Special Protection Waters streams and rivers typically ranges between 50 mg/L and 100 mg/L, five-to-ten times below the common 500 mg/L TDS criteria (DRBC 2008a, DRBC *unpublished data*). Thus, the Delaware River and its Special Protection Waters tributaries currently maintain concentrations of dissolved solids (including salts and other compounds) far below EPA-recommended criteria.

Nutrient concentrations in Special Protection Waters likewise are low relative to recommended or adopted nutrient criteria. This condition is notable given the high nutrient levels pervasive in waters throughout the United States and the water quality impairments caused by these excess nutrient levels (Dubrovsky et al. 2010). Among the DRBC and its four primary basin states, only New Jersey has numeric nutrient criteria for streams and only for phosphorus (100 μg/L TP; NJDEP 2010). In 2000 and 2001, the USEPA recommended candidate nutrient criteria for streams based solely on the distribution of nutrients at ecoregional reference sites; in the four ecoregions covering the Delaware River, total phosphorus recommendations ranged from 10 μg/L to 37 μg/L while total nitrogen recommendations ranged from 0.31mg/L to 0.71 mg/L (USEPA 2000a, USEPA 2000b, USEPA 2000c, USEPA 2001). Given these remarkably low recommendation from the USEPA, many states, tribes, and interstate agencies have sought to develop effects-based nutrient criteria rather than simply adopting the reference distribution-based criteria from the USEPA (USEPA 2008). New York is among the states developing such effects-based criteria, with recently-developed candidate criteria ranging from 30 to 65 μg/L for total phosphorus, and 0.7 mg/L for total nitrogen (Smith et al. 2006, Smith and Tran 2010). Yet the observed concentrations of nutrients in the mainstem Delaware for the Marcellus region have typically been around 30 μg/L total phosphorus and 0.50 mg/L total nitrogen (DRBC 2008). Recent results from tributaries around the Delaware Water Gap National Recreation Area (all within SPW; the PA tributaries overlapping Marcellus region) likewise indicate low nutrient concentrations, with median values around 20 μg/L for total phosphorus and 0.30 mg/L for total nitrogen (Hickman and Fischer 2007). Thus, both the mainstem Delaware River and SPW tributaries typically maintain nutrient concentrations in the range of the various recommended criteria, and far below the only established nutrient criterion in the basin of 100 μg/L total phosphorus (New Jersey). Again, for a water quality parameter central to maintaining the quality and health of the Delaware River and its tributaries, data indicate that the Delaware River maintains a quality comparable to regional reference conditions. Indeed, the Delaware River was selected as a regional reference site for the 2008-2009 National Rivers and Streams Assessment by USEPA (J. Kurtenbach, *personal communication*).

This combination of extraordinary qualities in a single river system helps maintain a high level of overall ecological health and diversity within the Special Protection Waters streams and rivers. This ecological health has been recognized, in part, through the disproportionate designation of streams in the region with the states' highest levels of anti-degradation protections. As noted above, such ecological distinction can also be seen in the high density of freshwater mussels in the Delaware River and the maintenance of the regional diversity of this increasingly imperiled group of organisms. Recent surveys of the fish community in the Delaware Water Gap National Recreation Area and the Upper Delaware Scenic & Recreational River likewise document the persistence and relatively strong populations of many native fishes (Horwitz et al. 2008).

The brook trout (*Salvelinus fontinalis*) is another species that provides evidence of the relatively intact ecological conditions of Special Protection Waters and their tributaries. While declining through much of its native range in the United States, brook trout populations within the Special Protection Waters watershed have persisted, and these populations remain vital for the conservation of this species both within the Delaware Basin and within the states of Pennsylvania, New Jersey, and New York (Hudy et al. 2008). Brook trout are noted for their sensitivity to elevated water temperatures, among other parameters, with forest clearing and riparian disturbance playing a key role in the decline of this species within the mid-Atlantic region (e.g., Stranko et al. 2008)

The extraordinary condition of the Delaware River is further demonstrated by its native aquatic plant community, with many species of aquatic plants continuing to thrive in the Delaware River (TNC 1994). Most notable among these is the single species from the family Podostomaceae within the United States, *Podostemum ceratophyllum* (common names of threadfoot or riverweed), a state-listed species across much of its distribution including New York (state-threatened; Young 2010). The Delaware River population remains the single largest remaining *Podostemum* population in the region, with a limited number of additional populations in Special Protection Waters tributaries (Munch 1993). This fast-water obligate plant is particularly relevant because of its acute sensitivity to mining activity, with complete elimination of the species in the Lehigh River and other Pennsylvania streams below the first mine drainage stream (Munch 1993). Thus, *Podostemum* may be among the most sensitive species to industrial activity within the Delaware basin, with the most abundant populations of this sensitive indicator within the overlapping areas of Marcellus Shale and Special Protection Waters.

More broadly, biological surveys of stream conditions within the Special Protection Waters region document the relatively pristine status of these streams' ecological structure. Such surveys are largely based on collections of benthic invertebrates, with the overall diversity across the Delaware Basin documented at more than 800 species (Bilger et al. 2005). These surveys have found the invertebrate communities to be diverse and abundant, maintaining a complement of sensitive species comparable to the highest quality reference streams for the region (DRBC 2008b, NYSDEC 2008, NJDEP 2009, NYSDEC 2010, DRBC 2010, PADEP 2010).

The Delaware River thus remains an exceptional river within the eastern United States, supporting diverse population of native mussels, fishes, plants, and invertebrates. Both its free-flowing status and its high water quality play critical roles in supporting and maintaining this healthy ecological condition. Moreover, many of these species are declining or imperiled within the larger region in which they historically thrived, further demonstrating the vital role the Delaware basin populations play in their overall conservation and underscoring the need to maintain the exceptional conditions upon which these species depend. The DRBC's Special Protection Waters program, adopted in 1992 (for control of point source discharges) and 1994 (for control on non-point source discharges), is the centerpiece of current protection efforts, but the region and the nation have invested in conserving the qualities of the non-tidal Delaware River for more than three decades, beginning with the designation of over 100 miles of the upper and middle Delaware to the federal Wild & Scenic Rivers System in 1978. Development of natural gas resources underlying the Special Protection Waters region must be undertaken deliberately and with great care if the qualities for which the region's exceptional water resources have been managed for more than three decades are to be protected.

C. Risk to SPW Resources Posed by Natural Gas Development

The exploration and development of natural gas shales, made possible by the application of horizontal drilling and hydraulic fracturing technologies, represents a new industrial activity for the Delaware River Basin. During the exploration phase alone, both novel landscape activities and expansions of existing human uses will occur. These activities and uses include:

- grading of exploratory well site pads
- construction of drilling pits
- storage of fuel and chemicals in previously undeveloped locations
- operation of heavy machinery
- improvement or construction of access roads
- clearing of natural vegetation, including forests
- mixing, use, and re-capture of drilling fluids

- transport of hazardous materials
- storage and disposal of deep-well drill cuttings
- direct interconnection of formerly isolated geologic formations
- diversion of surface waters

Each of these activities involves risks of environmental degradation affecting water resources. Such degradation can be direct (e.g., release of a toxic material into a stream) or indirect (e.g., hydrologic alterations from roads and site development), but the effects from these activities on water quality and aquatic organisms are well-established in the scientific literature. Below, I briefly review the mechanisms by which such environmental impacts can occur to document the risk that the development of natural gas exploratory wells may have a substantial adverse effect on DRBC's Special Protection Waters.

As I review these effects, it is important to note that the likelihood of environmental damage and ecological impacts increases with the extent of exploratory well drilling. For the majority of the impacts identified herein, limited exploratory well activity leads to a relatively low risk that environmental damage will be measureable and significant. Such low risk arises from two processes. First, the magnitude of the human alteration remains low for a small number of activities. Second, the likelihood of a single low-probability event (e.g., catastrophic spill) occurring with only a small number of actions remains low. Yet with increased activity, both of these processes increase. First, the magnitude of human alteration increases both locally and regionally, leading to greater effects within smaller watersheds and increased likelihood that effects will promulgate to larger streams and rivers. Second, low-probability events become increasingly likely to occur as the number of actions increases. To date, the exemptions allowed under the DRBC Supplemental Executive Director Determination (14-June-2010) provide opportunities for approximately twelve exploratory wells within the Delaware Basin. My understanding is that the actual number may be fewer. By contrast, the number of exploratory wells that could be developed and drilled in the Delaware basin without DRBC review in the absence of this Supplemental Determination would be unlimited and is not known. An increase by one to two orders of magnitude beyond the current activity would be accompanied by a commensurate increase in the risk to water quality and ecological conditions, with such an expansion possible if the exemption from DRBC review were to be extended indefinitely for all exploratory wells.

Site Preparation: Early in the exploration process, construction activities on the well-pad sites, including site grading and drilling pit excavation, increase the likelihood of higher sediment yields into receiving streams of DRBC's Special Protection Waters area (Wolman and Schick 1967, Williams et al. 2008). Such sedimentation within stream channels leads to multiple direct and indirect effects on water quality and biological communities (see reviews by Waters 1995, Wood and Armitage 1997). Reduced light penetration, increased bed scour, and direct deposition on benthic substrates negatively affect primary producers, the organisms at the base of these stream food webs. Sediment deposition can affect habitats and food quality of benthic invertebrates, and can cause direct fouling on filtering structures and on respiratory structures for different species. For fish, increases in fine sediments negatively affect spawning habitats and the survival of immature fish stages associated with sediments. Increased sediments also cause fouling of gills, and affect food quality and foraging efficiency. Increased sediment yield from exploratory well pad construction therefore provides many mechanisms for possible water quality changes, habitat alterations, and ecological effects throughout the aquatic food web.

Site Access: The expansion and improvement of the road network to transport equipment and materials to and from exploratory well pads provides multiple pathways for environmental contamination and degradation to Special Protection Waters. First, the roads themselves lead to negative effects on water quality and ecological conditions through altered hydrology, increased sediment yields, increased hydrocarbon and metals penetration into the landscape, altered stream channel dynamics, increases in water temperature, increased salt concentrations, interruption of dispersal pathways, and other mechanisms (Forman and Alexander 1998, Trombulak and Frissell 2000). Second, the development of exploratory wells will lead to increased industrial traffic and increased transport of fuels and chemicals into the region, thus increasing the probability of accidental spills of harmful compounds into surface waters and surficial aquifers (e.g., Hartle 2006). Third, road networks and increased road traffic elevate the risk from the introduction and spread of invasive species, putting native species and habitats at greater risk for ecological change and species replacements (Trombulak and Frissel 2000, Jodoin et al. 2008).

Operation and Maintenance of Exploratory Wells and Well Pads: The suite of industrial chemicals used in the operation and maintenance of exploratory wells and well pads includes many compounds with acute and chronic effects on a broad range of aquatic organisms (Cranford et al. 1999, Barlow and Kingston 2001, DRBC 2008a, USEPA 2009, Colburn et al. *in press*, Emofurieta and Odeh *in press*). The storage and use of fuels and industrial chemicals on drilling sites increases the risks that these materials will be released into surface waters. Recent widespread problems with fuel and chemical storage (e.g., MTBE groundwater contamination; see USEPA 2005) indicate that the risks from storage of such chemicals have not been eliminated. Moreover, the drilling of natural gas wells in shales involves the mixing, use, and re-capture of industrial chemicals on-site, further increasing the risk of accidents. The flammable and explosive potential from pressurized natural gas likewise presents a risk for catastrophic events, the severity of which may be magnified by the close proximity to industrial chemicals. The suite of these on-site activities further increases the risk of release of harmful chemicals into the surrounding landscape, leading to elevated risks to Special Protection Waters and the biological resources inhabiting them.

Storage and Disposal of Drilling Wastes: The storage and disposal of drill cuttings also poses a risk to Special Protection Waters. The combination of poorly weathered sediments, natural accumulations of metals and radioactive materials in formation rocks, and the addition of materials to assist in drilling operations provides a source of new material that is expected to differ strongly in composition and concentration compared to surficial soils in the Special Protection Waters region (see Resnikoff 2010). Weathering of these materials provides an additional source of environmental change, with documented effects from drill cuttings in other aquatic environments highlighting the potential for these materials to affect both water quality and the biota of Special Protection Waters (e.g., Trannum et al. 2010).

Hydrologic Alteration: The need to protect in-stream flows highlights an additional risk from the water withdrawals for exploratory wells (up to 100,000 gallons per well). The maintenance of in-stream flows, not solely during low flow periods but throughout the year and throughout the hydrologic cycle, has increasingly been recognized as a vital link in maintaining the ecological health of aquatic communities (Arthington et al. 2006, Acreman and Ferguson 2010). Seasonal flow cues, habitat protections at low and high flows, elimination of rapid flow ramping, and durations for low-flow and high-flow events are all important components to the flow regime that, if altered, can lead to negative effects on water quality and the living aquatic resources inhabiting streams and river. Thus, indiscriminate abstraction of water from Special Protection Waters streams and their tributaries has the potential to alter the hydrology of these systems and thus negatively affect these aquatic resources (e.g., Freeman and Marcinek 2006, Carlisle et al. 2010).

Invasive Species: In addition to the effects on hydrology, the diversion of surface water for exploratory wells creates a risk for invasive species introductions and spread. The Delaware River basin now harbors populations of the invasive diatom alga, *Didymosphenia geminata*, commonly known as "Didymo" or "rock snot" (NYDEC 2010, PFBC 2010). This stalked diatom can dominate the periphyton community in streams and can foul the stream substrate, with implications for the entire ecological food web (e.g., Shearer et al. 2007, Gillis and Callifour 2010). A potentially even more serious threat is the discovery of the golden alga, *Prymnesium parvum*, within Pennsylvania (Renner 2009). This species of algae thrives at higher TDS concentrations, a particularly high risk in areas with extensive mining activity. And most alarmingly, blooms of *P.parvum* can cause widespread mortality among many aquatic life forms from the production of toxins (e.g., Reynolds 2009). The use of water diversion equipment in connection with well drilling throughout the Special Protection Waters region of the Delaware Basin will increase the likelihood that one or more invasive species, such as Didymo or *P.parvum*, will be transported to new areas where the invasives may cause important shifts in the ecological systems.

In conclusion, exploratory well drilling both heightens the risks via expanded human activity and creates novel environmental threats to water quality for both the tributaries and the mainstem Delaware River designated as Special Protection Waters. When combined, these individual risks lead to a cumulative probability of impacts that is not trivial. Should these risks be maximized through inadequate oversight and insufficient regard for the environmental hazards, I believe the potential exists for substantial impacts to water quality of Special Protection Waters. Because the risk of substantial effects directly attributable to activities associated with exploratory well drilling or operations is manifest, a regulatory regime is needed to: (a) reduce the risks to the extent possible; (b) institute pre-and post-development monitoring requirements in order to identify measurable adverse effects and institute measures to stop degradation before it becomes irreversible; and (c) ensure that operators responsible for adverse effects have the resources necessary and the legal obligation to mitigate them.

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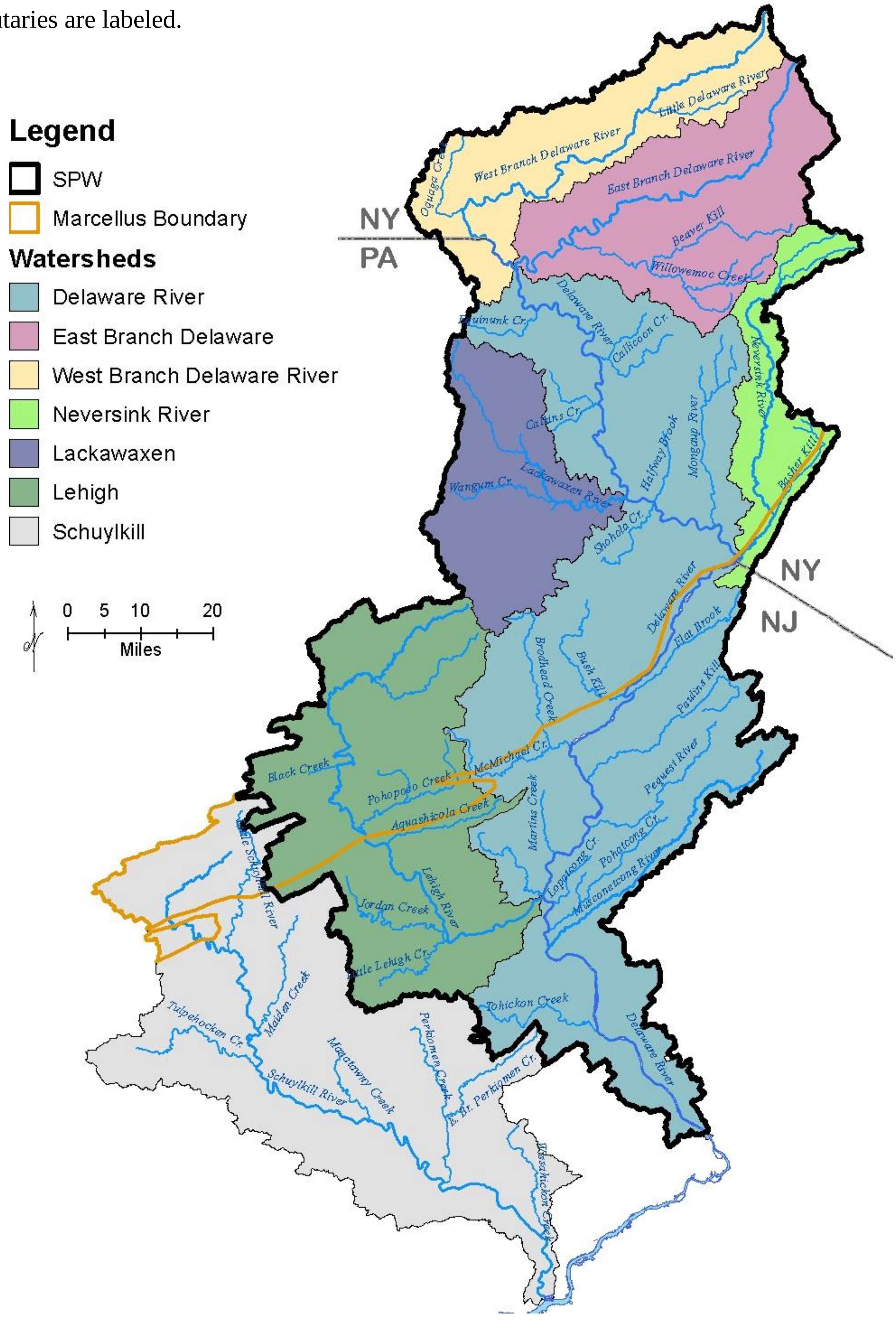
Map 1. Marcellus Shale and Special Protection Waters Areas within the Delaware River Basin. Major rivers within the region are highlighted with separate color schemes, and significant tributaries are labeled.



Expert Report on the Relationship Between Land Use and Stream Condition (as Measured by Water Chemistry and Aquatic Macroinvertebrates) in the Delaware River Basin

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Area of Expertise – Stream and river ecology, aquatic macroinvertebrates.

I. Link between land use and water chemistry – Although differences among sites can be a reflection of underlying geology, soils and vegetation covering the land, changes in land and water use also can change the concentrations of major ions, nutrients, and organic compounds, and introduce elements or compounds to a waterway that were not there naturally.

The link between water chemistry and underlying geology, soils and vegetation is well known, and covered in most limnology and stream ecology texts (e.g., Wetzel 2001 and Allan and Castillo 2007). Our research in the drinking water watersheds of New York City, which include the East and West Branches of the Delaware as well as the Neversink River and lower Hudson River tributaries (SWRC 2008), identified a number of differences in water chemistry among groups of sites that illustrate the variation in water chemistry (i.e., base cations) that occurs naturally. The gray dashed line in Figure 1 is a regression that describes the relationship between base cations (e.g., calcium, magnesium, sodium, potassium) and alkalinity (acid neutralizing capacity, primarily bicarbonate) for sites in the Catskill Mountains that are forested (>97% forest cover in the EBD, WBD, NRD) and do not have known point sources. It shows the consistent, positive relationship between alkalinity and base cation concentration - base cation concentration increases as alkalinity increases. The range of values along this line reflects differences in underlying geology, soils, and vegetation that occur naturally between basins and sub-basins across the Catskill Mountains (e.g., consistently low concentrations in the Neversink River, higher and variable concentrations in the West and East Branches of the Delaware River). Data points above the gray dashed line in Figure 1 reflect increases in cation concentration relative to alkalinity that is presumably a result of anthropogenic land and water uses such as salts used to deice roads, fertilizers applied to fields or lawns, or treated sewage discharged to land or waterways.

When examining changes in differences in water chemistry among sites, we have found that one of the best single predictors of these changes is often % forest cover in the watershed. As the percentage of upstream forests is reduced (i.e., converted to other land uses and covers), we have observed higher values for a number of parameters that are a reflection of changes in cations and anions such as conductivity, sodium, potassium, calcium, magnesium, and chloride as well as changes in nitrogen and phosphorus (Figure 2). We have also observed higher concentrations of elements or compounds that are directly or indirectly waste products or residuals from human activity or human-related land uses. For example, sulfate is often associated combustion engine exhaust, motor oil, and tires, and its concentration tends to be higher when road density is higher (Figure 3).

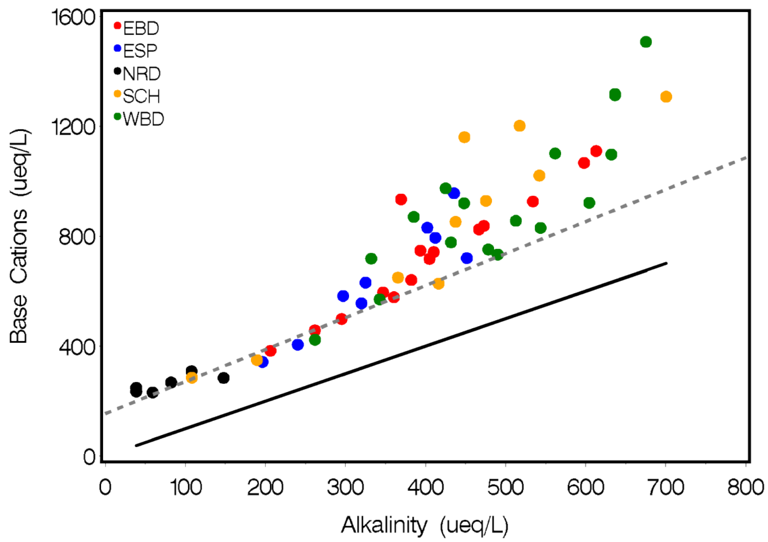

Fig. 1. Plot of alkalinity and base cation concentration for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch (EBD) and West Branches (WBD), and the Neversink River (NRD) as well as sites in Rondout (NRD), Esopus (ESP) and Schoharie (SCH) Creeks. The gray dashed line is a regression between base cations and alkalinity for forested sites (>97% forest cover in the EBD, WBD, NRD) that do not have known point sources. The solid black line is the 1:1 line.

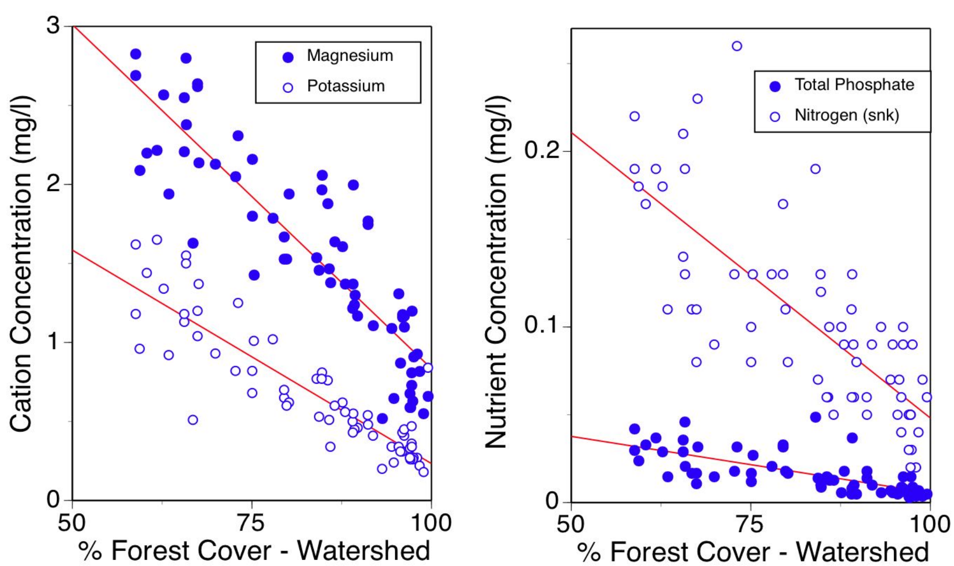

Fig. 2. Plot of cation (magnesium and potassium) and nutrient (total phosphorus and nitrogen) concentrations versus % forests cover at the watershed scale for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

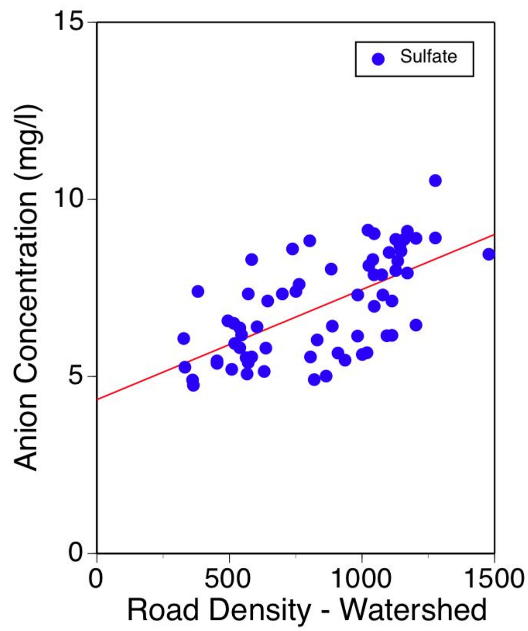

Fig. 3. Plot of anion (sulfate) concentrations versus road density at the watershed scale (m per 100 sq. km) for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

II. Stream macroinvertebrates as indicator of water quality

Stream macroinvertebrates (primarily insects, but also other invertebrates such as aquatic worms, crayfish, and molluscs) have provided water quality assessment programs with valuable insight for more than 100 years (Rosenberg and Resh 1993). The presence or conspicuous absence of certain macroinvertebrate species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs that rely on periodic water chemistry samples. Local, state, and federal agencies have developed a wide variety of stream bioassessment protocols that rely on macroinvertebrates. Stream macroinvertebrates are commonly used and widely accepted tools in water quality monitoring programs for a number of reasons.

(1) Most river and stream ecosystems have relatively diverse aquatic insect assemblages (100-200 species), with species from several different orders [e.g., Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Coleoptera (beetles), Diptera (true flies)]. Each of these species is to some degree evolutionarily unique; as a result, each potentially possesses different tolerances to changes in environmental conditions. Thus, together, the aquatic insects are a sensitive measure of environmental change and stress.

As an example of stream macroinvertebrate biodiversity, we sampled seven high quality tributaries to the Delaware River near the Water Gap in 2008 and 2009 (Stroud Water Research

Center, unpublished data). Among the seven sites, we identified 236 different macroinvertebrate species or taxonomic groups (i.e., identified to genus or higher taxonomic level and therefore may have represented more than one species), and the number at any one site ranged from 97 to 150 species. Many of these species are known to be pollution sensitive such as the mayflies, stoneflies and caddisflies (i.e., Ephemeroptera, Plecoptera, Trichoptera, or EPT). Among the 236 different species or taxonomic groups identified in the Water Gap tributaries, 105 (44%) were EPT species. The species in these insect orders are often grouped together and used as a pollution indicator (e.g., the number of EPT species, also known as EPT Richness). Because these seven Water Gap tributaries were clean streams draining well forested watersheds with limited anthropogenic activity, each supported a variety of these pollution-sensitive EPT species (43-53 per site) that together represented 37-46% of the macroinvertebrate species identified at a site.

Similar taxonomic richness was observed among Catskill Mountain tributaries in the headwaters of the Delaware River when we sampled 3-6 times between 2000 and 2005 (SWRC 2008, unpublished data). For example, across 15 tributary and main stem sites for the East Branch of the Delaware River, we identified 285 different macroinvertebrate species or taxonomic groups, 117 (41%) of which were pollution-sensitive EPT species. Individual sites had between 84 and 154 species, including 35-60 EPT species (34-47%). Similarly, we identified 287 different macroinvertebrate species or taxonomic groups (including 108 (38%) that were pollution-sensitive EPT species) across 17 tributary and main stem sites for the West Branch of the Delaware River, and 183 different macroinvertebrate species or taxonomic groups (including 73 (40%) that were pollution-sensitive EPT species) across four tributary and main stem sites for the Neversink River.

The same samples used above to describe the biodiversity for stream macroinvertebrate can also be used to describe abundance. For example, the Water Gap tributaries had an average macroinvertebrate density of 6,091 individuals/m^2 (Stroud Water Research Center, unpublished data). The upper Delaware River sites supported higher densities: 21,923 individuals/m^2 among the 15 West Branch sites, 20,981 individuals/m^2 among the 17 East Branch sites, and 15,606 individuals/m^2 among the 4 Neversink sites (SWRC 2008). Thus, the Delaware River and its tributaries support a diverse and abundant macroinvertebrate community that includes many pollution-sensitive species.

III. Response of stream macroinvertebrates to changes in land and water use

In general, concentrations of selected ions, nutrients, and organic compounds increase as forests are converted to other land uses. Concentrations of anthropogenic compounds (e.g., herbicides, insecticides, heavy metals, oil-derived compounds) that are associated in these new land and water uses also increase. For the Delaware River basin, examples of these relationships can be seen in Figures 1, 2, and 3, above.

Parallel changes in macroinvertebrate faunas have also been observed as forests are replaced by other land uses (which often is accompanied by different water uses such as domestic, commercial, and industrial consumption and waste and storm water runoff). Many streams in the

Delaware River basin drain watersheds that are almost completely forested and are high quality (Figure 4), but they already show evidence of stress (e.g., changes in relative abundance but without local macroinvertebrate species extinctions) in response to local changes in land and water use (Figure 5). More intensive changes in land cover and water use are generally accompanied by the loss of pollution-sensitive macroinvertebrate species (Figure 6). In some cases, local land and water use changes have already resulted in moderate to severe impairment of the macroinvertebrate species (i.e., a loss of 50-75% of the pollution-sensitive species). In many cases, the cause of stream degradation is a current activity such as erosion from recently plowed fields or outflow from a poorly functioning wastewater treatment plant. In other cases, present degradation reflects past land use decisions, including how and where changes were implemented, sediment and erosion control practices, and management of wastestreams. For example, most of the anthracite coal field in the Schuylkill River basin have not been actively mined for decades yet many of the streams in contact with the waste piles or mine outflows are currently some of the severely impaired in the basin because they still have excessive acid and metals in the water (Figure 8).

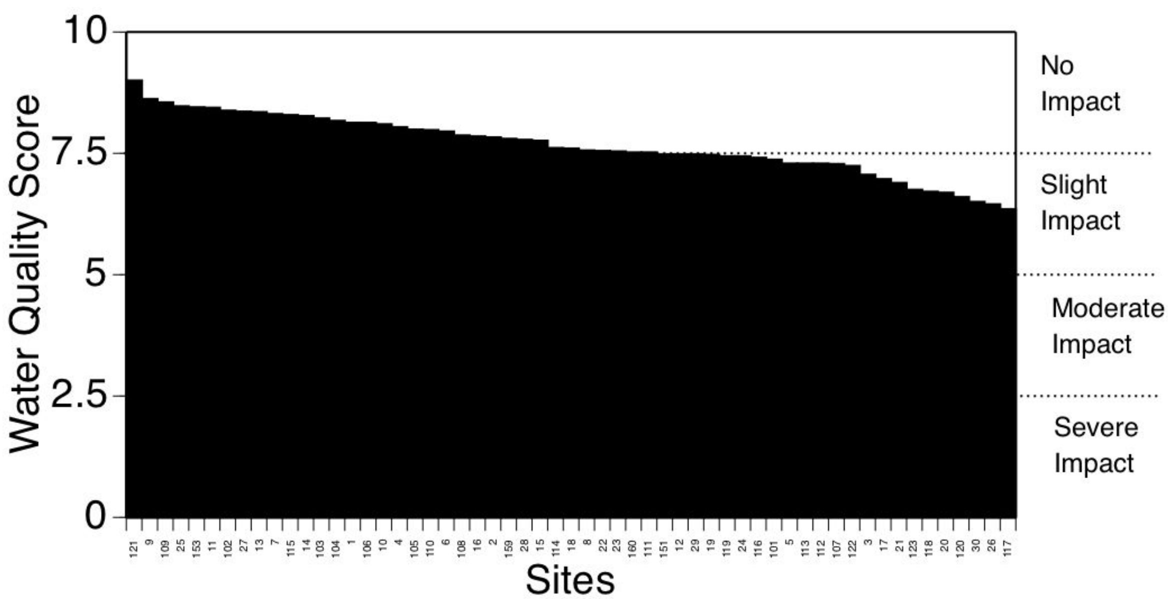

Fig. 4. Plot of Water Quality Score (sorted from highest to lowest) for 57 stream sites draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

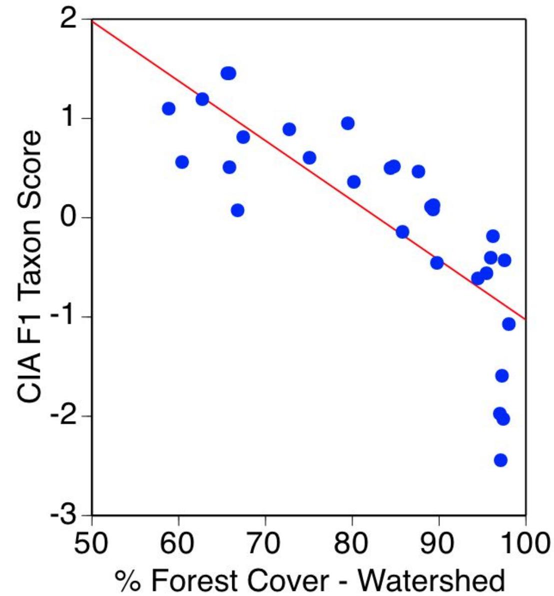

Fig. 5. Plot of macroinvertebrate community structure (as expressed by Co-Inertial Analysis Factor 1) versus % Forest Cover at the watershed scale for 30 stream sites draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

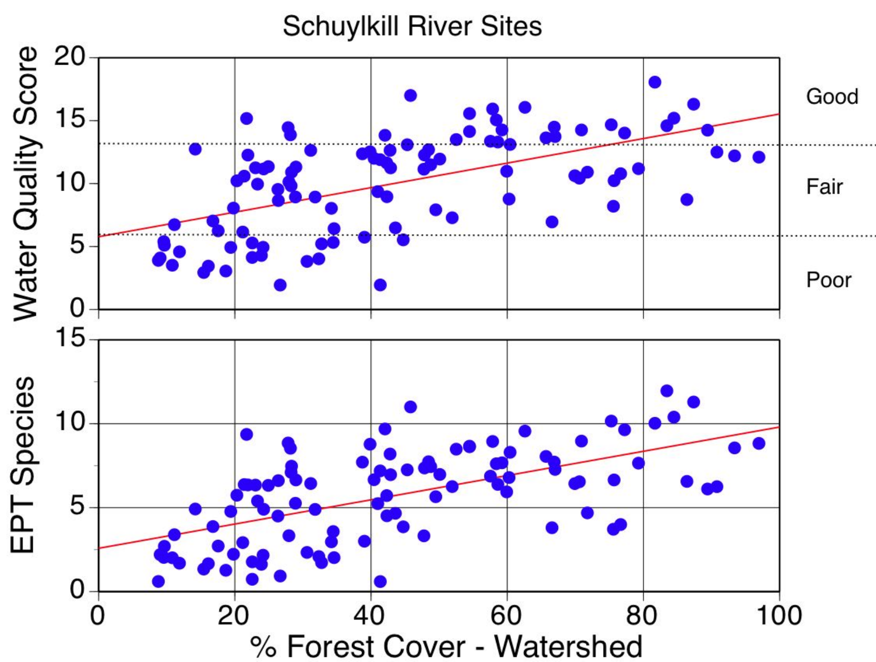

Fig. 6. Plot of macroinvertebrate community structure (as expressed by MAIS Score and EPT Richness) versus % Forest Cover at the watershed scale for 104 sites in the Schuylkill River basin, the largest tributary to the Delaware River.

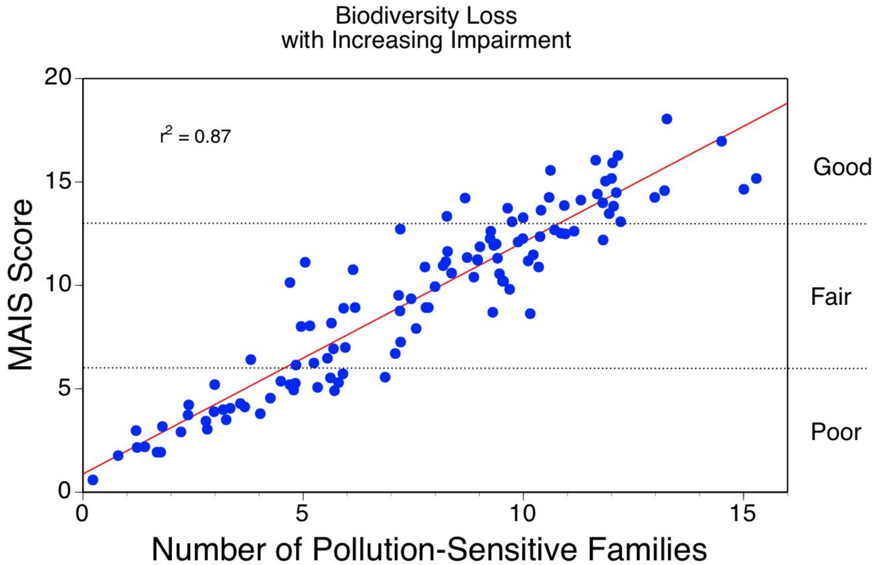

Fig. 7. Plot of macroinvertebrate community structure (as expressed by MAIS Score) versus the number of pollution-sensitive macroinvertebrates in the Schuylkill River basin, the largest tributary to the Delaware River.

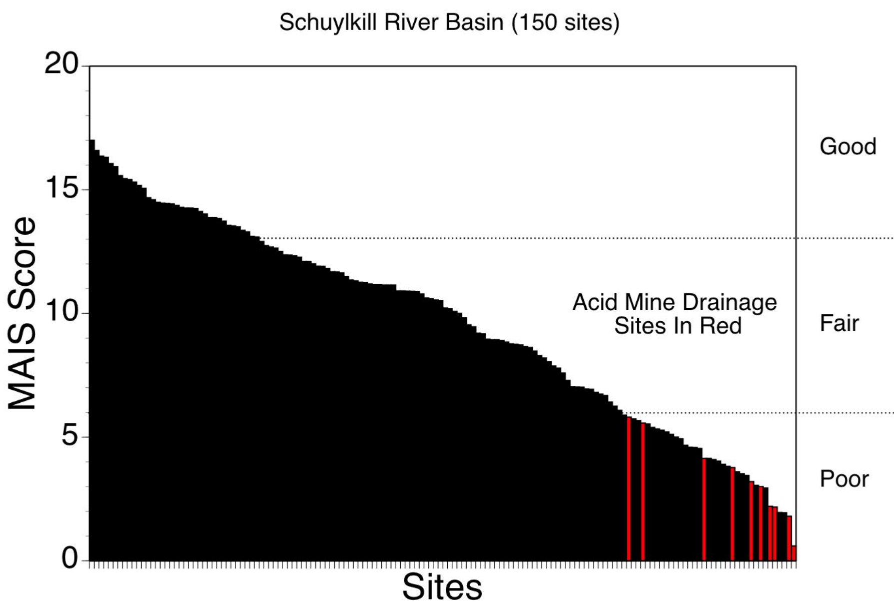

Fig. 8. Plot of MAIS Scores for 150 sites in the Schuylkill River basin, sorted from highest to lowest score. Sites with clear evidence of acid mine drainage are shown in red.

IV. Stream and watershed changes associated with Marcellus Shale exploration and development

The potential for stream degradation associated with Marcellus Shale exploration and development depends on the location and intensity of changes in land cover and water use that may then result in changes in changes in stream habitat, water quality and/or water quantity. Because many of these watersheds are well forested, Marcellus Shale exploration and development are going to result in replacing forests with other land uses. Changes in land and water use may result from the construction, expansion, and maintenance of drill sites, roads, stream crossings, and pipelines as well as additional infrastructure in support of the new industry (e.g., new or modified sites, roads, stream crossings, pipelines, and power lines). This can lead to stream degradation if it results in changes in local hydrology (flood maxima and low base flow, sediment erosion in the stream corridor and in upland areas, warming of the waterways (from reduced shading) as well as the presence or increase in naturally occurring chemicals (silt, salts, naturally occurring radioactive material), chemicals resulting directly from drilling and fracking process, and potential pollutants associated with additional developed lands (directly and indirectly associated with exploration and production) or more intensive use of previously developed lands (e.g., more traffic and people resulting in more road salt, heavy metals, oil-derived compounds).

The effects from land use changes (e.g., converting forest to agricultural, industrial, commercial, or residential uses) on water chemistry and macroinvertebrate communities are well established in areas both within and outside of the Delaware Basin. Based on these scientific studies, impacts to water chemistry and aquatic communities could potentially result from land use changes associated with Marcellus shale exploration and development (e.g., replacing forests with infrastructure associated with or in support of the new industry). As a result, careful review and regulation of land use changes associated with all shale gas well development activity, including exploratory well development, appears warranted to minimize the extent to which the sensitive aquatic resources in the Delaware River basin are affected.

References:

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