Report on Selected Environmental Impacts of Exploratory Gas Drilling in the Delaware River Watershed

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Executive Summary

This report is concerned with the construction and operation of exploratory vertical gas wells in the Special Protection Waters portion of the Delaware River watershed.

Current well drilling technologies, as applied in practice, do not guarantee that surrounding groundwater and surface water will be protected from the effects of exploratory well drilling. Regulators should proceed with caution in evaluating the impact of exploratory gas wells on surrounding surface waters. Current regulations in Pennsylvania do not require analysis of surrounding surface waters and there is no evidence that the well operators will perform or have performed any surface water analysis prior to, during or after drilling of these wells.

Stream buffer strips have proven to be an effective means of reducing the effect of land development on surface waters, both in general land development and in the particular case of drilling for oil and gas exploration and extraction. Pennsylvania regulations only require a 100 foot separation distance between a gas well and a surface water body. This is wholly inadequate as a stream buffer and will not provide needed protection to the Special Protection Waters of the Delaware River.

The loss of intact forest land and the increase of forest fragmentation associated with oil and gas development is well documented. In this Special Protection Waters area, development that results in such changes to the land should be carefully evaluated. Where such development is approved, mitigating steps or measures should be implemented in order to preserve water quality. Pennsylvania regulations do not provide adequate protection of forest and does not prevent or reduce forest fragmentation leading to inadequate protection of forest cover required to protect the Special protection Waters of the Delaware River Basin.

At issue here is the impact of multiple exploratory wells. It is important that, in evaluating the environmental impact of these wells, the evaluation consider not only the impact of each individual well site, but also of the cumulative impact of all sites operating together and simultaneously. When viewed in this manner, the impact of the exploratory wells in question is amplified. There is no evidence that any cumulative impact analysis of the potential impacts of and risks posed by the multiple exploratory wells on receiving water bodies, particularly the main stem Delaware River, has been done.

It has been found (The Nature Conservancy and Pennsylvania Audubon, 2010) (Exhibit 1) that, with proper planning in advance of well construction, integration of conservation features into the development of well sites can lead to significantly reduced impacts on surface waters. However, there is no evidence that such planning has occurred in the development of the exploratory well sites that are of interest here. As a result, it is prudent that the procedures used in selecting the sites for the exploratory sites, and the activities on these sites, be carefully reviewed. This is particularly important given the Special Protection Waters status of the watershed.

The opinions provided in this report are stated to a reasonable degree of scientific and professional certainty

Introduction

Exploratory gas wells have been or are permitted to be drilled in northeastern Pennsylvania as a part of a project to extract natural gas from the Marcellus shale formation. This gas extraction will use the process of hydraulic fracturing in the future to extract the gas from this deep geologic formation. The portions of the Delaware River watershed where the exploratory wells grandfathered under the Supplemental Executive Director Determination (SEDD) at issue in this hearing are located have been designated as Special Protection Waters (SPW) by the Delaware River Basin Commission (DRBC). Waters receiving this designation have been found to have exceptionally high scenic, recreational, ecological and/or water supply values. The regulations establishing SPW significantly restrict new and increased discharges of wastewater directly to the designated waterways by prohibiting discharges that create any measurable change in water quality.

Groundwater Contamination

An important issue in evaluating potential pollution pathways from exploratory gas wells is groundwater contamination from poorly constructed water wells. Generally, drinking water wells are shallower than natural gas wells, and their casing may not extend their entire depth. This is particularly the case for domestic water wells that may not be subject to the same level of oversight and scrutiny as municipal or privately owned water supply facilities. This is particularly true for older water wells and for spring wells, which are used in the regions of the Delaware River watershed that are underlain by Marcellus shale, including Wayne County, and the local areas immediately adjacent or quite close to where these grandfathered exploratory wells are located. A water well that is not cased from the surface, or is not constructed and cased properly, might allow contaminated water to flow from the ground surface and enter the water well, possibly compromising the quality of drinking water in the well, as well as the drinking water aquifer itself.

In such instances, and particularly where natural gas drilling activities are nearby, leaky surface impoundments or careless surface disposal of drilling fluids at the natural gas operation could increase the risk of contaminating the nearby water well. While the quantity of chemicals used in the installation of exploratory wells may be less than for production wells, the potential for this type of contamination is significant. The grandfathered wells under the SEDD are each located close to groundwater wells or springs providing potable water to residents in, adjacent to, and downgradient from these exploratory well sites.

Surface Water Impacts of Well Drilling

The Pennsylvania Academy of Natural Sciences has called for a comprehensive research plan that would result in guidelines and an assessment tool for regulators and managers in order to minimize the environmental impact of Marcellus Shale gas drilling. Dr. David Velinsky Testimony (Exhibit 2) (available at http://www.ansp.org/about/news/marcellus-shale.php)

The research described by Dr. Velinsky found that there is very little information available as to the impacts of long-term exposure of a watershed to Marcellus Shale drilling activities. It is unknown if there is a cumulative impact of drilling activity on a small watershed. Initial research by Academy scientists shows the environmental impact of drilling may be directly related to the density of drilling in a specific area. This research has pointed out that a question that needs to be addressed is whether there is a threshold point past which a certain amount of drilling activity has an impact on the ecological health and services of the watershed, regardless of how carefully drilling is conducted. This is very important in regards to the exploratory wells that are being drilled in the Basin under the grandfathered wells provision of the SEDD. Three of the grandfathered wells in southern Wayne County drain over a short distance to a relatively small stretch of the Delaware River that influences vulnerable species such as dwarf wedge mussel, a federally listed endangered species, and other fish, wildlife and aquatic species that are sensitive to water quality and flow changes.

The Academy scientists examined small watersheds in northeastern Pennsylvania—three in which there had been no drilling, three in which there had been some drilling and three in which there had been a high density of drilling. At each site, they tested the water, the abundance of certain sensitive insects, and the abundance of salamanders. The presence of salamanders is particularly important because amphibians are especially vulnerable to changes in the environment. The absence of amphibians is often an ecological early-warning system. For each of the measures, there was a significant difference between high-density drilling locations and locations with no drilling or less drilling. The studies showed that water conductivity (which indicates the level of contamination) was almost twice as high in the high density sites as the other sites, and the number of both sensitive insects and salamanders were reduced by 25 percent.

Site preparation on the surface at the well site is likely to cause increased erosion and runoff into surrounding streams. For both exploratory and production wells, the wellbore acts as a conduit between adjoining geologic formations, which can allow contaminants to flow into shallow groundwater or surface waters.

It has been reported (DRBC 2009) that wastewater generated during the drilling of the Matoushek well (which was completed as a future production well but has not gone into production and therefore is similar to an exploratory well) was stored on site and then trucked to a municipal wastewater treatment plant in Athens, PA. It is known that the wastewater treatment processes used at municipal treatment plants, including the plant at Athens, are not capable of removing the industrial pollutants (organic chemicals, heavy metals, etc.) that are present in the wastewater that is generated by well drilling operations. As a result, it is likely that these pollutants were discharged into either surface or groundwater without treatment. The grandfathered exploratory wells at issue here either have already generated wastewaters or will generate them when they are drilled and such wastewaters will most likely be transported from the well site to another treatment or disposal location that has not been identified by DRBC because it is not exercising any regulatory control over these wells.

Land Disturbance - General

Drill sites involve land disturbance, making sites susceptible to runoff during storm events that can cause pollution of streams, lakes, ponds, etc. downstream from the site. Construction of drill pads as a surface for operations and storage of large equipment/containers is completed prior to the commencement of drilling and can be as large as five acres. Roads may also need to be built for access to the site. Phase II Stormwater Regulations require that construction activities disturbing one or more acres of land must have a stormwater discharge permit. In New York such permits are issued by NYS DEC under its State Pollutant Discharge Elimination System (SPDES) General Permit for construction activities. As part of this permit, a Stormwater Pollution and Prevention Plan (SWPPP) would be required, with NYS DEC charged with ensuring the SWPPP is met. Apparently no such permitting of this type is required in Pennsylvania for oil and gas projects less than 5 acres. Stormwater runoff from the grandfathered exploratory well sites is a source of pollutants to the Special Protection Waters.

With regard to land disturbance, the grandfathered exploratory wells that are at issue here are generally the same as production wells. This includes disturbance on the well site itself, placement of well facilities such as the well pad and pit, and in the construction of access roads to the site, and traffic on such roads.

It should be noted that the Marcellus shale formation underlies a significant portion of the watershed of the New York City water supply system in southeastern New York State and the watershed for water supply to Philadelphia, central and southern New Jersey, and all of the communities along the Delaware River. The New York City public water supply is unusual in that there is no filtration applied to the water diverted from the Delaware River Basin before delivery to the public. New York City has been granted a waiver from federal regulations that require such filtration. The granting of this waiver is dependent on enforcement of various regulations in the watershed that are designed to maintain water quality. The goals and associated requirements of the Special Protection Waters status of the portion of the Delaware River watershed where the grandfathered exploratory wells are located are applicable to protect the downstream water users and are similar in many ways to the requirements that exist in the watershed of the New York City water supply system.

The entire New York City watershed located west of the Hudson River (the Catskill and Delaware portions of the watershed) is underlain by Marcellus shale, and gas development has been proposed in this area. In response to this potential gas development, the New York City Dept. of Environmental Protection completed a study to evaluate the impact of gas development on general water quality in the watershed, and specifically on the risk to the federal filtration waiver (Hazen and Sawyer 2009)(Exhibit 3).

While this study was concerned with both gas exploration and production, many of the findings and recommendations apply to the grandfathered exploratory wells in question here, because, as reported by Dr. Rubin in recent comments to the U.S. Environmental Protection Agency (Exhibit 4), the geology of the Delaware River Basin watershed below the New York City reservoirs is the same as the geology of the areas of New York state addressed by Hazen and Sawyer. Among other conclusions, the Hazen and Sawyer study found that land disturbance associated with gas exploration and development would lead to increased risk to the water supply. With regard to land disturbance, these conclusions also apply to the Special Protection Waters of the Delaware River watershed. The Hazen and Sawyer study more generally documented the problems that may be associated with well drilling (exploratory or production), such as migration of drilling muds, hydrocarbons, and naturally occurring radioactive compounds into surface and groundwater.

Projects that involve only exploratory wells have been found to result in problems affecting surrounding land and water resources (U.S. Forest Service, 2005). Monitoring of the Gunnison Energy Exploratory Gas Drilling Project in the Grand Mesa/Uncompahgre/Gunnison (GMUG) National Forest and the Willsource Exploratory Project in the White River National Forest demonstrated unexpected negative environmental impacts after exploration began. Gunnison Energy Corp., the developer at the GMUG National Forest, experienced the movement of significant quantities of sediment from well sites into nearby streams. Measures that were designed to prevent an increase in runoff from well sites were found to not be effective. At the Willsource Exploratory Project, sediment from access roads was deposited in nearby stream channels, and runoff from well sites was not properly controlled. The grandfathered well sites at issue here present similar runoff pollution risks.

Land Disturbance - Buffer Zones

A riparian forest buffer is a streamside forest composed of native trees, shrubs and herbaceous plants (Lee et al. 2004). Use of such buffer areas provides various benefits. Buffers are natural filters. Leaf litter on the forest floor traps sediments before they can enter the stream. In addition, the presence of trees and shrubs along a stream's banks minimizes erosion and the effects of flooding. Buffers also encourage groundwater infiltration. Trees convert the excess nutrients in stormwater runoff into a form that actually sustains the growth of the forest. In addition, buffers provide shade necessary to maintain cool water temperatures and higher dissolved oxygen levels. Native trout, for example, require water temperatures below 68^{o}F to survive, and forested streams are as much as 10 degrees cooler than streams that flow through meadows (Lee et al. 2004). In addition, insects, the primary food for trout, are abundant both above and in wooded streams and cannot survive in water temperatures that exceed 68^{o}F.

The results demonstrate the positive impact of forest buffer zones in reducing the influence of agricultural nutrients and chemicals on surface stream waters (Anbumozhi et al. 2005).
Some of the adverse effects of impervious surfaces (such as paved roads, parking lots, and manmade structures) and agricultural areas can be mitigated by tree cover and streamside vegetation buffers, which reduce the force of overland flows, uptake excess nutrients, maintain stream bank integrity, and provide shade that reduces solar warming of waterways (Goetz et al.

2004). In addition, it has been found that forest cover provides more optimal land cover for protecting water quality than many of the potential uses to which that land may be converted (Hall et al. 2008).

There is solid evidence that providing riparian buffers of sufficient width protects and improves water quality by intercepting nonpoint source pollution (NPSP) in surface and shallow subsurface water flow (Lowrance et al. 1984; Pinay and Decamps 1988). The spatial placement of buffer strips within a watershed can have profound effects on water quality. Riparian buffers in headwater streams (i.e., those adjacent to first-, second-, and third-order systems) have much greater influences on overall water quality within a watershed than those buffers occurring in downstream reaches. Downstream buffers have proportionally less impact on polluted water already in the stream (Fischer and Fischenich, 2000).

The areas that have been or will be disturbed by the construction of the grandfathered well sites at issue here include forested and other land areas that will be or have been disturbed. This will compromise buffer zones to streams and creeks in close proximity to the well sites. These streams and creeks are mostly classified as high value or exceptional value streams and provide spawning habitat for native trout, among other important aquatic species.

It has been found that species richness was positively correlated with wetland area, forest cover, and the amount of wetlands on adjacent lands and negatively correlated with road density (Houlahan and Findlay, 2003). Lowrance et al. (1997) found that riparian forest buffers retain 50%–90% of the total loading of nitrate in shallow groundwater, sediment in surface runoff, and total nitrogen in both surface runoff and groundwater, thereby reducing the loading of these nutrients to downstream waters.

In a study of Pennsylvania streams by Brenner et al. (1991), riparian woodlands were effective in reducing fecal coliform, suspended solids, and total phosphorus. The establishment and maintenance of wetlands and riparian vegetation were determined to be a cost effective means of non-point source pollution abatement. Stormwater treatment strategies that focus on infiltration and take advantage of trees and intact forest buffers can counter the unhealthy effects of development. The areas surrounding the grandfathered well sites generally provide all or most of these land features.

Pennsylvania's Independent Regulatory Review Commission (IRRC) recently passed two new regulations that provide protections for water resources and for drinking water and watersheds from the impacts of natural gas drilling pollution as well as other new development projects. The rules fall under Title 25, in the PA code, Chapter 95, Wastewater Treatment Requirements, and Chapter 102, Erosion and Sedimentation Control. Changes to Chapter 102 state regulations approved by the IRRC will require some developers to maintain or create a 150-foot natural vegetative buffer beside Pennsylvania's best rivers and streams. These rules affect so-called E&S permitting or Erosion and Sedimentation Control measures implemented with construction projects to reduce impact on streams and rivers. Streams in the top 20% statewide for water quality will be subject to the increased protections. This would presumably include streams designated as Special Protection Waters. Unfortunately, natural gas projects are exempted from the additional buffer width requirements that are being adopted for Pennsylvania's best streams.

The subject exploratory wells will not employ these extra buffer protections, exposing the high and exceptional water quality of the tributaries and main stem Delaware River in the Wayne County region to degradation in proximity to the places where the grandfathered wells have been or will be located.

Streamside buffers are widely considered to be the best and most effective long-term solution for protection water quality. Buffers help filter water, reduce the impacts of flooding, shade and reduce water temperatures creating better habitat for fish and aquatic species. Over 200 municipalities within Pennsylvania require streamside buffers for such development projects. Again, no natural gas well, exploratory or production well, will be required to follow this rule to which all other development projects are now subject.

Land Disturbance - Intact Forest Land Cover and Forest Fragmentation

Ecosystem fragmentation generally causes large changes in the physical environment as well as biogeographic changes (Saunders et al. 1991). The exchange of solar radiation, water, and nutrients across the land surface and landscape are altered significantly. These in turn can have important influences on the biota within remnant areas, especially at or near the edge of the remnant. It has generally been found that intact forests that have not been subject to fragmentation by construction of roads and pipelines support more diverse and healthier ecosystems (Spellerberg 1998).

Areas of high ecological integrity that may serve as core refugia include: intact old growth forests, native forest ecosystems operating within the bounds of historic disturbance regimes, intact watersheds and large roadless areas (DellaSala et al. 2003). Intact natural vegetation helps to reduce or control floods and retain moisture in the soils (O'Neill et al. 1997; Hunsaker and Levine. 1995). Construction of logging and other roads in forested areas has been correlated with decrease in the acreage of intact forest (Heilman et al. 2002).

For gas well drilling in forested areas, trees and vegetation are removed for the well pad, access roads, and pipelines (Woodring 2009). This habitat destruction and forest fragmentation has the potential to seriously disrupt and endanger flora and fauna. Furthermore, noise from traffic could have a negative effect on local wildlife and clearings for pipelines may present an opportunity for increased traffic from off-road vehicles (Woodring 2009). Indirect impacts include road-building and pipeline development, which may result in habitat fragmentation and increased access to remote areas. While larger intact forest ecosystems may withstand the impacts of mining and oil development, smaller fragments are likely to be particularly sensitive to clearing (Mooney et al. 1995). Several of the sites where grandfathered wells have been or will be located will suffer forest fragmentation from the construction of these well sites.

General decline in the diversity of animal populations has been observed as a result of forest fragmentation in Pennsylvania (Yahner 1996). One potential repercussion of forest fragmentation is a decline in migratory bird populations, which become more vulnerable without continuous forest cover (Robinson et al. 1995). It has been found that maintenance of intact forests encourages the vitality of bird populations in Pennsylvania (Porneluzi et al. 1993). Food supply for various bird species in Pennsylvania has been found to be reduced as a result of forest fragmentation (Robinson 1998).

Forest fragmentation has been found to increase the susceptibility of forests to damage from unusual weather events. For example, in the first autumn after fragmentation, a period with high winds caused severe blowdown and other forest damage in all five fragments of a previously intact forest. Total tree mortality after 67 months showed a steep increase with decreasing area of contiguous forest areas (Esseen 1994). Because the Executive Director of the Delaware River Basin Commission decided in the SEDD not to exercise the Commission's review jurisdiction over the grandfathered sites, there is no assessment from the Commission staff whether the cumulative effect of these grandfathered projects could result in similar forest fragmentation and its consequences.

Conclusions

Current well drilling technologies, as applied in practice, do not guarantee that surrounding groundwater and surface water will be protected from the effects of drilling the grandfathered exploratory wells.
The loss of intact forest land and the increase of forest fragmentation associated with grandfathered exploratory gas wells can be expected to have measurable impact in the Special Protection Waters area. Mitigating steps or measures, such as the provision of stream buffers, will not be required by the Commission because it is not exercising jurisdiction over the grandfathered wells. Such mitigation measure should be taken in order to preserve water quality.

The multiple exploratory wells that are at issue here should not only be reviewed as to the individual impact of each site, but also the cumulative impact of all exploratory sites in the Special Protection Waters. The surface waters of the Delaware River Basin, in particular the Special Protection Waters are at significant risk of degradation associated with construction and operation of exploratory gas wells. These waters are not protected adequately by present regulations.

The opinions expressed herein are stated to a reasonable degree of scientific and professional certainty.

Signature: Emmet M. Owens

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Date: November 18, 2010

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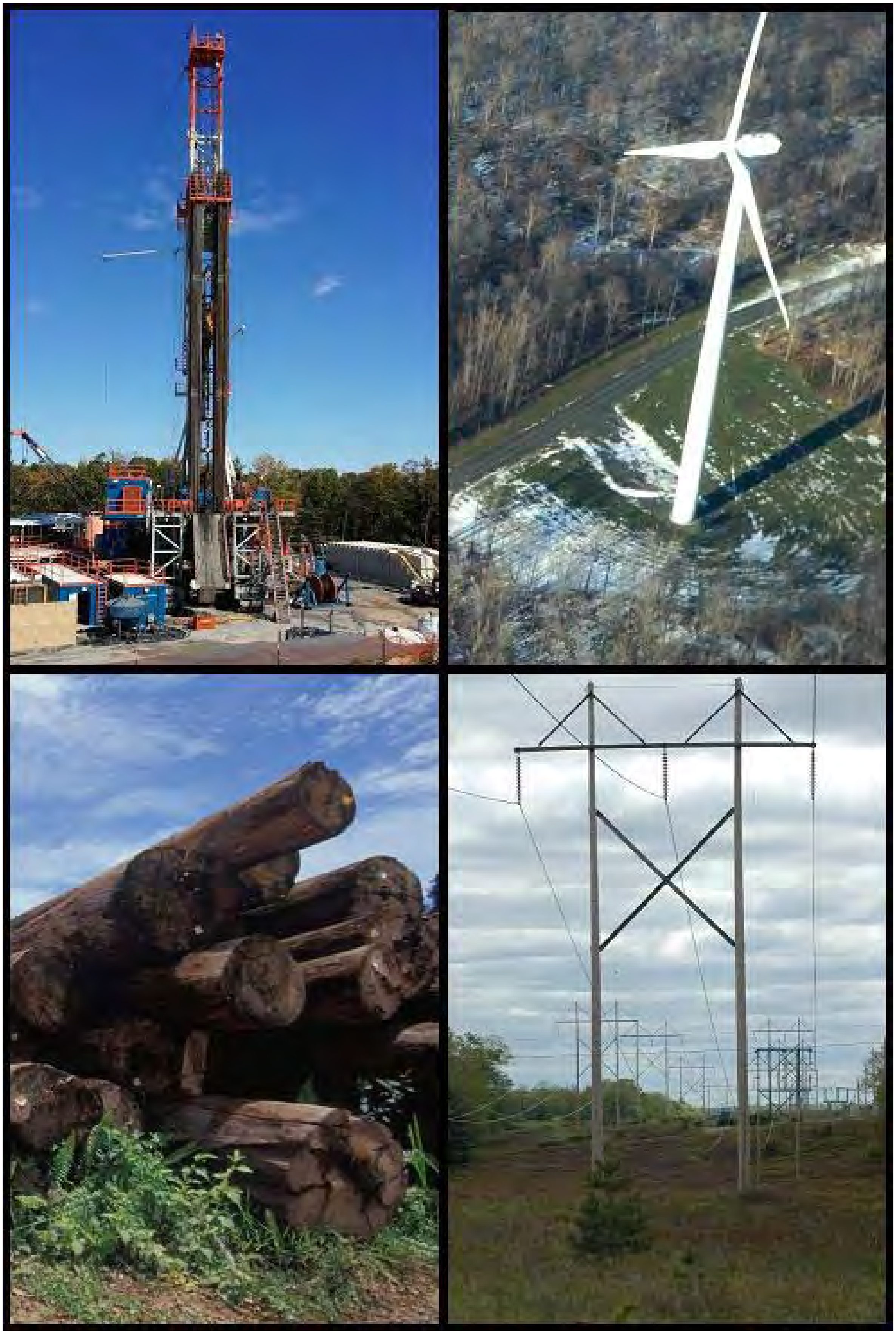
Pennsylvania Energy Impacts Assessment

Report 1: Marcellus Shale Natural Gas and Wind



Pennsylvania Energy Impacts Assessment

Report 1: Marcellus Shale Natural Gas and Wind

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1. The Nature Conservancy – Pennsylvania Chapter
2. Western Pennsylvania Conservancy – Pennsylvania Natural Heritage Program
3. Audubon Pennsylvania

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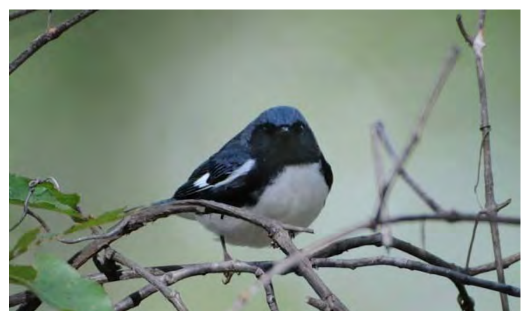
Table of Contents

Executive Summary

Forest landscape along the West Branch Susquehanna River, Clinton County. © George C. Gress / TNC

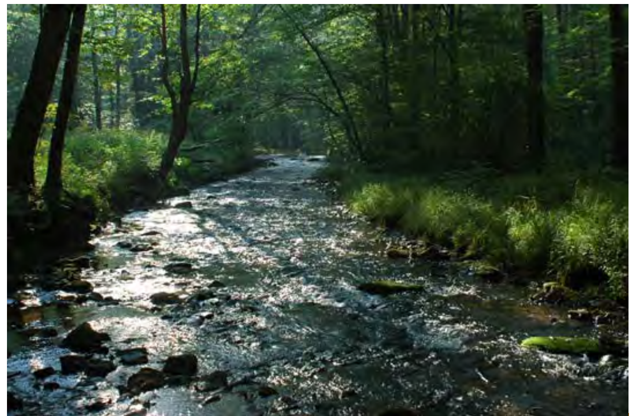
Within a few weeks during the summer of 2000, eight towers rose two hundred feet above an agricultural field on a low ridge top along the Pennsylvania Turnpike. Not long after, large blades began sweeping the Somerset County sky as Pennsylvania's first industrial wind facility went on line. Several years later and an hour drive to the west, an unusual natural gas well was drilled over a mile down and pumped full of water. That well in Washington County yielded a surprising amount of gas flowing from fractures in a shale formation that geologists had long suspected held plenty of gas but has been too expensive to develop. Meanwhile, a Canadian company bought a small sawmill in Mifflintown and started producing wood pellets for stoves, boilers, and electric plants. It soon became one of the region's largest producers of wood biomass energy supplies. In the decade since, these three new energy technologies have expanded rapidly across the state. By the end of this year, 500 wind turbines will be turning on Pennsylvania ridgelines, nearly 1,800 Marcellus natural gas wells will be scattered across rolling fields and forests, and over 50 facilities will be producing wood pellets or burning wood for energy. Thousands of miles of pipelines and powerlines already crisscross the state to get energy supplies to major markets in the Northeast.



Black-throated blue warblers and other interior forest species could be impacted by forest fragmentation caused by energy development. © Gary Irwin

Each of these energy sources carries both promise and risk for people and nature. The promise is that wind, natural gas, and wood biomass energy can replace coal and oil and their higher greenhouse gas emissions, generate jobs, and increase energy security. The risk is that extensive land use change and loss of natural habitats could accompany new energy development and transmission lines. Impacts to priority conservation habitats across the state have been modest thus far. For example, aerial photo analysis indicates Marcellus gas development has so far cleared just 3,500 acres of forest (about 1,000 acres for wind turbines). An additional 8,500 acres of forest is now within 300 feet of new fragmenting edges created by well pads, and associated roads and infrastructure (5,000 acres for wind turbines). This fragmentation deprives "interior" forest species, such as black-throated blue warblers, northern goshawks, salamanders, and many woodland flowers, of the shade, humidity and tree canopy protection that only deep forest environments can provide.

By all accounts, each of these energy types is likely to grow substantially in Pennsylvania during the next two decades. The Marcellus shale formation, which underlies two-thirds of the state, is now believed to be one of the largest unconventional shale gas reserves in the world. The Pennsylvania Alternative Energy Portfolio Standards Act of 2004, along with state and federal incentives, will likely boost expansion of wind, wood biomass, and other alternative energy types over the next two decades. But, how much of each energy type might be developed? What transmission infrastructure will be needed to get more electric power and natural gas to consumers? And, where are these energy types most likely to be developed? How does the likely scale and location of future energy development overlap with priority conservation areas? The Pennsylvania Energy Impacts Assessment seeks answers to these questions so that conservationists can work more effectively with energy companies and government agencies to avoid, minimize or mitigate habitat impacts in the future.



Nine Mile Run Creek in PA's North Central Highlands
© George C. Gress / TNC.

Assessment Goal: Develop credible energy development projections and assess how they might affect high priority conservation areas across Pennsylvania. Marcellus natural gas, wind, wood biomass, and associated electric and gas transmission lines were chosen as the focus since these energy types have the most potential to cause land-use change in the state over the next two decades. The conservation impacts focus is on forest, freshwater, and rare species habitats. The assessment **does not** address other potential environmental impacts, including water withdrawal, water quality, air quality and migratory pathways for birds and bats.

Key Assumptions: Any assessment of future trends must include certain assumptions. Among the most important assumptions of the Pennsylvania Energy Impacts Assessment are the following:

- A 20-year time period is used to assess potential cumulative habitat impacts from energy development;
- Given uncertainties about how energy prices could change, it was assumed that prices and capital investment (and policy and social conditions) will be sufficient to promote steady development growth for each energy type during the next two decades;
- Given uncertainty about how technology changes could affect spatial footprints, it was assumed that spatial footprints per well pad, turbine, and mile of transmission line will not change significantly during the next two decades;
- Given the proprietary nature of data on leases, Marcellus Shale porosity, fine resolution wind power, etc., all projections are based on publicly available information;
- It was assumed that recent trends and patterns of energy development will continue for the next two decades absent significant changes in government policies and industry practices;

Energy projections contained in this assessment are informed scenarios – **not predictions** – for how much energy development might take place and where it is more and less probable. Projected impacts, however, are based on measurements of actual spatial footprints measured for hundreds of well pads and wind turbines.

Analytical Steps: Key analytical steps for the Pennsylvania Energy Assessment included:

1) *Data collection* – Over 50 spatial data layers on energy resources, development permits, road and transmission infrastructure, physical features, and conservation priorities were compiled for the assessment;

2) *Spatial footprint analysis* – Spatial footprints for Marcellus gas well and wind turbine pads, associated roads, associated pipelines, associated electric transmission lines, and associated other clearings (*e.g*., gas containment pits, equipment staging areas, electrical substations) were digitized using aerial photos of sites before and after construction;

3) *Scale projections* – Low, medium, and high scenarios for ***how much*** Marcellus Shale natural gas, wind, wood biomass, and transmission line development might occur were based as much as possible on existing projections and data from credible sources.

4) *Geographic projections* – Projections of ***where*** new Marcellus natural gas and wind energy development is more and less likely to occur were based on modeling the probability of a map pixel's land-use change to energy production based on sets of drivers and constraints developed for each energy type. Geographic projections for wood biomass and energy transmission were not modeled due to a lack of data. Conclusions about regional patterns of wood biomass and transmission development and potential conservation impacts will be presented in Report 2 of the Pennsylvania Energy Impacts Assessment.

5) *Conservation impacts analysis* – The potential impacts of future energy development were assessed for forest and freshwater habitats across the state. In addition, sites recognized as important for species of conservation concern were assessed. Conservation datasets for these assessments included, among others, large forest patches from The Nature Conservancy and the Western Pennsylvania Conservancy, habitat areas for rare species from the Pennsylvania Natural Heritage Program, densities for interior forest nesting bird species from the 2nd Pennsylvania Breeding Bird Atlas, and intact watersheds for native brook trout populations from the Eastern Brook Trout Joint Venture.

6) *Review* – A dozen energy experts in government, industry, and research organizations provided technical review of the energy projections.

Energy Projections: The Pennsylvania Energy Impacts Assessment developed low, medium and high scenarios for the amount of energy development that might take place in Pennsylvania by 2030. The projections include:

- *Marcellus Shale* – Sixty thousand wells could be drilled on between 6,000 and 15,000 new well pads (there are currently about 1,000) , depending on how many wells are placed on each pad. Gas development will occur in at least half of the state's counties, with the densest development likely in 15 counties in southwest, north central, and northeast Pennsylvania.

- *Wind* – Between 750 and 2,900 additional wind turbines could be built (there are currently about 500), depending on the wind share of electric generation by 2030. Most turbines would be built along the Allegheny Front in western Pennsylvania and on high Appalachian ridgetops in the central and northeastern parts of the state.

- *Wood Biomass* – Wood biomass energy demand could double or even triple today's wood energy use, depending on whether and how many coal power plants co-fire with wood biomass. Wood biomass energy development is likely to be widespread across the state in all three scenarios.

- *Transmission Lines* – Preliminary findings indicate between 10,000 and 15,000 thousand miles of new high-voltage power lines and gas pipelines (especially gathering lines) could be built during the next twenty years. There is considerable uncertainty about exactly where these lines will be built but recently proposed electric and gas transmission lines provide insights into potential habitat impacts.

Conservation Impacts: This first Pennsylvania Energy Impacts Assessment report focuses on the overlap between likely Marcellus gas and wind development areas and Pennsylvania's most important natural habitats. A second report will focus on the potential for additional impacts from new wood biomass energy plants, electric power lines, and natural gas pipelines. Key findings for impacts from Marcellus natural gas and for wind development include:

Forests. By 2030, a range of between 34,000 to 82,000 acres of forest cover could be cleared by new Marcellus gas development in the state. Forest clearing for the wind development scenarios is much smaller, ranging from 1,000 to 4,500 acres. Such clearings would create new forest edges where the risk of predation, changes in light and humidity levels, and expanded presence of invasive species could threaten forest interior species in 85,000 to 190,000 forest acres adjacent to Marcellus development and 5,400 to 27,000 forest acres adjacent to wind development. Forest impacts will be concentrated in the north central and southwest parts of the state where many of the state's largest and most intact forest patches could be fragmented into smaller patches by well pads, roads, and other infrastructure. Impacts to forest interior species will vary depending on their geographic distribution and density. Some species, such as the black-throated blue warbler, could see widespread impacts to their relatively restricted breeding habitats in the state while widely distributed species, such as the Scarlet Tanager, would be relatively less affected. Locating energy infrastructure in open areas or toward the outer edges of large patches can significantly reduce impacts to important forest areas.

Freshwater. Aquatic habitats are at risk too. Once widespread, healthy populations of native eastern brook trout in Pennsylvania are now largely confined to small mountain watersheds. Nearly 80 percent of the state's most intact brook trout watersheds could see at least some Marcellus gas and wind development during the next twenty years. Strongholds for brook trout are concentrated in north central Pennsylvania, where Marcellus development is projected to be relatively intensive in over half of the state's best brook trout watersheds. Exceptional Value streams – the Department of Environmental Protection's highest quality designation – could see hundreds of well pads (perhaps 300 - 750) and dozens of wind turbines (perhaps 50 – 200) located within one-half mile under the projections. Because many intact brook trout

Brook trout © TNC

and EV streams are in steep terrain, rigorous sediment controls, and possibly additional setback measures, are needed to help conserve these sensitive habitats.

Rare Species. Nearly 40 percent of Pennsylvania's globally rare and Pennsylvania threatened species can be found in areas with high potential for Marcellus gas development. These species tend to be associated with riparian areas, streams, and wetlands, while others are concentrated in unusually diverse areas such as the Youghiogheny Gorge. A handful of rare species have most or all of their known locations in high potential areas for Marcellus gas development. For example, three-fourths of all known snow trillium populations are in high potential Marcellus development areas as are all known populations for the green salamander. A much smaller number of known locations for globally and state rare species overlap with high potential wind development sites and they tend to be associated with rocky outcrops and ridgetop barrens habitats. Species with the greatest overlaps include timber rattlesnakes, Allegheny woodrats, and northern long-eared Myotis bats. More intensive surveys for globally rare and state critically endangered species in high potential Marcellus and wind development areas could help to minimize impacts before development begins. The Pennsylvania Game Commission is working with wind companies and other researchers to assess impacts to migratory pathways for birds and bats.

Recreation. Extensive overlaps are projected between Marcellus development and state forests, state parks, and state game lands. Just over ten percent of Pennsylvania's public lands are legally protected from gas development, most of it within State Wild and Natural Areas or in state parks where the Commonwealth owns the mineral rights. The state does not own mineral rights for 80% of State Park and State Game Lands, nearly 700,000 acres of State Forests have already been leased, and only about 300,000 acres of the remaining State Forest Lands are legally off-limits to future leases. Projections indicate between 900 and 2,200 well pads could be developed across all state lands, with most going on State Forest Lands, followed by State Game Lands, and State Parks. Wind development was not projected on state lands, though some facilities are projected near highly visited sites, including natural vistas.

Clearly, the heart of some of Pennsylvania's best natural habitats lie directly in the path of future energy development. Integrating information on conservation priorities into energy planning, operations, and policy by energy companies and government agencies sooner rather than later could dramatically reduce these impacts. Many factors – including energy prices, economic benefits, greenhouse gas reductions, and energy independence – will go into final decisions about where and how to proceed with energy development. Information about Pennsylvania's most important natural habitats should be an important part of the calculus about trade-offs and optimization as energy development proceeds. Would Pennsylvania's conservation pioneers, including Gifford Pinchot, Maurice Goddard, and Rachel Carson, expect anything less?

Marcellus Shale Natural Gas

Once thought to be inaccessible, deep shale formations with tightly held natural gas have become the most rapidly growing source of energy in North America. New technologies and methods have allowed companies to drill 6,000 to 10,000 feet down to reach the Marcellus shale, turn the well horizontally to follow the shale layer for a mile or more, and then pump in millions of gallons of water to fracture the shale and release the natural gas. Pennsylvania is at the epicenter of the Marcellus formation, one of the world's largest unconventional shale natural gas reserves. Situated right next door to huge markets in the Mid-Atlantic and Northeastern states, Marcellus gas development has expanded at a furious pace since the first wells were drilled just few years ago in Washington County. There are now nearly 2,000 drilled wells, most of them concentrated in the southwestern and northeastern parts of the state.

The Marcellus boom is bringing rapid economic growth to many rural communities that have been in economic decline for decades. Natural gas is also displacing higher carbon coal and oil supplies thus slowing the rise in greenhouse gas emissions. These benefits are real but not without costs. Large amounts of water must be withdrawn to frac each well (about 5 million gallons). The return flow water that comes back up from the well contains varying levels of chemicals, heavy metals, and even radioactive materials, and must be handled carefully to avoid spills when recycled or disposed. Heavy trucks and compressor stations rumble constantly in gas development areas putting heavy strains on roads, bridges and air quality. Because of known and perceived risks to environmental quality and human health, water use, air emissions and transportation demands are receiving growing attention from government agencies, researchers and energy companies. Thus far, relatively little attention, however, has been focused on Marcellus gas development impacts to natural habitats across the state.

What is Marcellus Shale Natural Gas?

The Marcellus is the largest gas-bearing shale formation in North America in both area and potential gas volume. It spans over 150,000 square miles across 5 states including the southern tier of New York, the northern and western half of Pennsylvania, the eastern third of Ohio, most of West Virginia, and a small slice of western Virginia. Estimates of the potential recoverable volume have increased steadily. The latest estimates by the U.S. Department of Energy are nearly 300 trillion cubic feet – enough to supply all natural gas demand in the United States for at least 10 years.

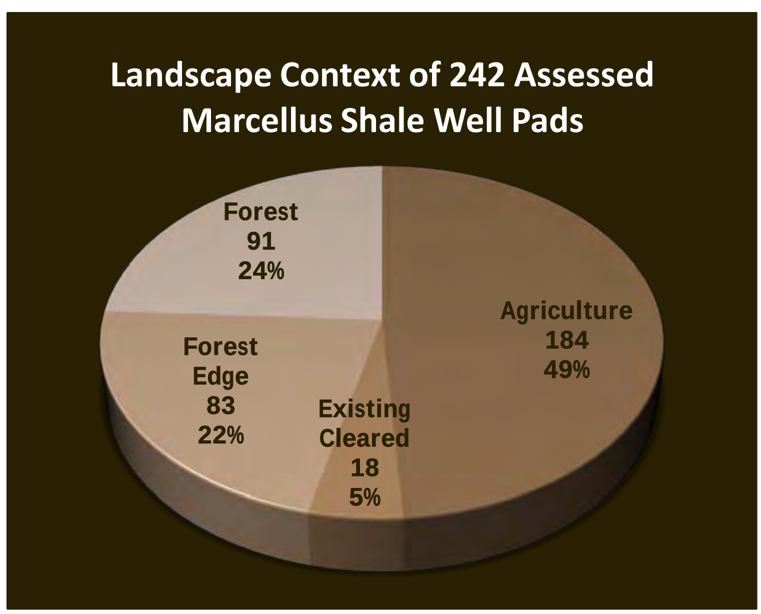
Map showing the extent of the Marcellus Shale formation. Data source: United States Geological Survey.

Geologists have long known the Marcellus formation is an organically-rich shale with potentially large amounts of natural gas, but it was too deep, too thin, and too dense to exploit. In 2005, Range Resources drilled the first production Marcellus well using horizontal drilling and hydraulic fracturing methods. The horizontal drilling is necessary because the shale is typically thin and vertical wells will only intercept a small part of the formation. Hydraulic fracturing (or "fracing") is a process that uses large volumes of water, sand, lubricants, and other chemicals to create small fissures in the shale rock. Hydro-fracing is necessary to release the gas which is tightly held in the dense black shale. These methods, first perfected for deep shale gas in the Barnett formation of Texas, unlocked the tremendous gas reserves in the Marcellus and other "unconventional" shale formations previously thought to be out of economic reach.

In contrast to shallow gas deposits in western Pennsylvania, the Marcellus is developed with multiple horizontal wells that can reach out 5,000 feet or more from one well pad. Everything about Marcellus development is bigger than conventional shallow gas plays. The well pads are more expansive (averaging just over 3 acres compared to a small fraction of an acre), the water used to frac wells is much greater (5 million gallons versus a hundred thousand gallons), and the supporting infrastructure is much larger in scale (24" diameter pipelines to gather gas from wells versus 2" or 4" pipelines in shallow fields). Individual wells are also vastly more productive (5 – 10 million cubic feet per day versus less than 100,000 cubic feet in peak early production). While the larger pad, greater water use, and more extensive infrastructure pose more challenges for conservation than shallow gas, the area "drained" by wells on each Marcellus pad is much larger than from shallow gas pads (500-1,000 acres versus 10-80 acres) since there are typically multiple lateral wells on a Marcellus pad versus a single vertical well on a shallow gas pad. The lateral reach of Marcellus wells means there is more flexibility in where pads and infrastructure can be placed relative to shallow gas. This increased flexibility in placing Marcellus infrastructure can be used to avoid or minimize impacts to natural habitats in comparison to more densely-spaced shallow gas fields.

Current and Projected Marcellus Shale Natural Gas Development

Projections of future Marcellus gas development impacts depend on robust spatial measurements for existing Marcellus well pads and infrastructure. We have been able to precisely document the spatial foot print for 242 Marcellus well sites across the state by comparing aerial photos of Pennsylvania Department of Environmental Protection (DEP) Marcellus well permit locations taken before and after development. The ground excavated for wells and associated infrastructure is the most obvious spatial impact.



For each well site, the area for the well pad, new or expanded roads, gathering pipelines, and water impoundments were digitized and measured.

Aerial photos before and after development of a Marcellus gas well pad site in Susquehanna County, PA. To assess the impacts of this type of energy development, we have digitized the spatial footprint of 242 gas well pad sites and associated infrastructure.

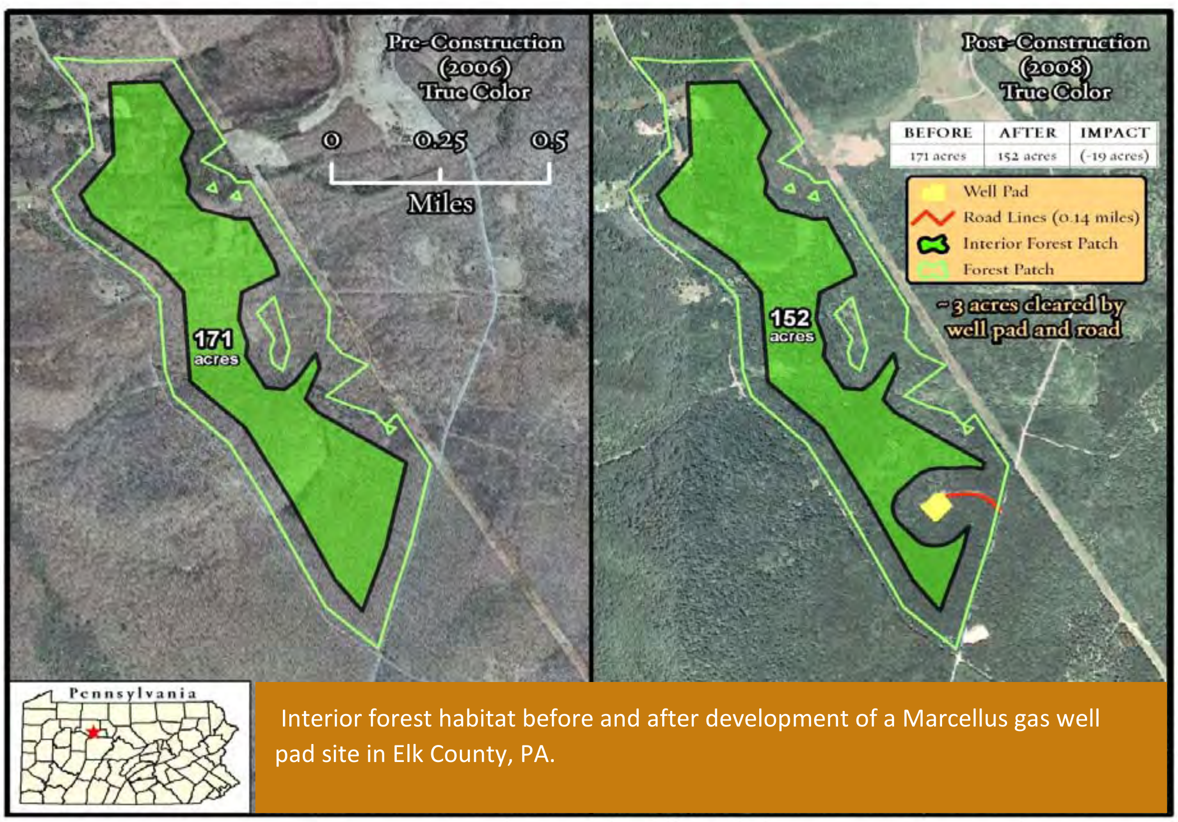
Average Spatial Disturbance for Marcellus Shale Well Pads in Forested Context (acres)		
Forest cleared for Marcellus Shale well pad	**3.1**	**8.8**
Forest cleared for associated infrastructure (roads, pipelines, water impoundments, etc.)	**5.7**	
Indirect forest impact from new edges	**21.2**	
TOTAL DIRECT AND INDIRECT IMPACTS	**30**	

Well pads occupy 3.1 acres on average while the associated infrastructure (roads, water impoundments, pipelines) takes up an additional 5.7 acres, or a total of nearly 9 acres per well pad.

Adjacent lands can also be impacted, even if they are not directly cleared. This is most notable in forest settings where clearings fragment contiguous forest patches, create new edges, and change habitat conditions for sensitive wildlife and plant species that depend on “interior” forest conditions.

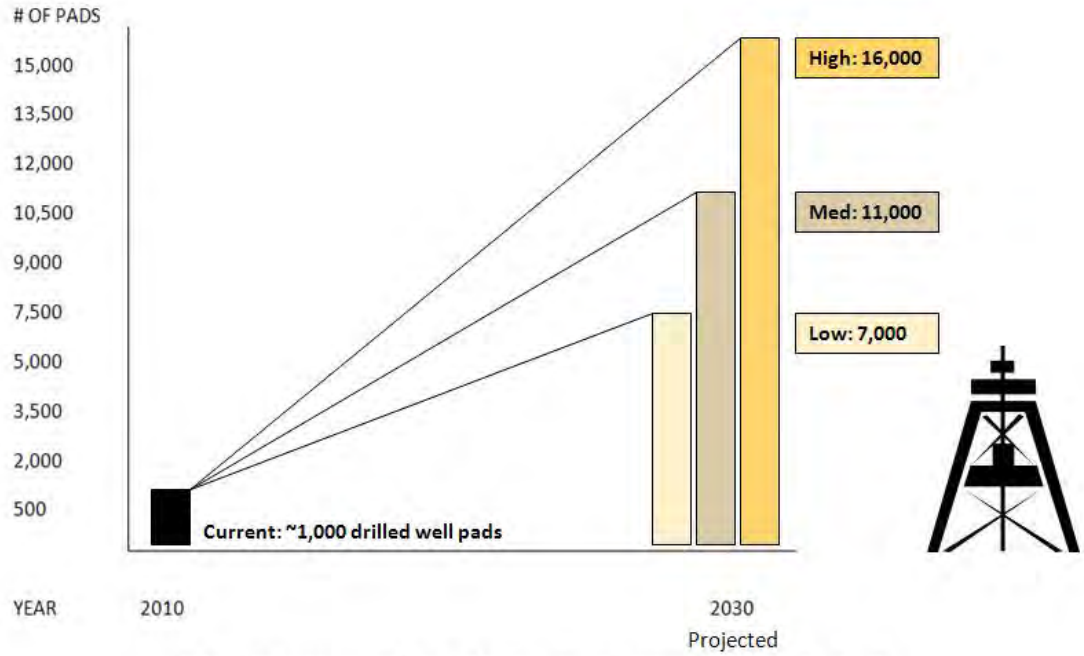
Forest ecologists call this the “edge effect.” While the effect is somewhat different for each species, research has shown measurable impacts often extend at least 330 feet (100 meters) forest adjacent to an edge. Interior forest species avoid edges for different reasons. Black-throated blue warblers and other interior forest nesting birds, for example, avoid areas near edges because of the increased risk of predation. Tree frogs, flying squirrels and certain woodland flowers are sensitive to forest fragmentation because of changes in canopy cover, humidity and light levels. Some species, especially common species such as whitetail deer and cowbirds, are attracted to forest edges – often resulting in increased competition, predation, parasitism, and herbivory. Invasive plant species, such as tree of heaven, stilt grass, and Japanese barberry, often thrive on forest edges and can displace native forest species. As large forest patches become progressively cut into smaller patches, populations of forest interior species decline.

To assess the potential interior forest habitat impact, we created a 100 meter buffer into forest patches from new edges created by well pad and associated infrastructure development. For those well sites developed in forest areas (about half of the 242 total sites), an average area of 21 acres of interior forest habitat was lost.



Interior forest habitat before and after development of a Marcellus gas well pad site in Elk County, PA.

The number of Marcellus wells drilled in Pennsylvania during the next two decades will expand steadily. Just how many wells are drilled will be driven by various factors including natural gas prices, technological improvements, human resources, regulatory changes in Pennsylvania and beyond (e.g., end of New York drilling moratorium), and social preferences. Assessing how these factors will change over the next two decades is very difficult; therefore our projections assume economic, policy, and social conditions remain stable enough to promote steady expansion of Marcellus gas development in the state. The first key variable in our projection is the number of drilling rigs that will be operating in Pennsylvania. By October 2010, the industry had moved just over 100 rigs into Pennsylvania to drill Marcellus wells according to the Baker-Hughes weekly rig count. Given the high productivity of the Marcellus and its proximity to major northeastern markets, most industry observers expect this number to continue growing steadily. The number of horizontal drill rigs operating in the Barnett Shale has peaked at about 200, but the



Key drivers: number of rigs, number of wells per pad.

We project 60,000 Marcellus wells will be drilled during the next twenty years based on company investor presentations and academic assessments of gas development potential. Depending on how many wells on average are placed on the same pad site (see illustration below), we project between 7,000 and 16,000 new well pad sites will be developed in Pennsylvania by 2030.

Low-Impact Scenario	Medium-Impact Scenario	High-Impact Scenario
10 wells per pad	6 wells per pad	4 wells per pad
Pads spaced ~5,200 ft apart	Pads spaced ~4,100 ft apart	Pads spaced ~3,350 ft apart

Marcellus Shale is much larger and could reach 300 rigs in Pennsylvania alone. We chose a conservative estimate of 250 maximum horizontal drill rigs for each scale projection scenario. Assuming that each rig can drill one well per month, 3,000 wells are estimated to be drilled annually. At that rate, 60,000 new wells would be drilled by the year 2030.

The second key variable, especially for determining land-use and habitat impacts, is the number of wells on each pad. Because each horizontal well can drain gas from 80 to 170 acres (depending on the lateral well length), more wells per pad translates to less disturbance and infrastructure on the landscape. It's technically possible to put a dozen or more Marcellus wells on one pad So far, the average in Pennsylvania is two wells per pad as companies quickly move on to drill other leases to test productivity and to secure as many potentially productive leases as possible (leases typically expire after 5 years if there is no drilling activity). In many cases, the gas company will return to these pads later and drill additional wells. The low scenario (6,000 well pads) assumes that each pad on average will have ten wells. Because many leases are irregularly shaped, in mixed ownership, or the topography and geology impose constraints, it is unlikely this scenario will develop. It would take relatively consolidated leaseholds and few logistical constraints for this scenario to occur. The medium scenario for well pads assumes 6 wells on average will be drilled from each pad, or 10,000 well pads across the state. Industry staff generally agree that six is the most likely number of wells they will be developing per pad for most of their leaseholds, at least where lease patterns facilitate drilling units of 600 acres or larger. The high scenario assumes each pad will have 4 wells drilled on average, or 15,000 well pads across the state. This scenario is more likely if there is relatively little consolidation of lease holds between companies in the next several years.

The number of well pads is less important than where they are located, at least from a habitat conservation perspective. To understand which areas within Pennsylvania's Marcellus formation are more and less likely to be developed, we used a machine-based learning modeling approach known as maximum entropy (Maxent 3.3.3a, Princeton University). Maximum entropy was used to find relationships between 1,461 existing and permitted well pad locations and variables that might be relevant to a company's decision to drill a Marcellus well. Such variables were chosen based on data availability and included Marcellus Shale depth, thickness and thermal maturity as well as percent slope, distance to pipelines, and distance to roads. The model produces a raster surface that represents the probability of an area to potentially support future gas well development. An additional 487 existing and permitted wells were used to test the validity of the model's probability surface and the model was found to be 80% accurate in predicting existing and permitted wells from randomly sampled undeveloped areas. The resulting probability map indicates wide variation across the Marcellus formation in terms of the likelihood of future gas well development.

To get a better sense of where gas development is most likely, we searched for the highest probability areas where well pads in each scenario might be located. The probability raster was re-sampled to a resolution that reflects the minimum separation distance between well pads for each of the three impact scenarios (low – 5,217 ft; medium – 4,134 ft; high – 3,346 ft). The minimum separation distance represents the drainage area for gas extraction and is dependent upon the number of wells per pad, which differs among the three impact scenarios. Using this method, each pixel of the raster represents the combined area of a well pad plus the minimum separation distance. The highest probable pixels were then selected until the threshold for each impact scenario was reached (low – 6,000 well pads; medium – 10,000 well pads; high – 15,000 well pads). Areas incompatible for future gas exploration (existing drilled Marcellus Shale wells, Wild and Natural Areas, and water bodies) were excluded from being selected as probable pixels. The highest probable pixels were then converted into points for map display purposes.

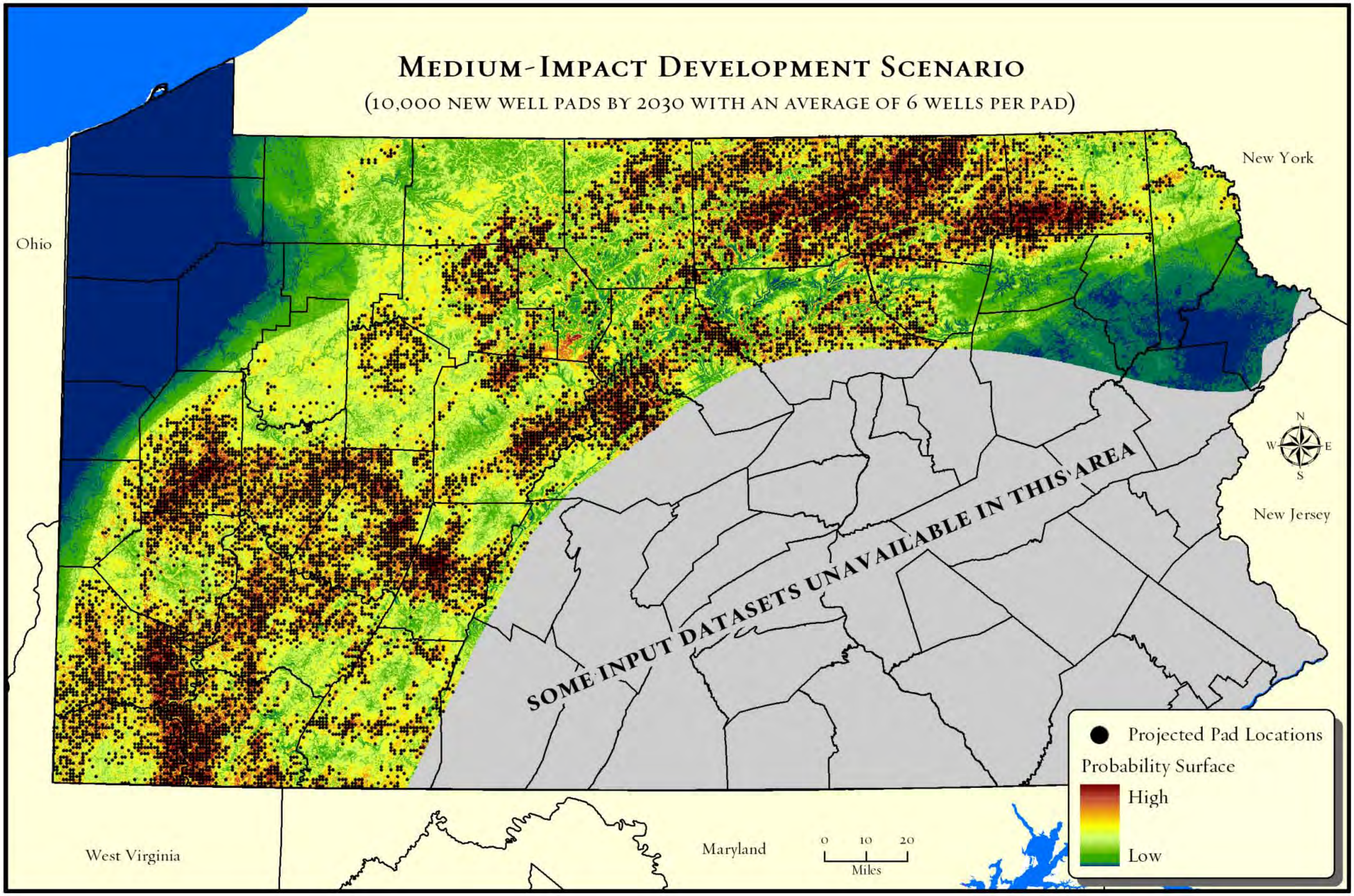
While the geographic area with projected well pads expands from low to high scenarios, the overall geographic pattern is not cumulative due to the differences in minimum separation distance between the three scenarios. Overall, hotspots for future gas development can be seen in half a dozen counties in southwestern Pennsylvania and half a dozen counties in north central and northeastern parts of the state.

These geographic projections of future Marcellus gas development are spatial representations of possible scenarios. They are not predictions. We faced several constraints in developing the geographic scenarios:

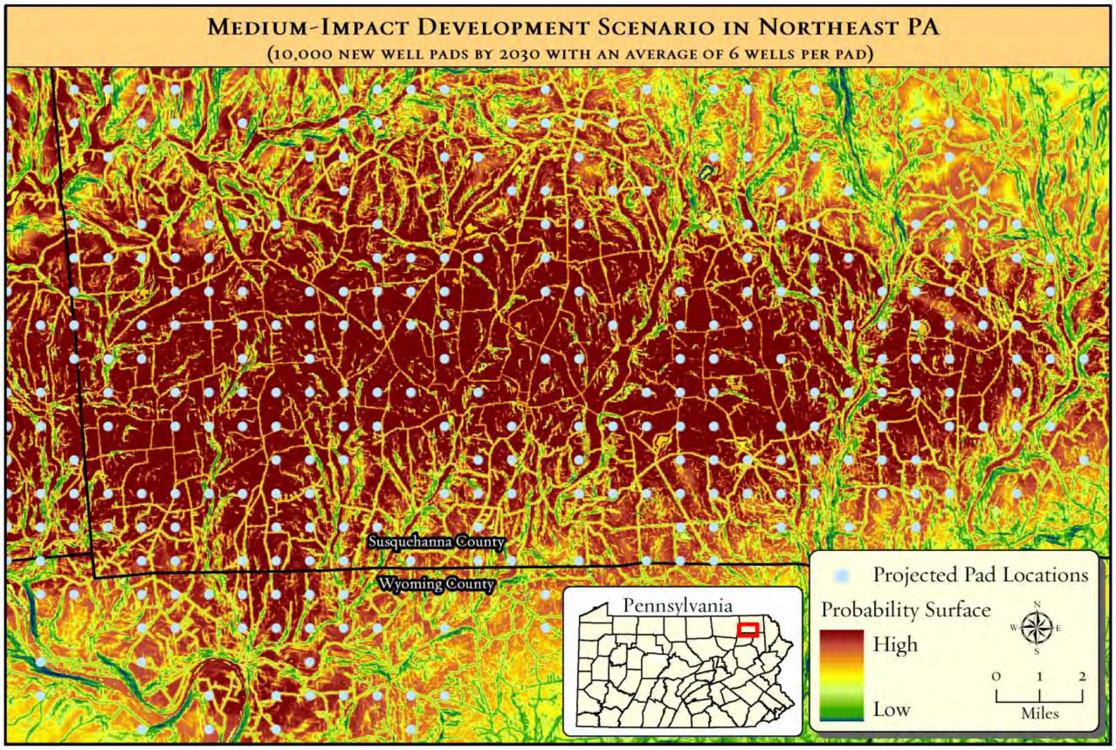
- We do not have access to proprietary seismic and test well geologic data that natural gas companies have. Shale porosity, for example, is a key factor but there are no publicly available data for this.

- We do not have the detailed location of gas company leases. Each company is looking for the highest probability locations across their lease holds while our model looks for the highest probability sites across the entire Marcellus formation in the state. Because there have only been a few Marcellus test wells and permits in the Delaware watershed, we believe the projections for new well pads are probably significantly underestimated in Wayne County.

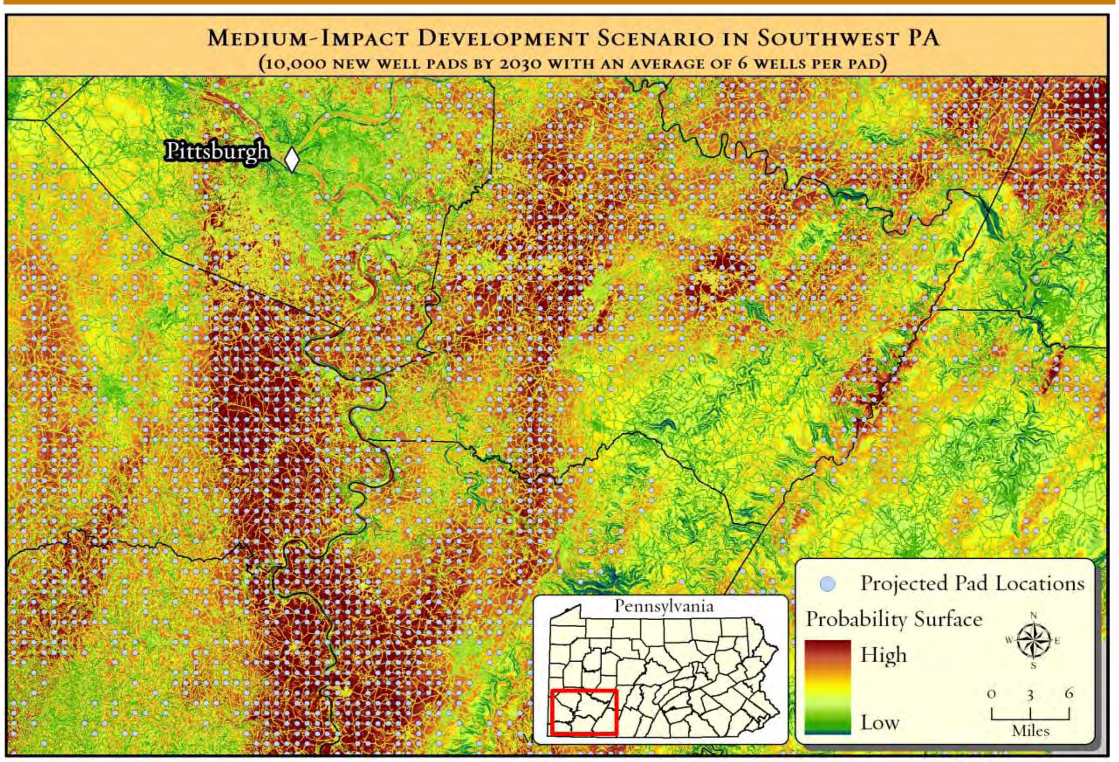
Still, we believe the overall geographic patterns in the projected gas development locations are relatively robust for several reasons. We used nearly 1,500 existing drilled or permitted well pads to build the model and nearly 500 additional drilled and permitted well pads to validate the model. This is typically a sufficient sample size for building predictive models. Additionally, reviews from industry, academic, and government agency reviewers indicate our methods and results are generally sound. Some reviewers expect future well pad locations to be more geographically expansive than our current projections indicate, especially in the Delaware watershed where only a few Marcellus test wells and permits have been issued. Our projections for Wayne County, for example, are likely underestimating future development potential.



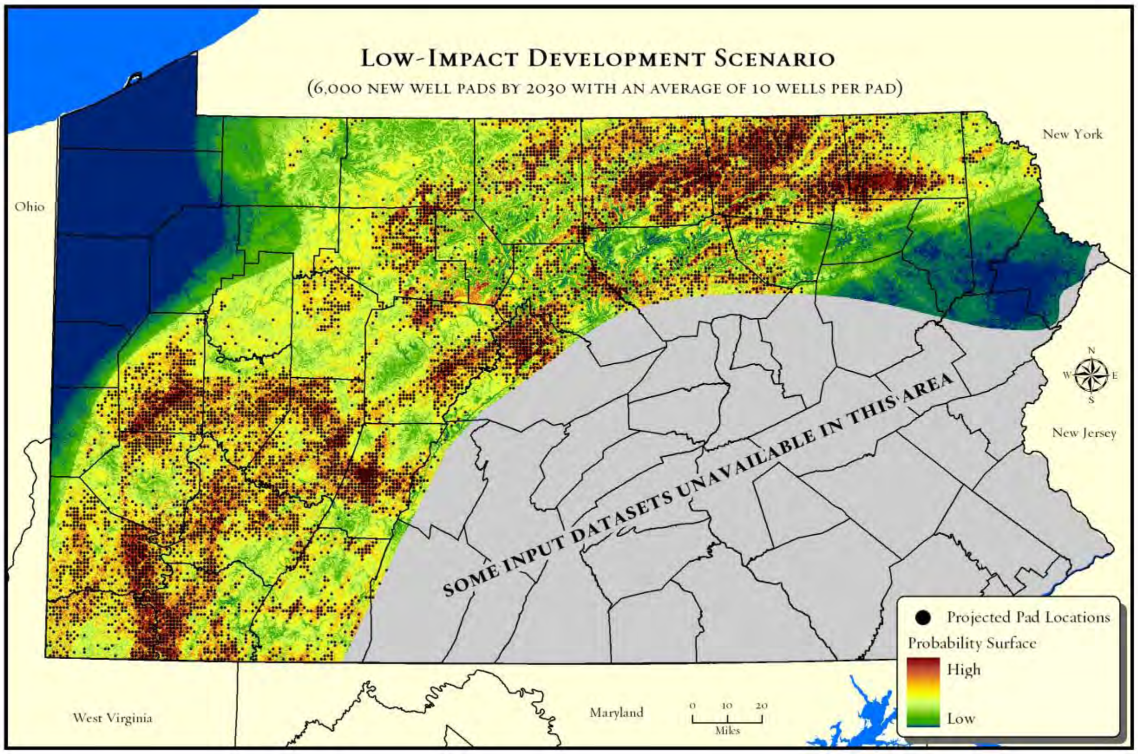
Map showing projected location of 10,000 new Marcellus Shale natural gas pads across Pennsylvania (medium development scenario).



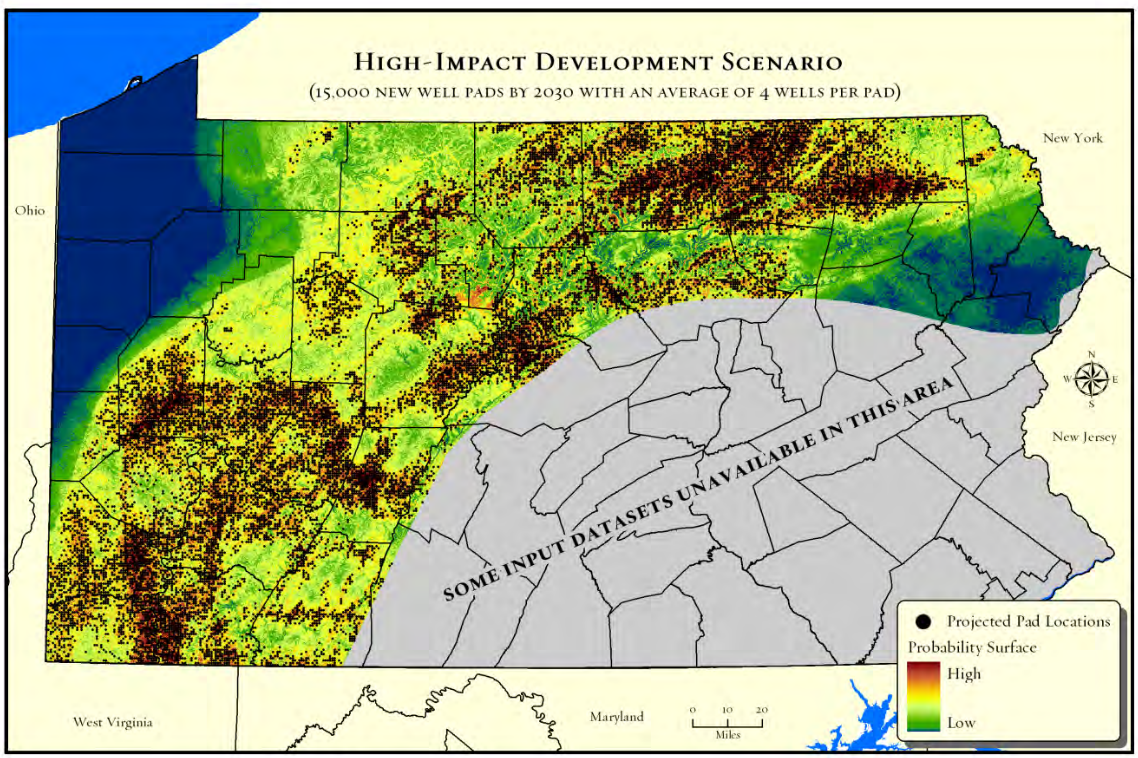
Map showing projected location of new Marcellus well pads in southern Susquehanna County under the medium development scenario.



Map showing projected location of new Marcellus well pads in southwestern Pennsylvania under the medium development scenario.



Map showing projected location of 6,000 new Marcellus well pads across Pennsylvania (low development scenario).



Map showing projected location of 15,000 new Marcellus well pads across Pennsylvania (high development scenario).

Conservation Impacts of Marcellus Shale Natural Gas Development

What is the overlap of the areas with the highest probability of future Marcellus gas development and those areas known to have high conservation values? To answer this question, we intersected the projected Marcellus well pads with areas previously identified and mapped as having high conservation values. We looked at several examples from four categories of conservation value, including:

- Forest habitats
- Freshwater habitats
- Species of conservation concern
- Outdoor recreation

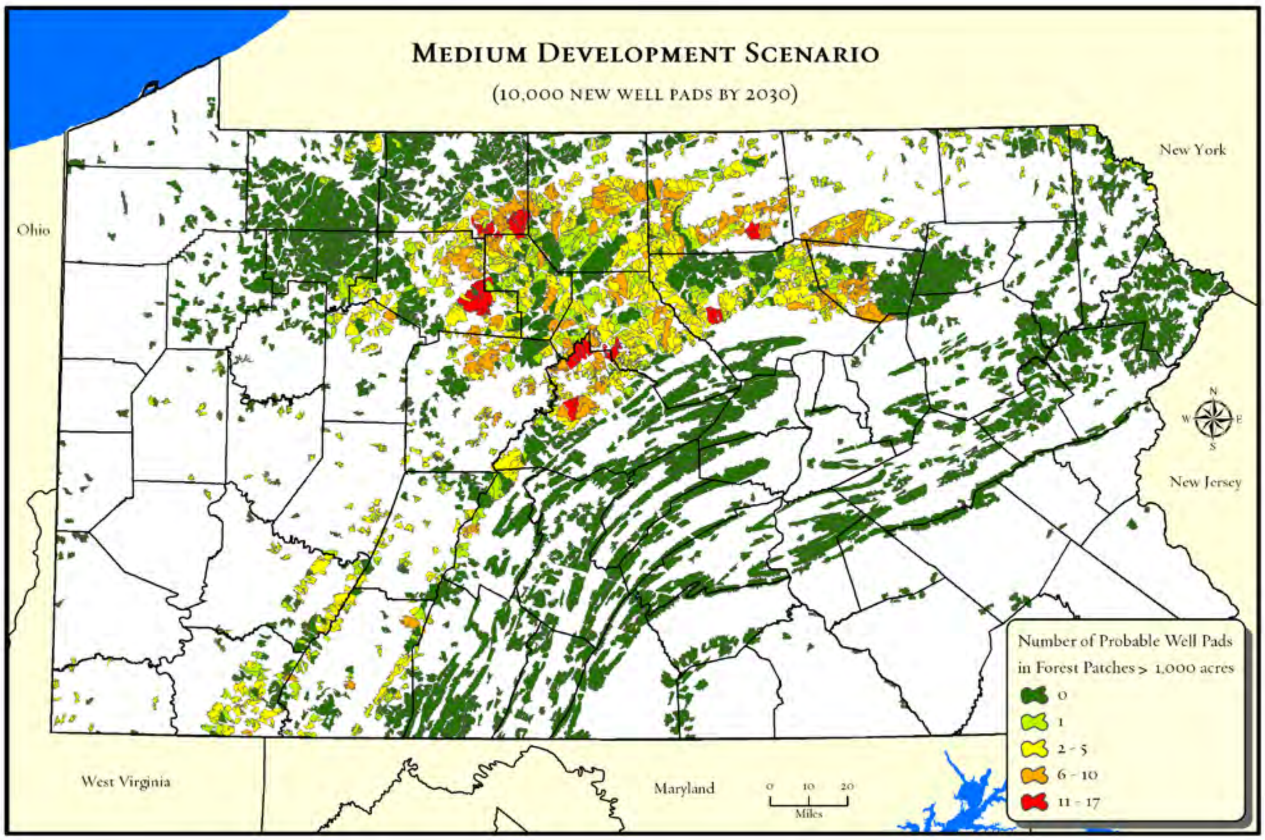
Substantial areas of overlap are indicated between likely future Marcellus development areas and Pennsylvania's most important forest, freshwater, sensitive species habitats, and outdoor recreation sites.

FORESTS

Forests are Pennsylvania's most extensive natural habitat type. Once covering at least 95 percent of the state's land area, forests were whittled away for agriculture, charcoal for iron smelting, and lumber until only a third of the state's forests remained. Forests have rebounded steadily to cover about 60 percent of the state, though a trend toward increasing net loss of forest has emerged during the past decade. Pennsylvania is famous worldwide for its outstanding cherry, oak, and maple hardwoods, and forests provide livelihoods for many thousands of Pennsylvanians in the forest products and tourism industries. They also contribute enormously to the quality of life for all Pennsylvanians by filtering contaminants from water and air, reducing the severity of floods, sequestering carbon dioxide emissions that would otherwise warm the planet, and providing a scenic backdrop to recreational pursuits.

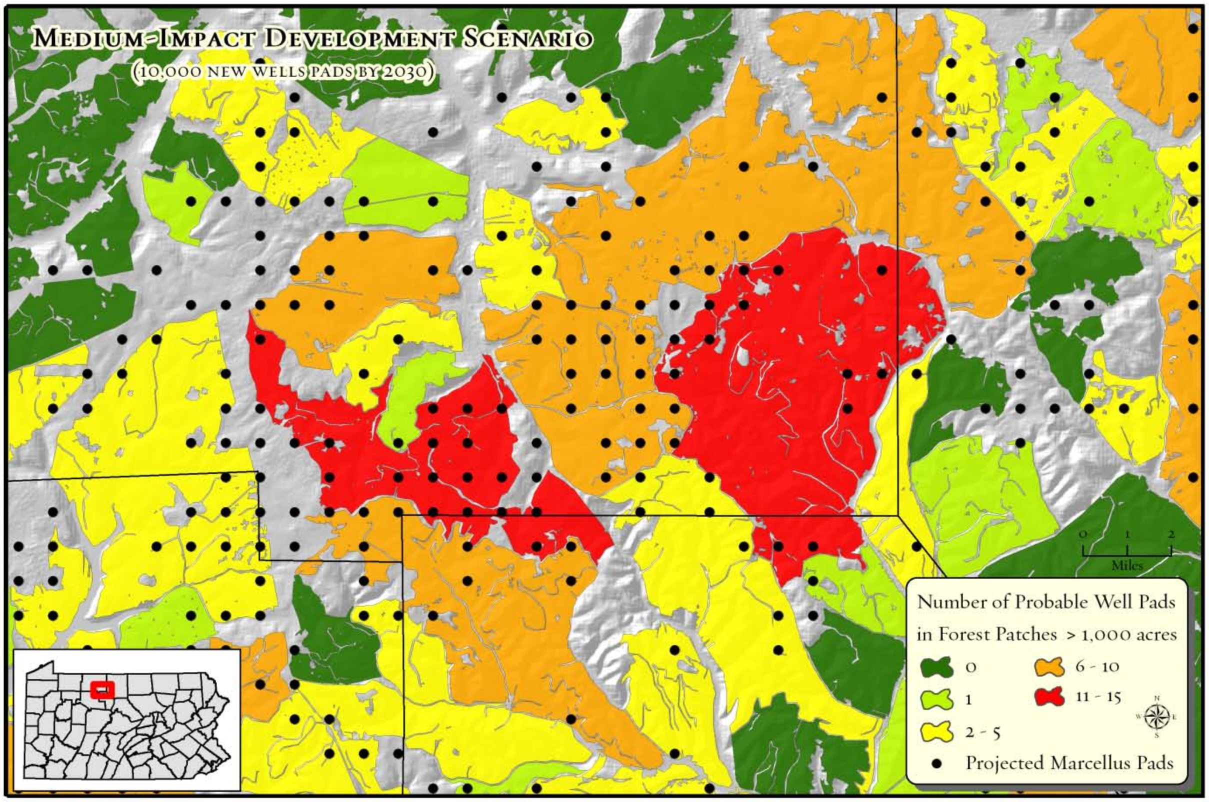
A majority of projected well locations are found in a forest setting for all three scenarios (64% in each case). The low scenario would see 3,845 well pads in forest areas. With an average cleared forest average of 8.8 acres per pad (including roads and other infrastructure), the total forest clearing would be approximately 33,800 acres. Indirect impacts to adjacent forest interior habitats would total an additional 81,500 acres. Forest impacts from the medium scenario (6,350 projected wells in forest locations) would be 56,000 cleared forest acres and an additional 135,000 acres of adjacent forest interior habitat impacts. For the high scenario (9,448 forest well pads), approximately 83,000 acres would be cleared and an additional 200,300 acres of forest interior habitats affected by new adjacent clearings. While the high Marcellus scenario would result in a loss of less than one percent of the state's total forest acreage, areas with intensive Marcellus gas development could see a loss of 2-3 percent of local forest habitats. Some part of the cleared forest area will become reforested after drilling is completed, but there has not been enough time to establish a trend since the Marcellus development started.

While all forests have conservation value, large contiguous forest patches are especially valuable because they usually sustain a wider array of forest species than small patches. They are also more resistant to the spread of invasive species, suffer less tree damage from wind and ice storms, and provide more ecosystem services – from carbon sequestration to water filtration – than small patches. The Nature Conservancy and the Western Pennsylvania Conservancy's Forest Conservation Analysis mapped nearly 25,000 forest patches in the state greater than 100 acres. Patches at least 1,000 acres in size are about a tenth of the total (2,700). Patches at least 5,000 acres are relatively rare (only 316 patches). In contrast to overall forest loss, projected Marcellus gas development scenarios indicate a more pronounced impact on large forest patches. For example, over 20 percent of patches greater than 1,000 acres are projected to have at least one well pad and associated infrastructure located in them. Most affected large patches have multiple projected well pads (as many as 29). The projections indicate larger patches are likely to be more vulnerable, with over a third projected to have at least one new well



Map showing number of probable Marcellus well pads in forest patches greater than 1,000 acres across Pennsylvania.

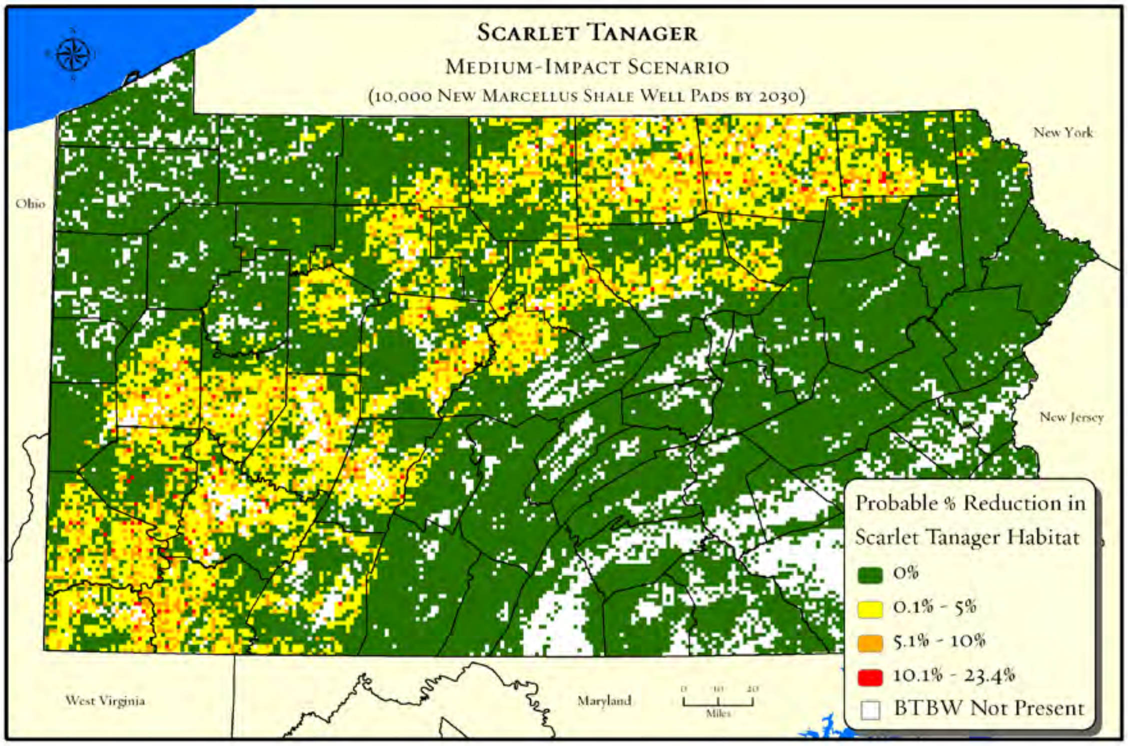
pad and road. Many affected large patches have multiple projected well pads (as many as 17 for patches). While one or two well pads and associated infrastructure will not necessarily fragment the large patch into smaller patches, each additional well pad increases the likelihood that the large patch will become several smaller patches with a substantially reduced forest interior habitat area.



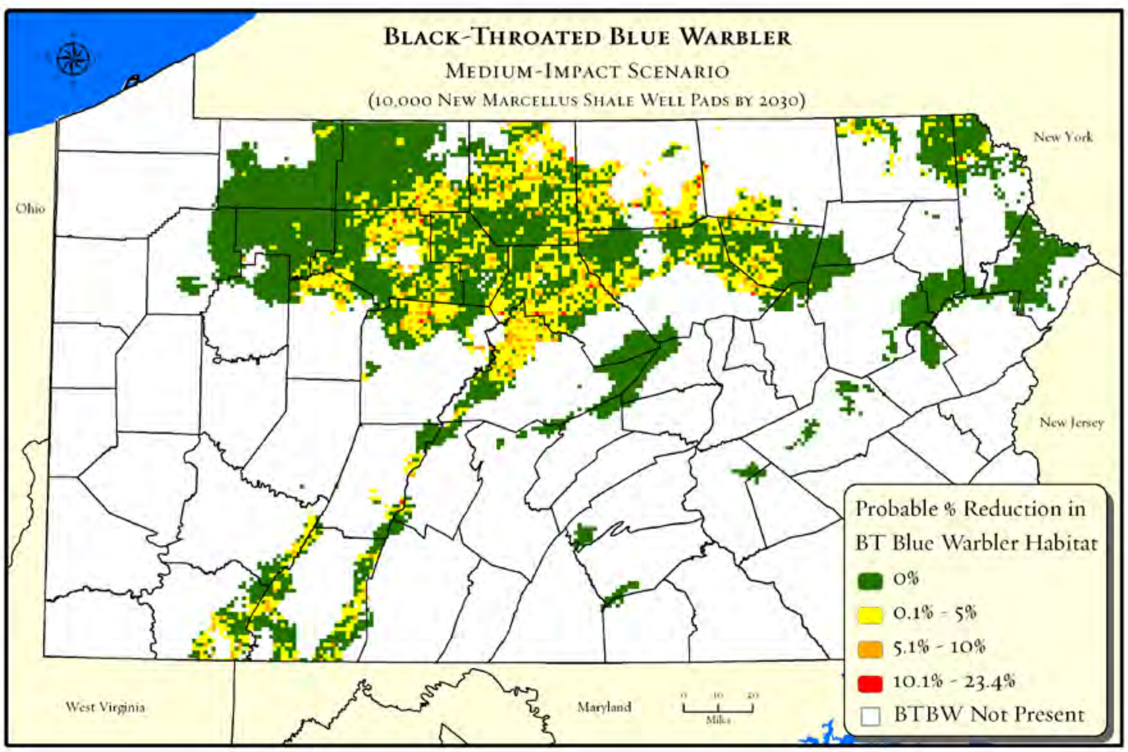
Map showing projected number of well pads in forest patches greater than 1,000 acres under the medium development scenario in Potter, Cameron, McKean and Forest Counties.

Bird species that nest in close canopy forest environments are often referred to as "forest interior" species. The Carnegie Museum of Natural History, Powdermill Nature Reserve and the Pennsylvania Game Commission recently completed Pennsylvania's Second Breeding Bird Atlas project. Thousands of experienced volunteer birders took point count counts using standardized protocols at 39,000 sites across the state. The result is an incredibly detailed data base that provides the most accurate reflection of the distribution and density of breeding birds in the United States. Density data for several forest interior nesting species were mapped and intersected with the projected Marcellus gas well pad locations. The resulting maps show the estimated reduction in habitat for that species in each Marcellus gas probability pixel (including both cleared forest and adjacent edge effects). Scarlet Tanagers are perhaps the most widespread forest interior nesting bird in the state. Since they are so widespread, a majority of their range in the state is outside of the most likely Marcellus development areas. In some locations, Scarlet Tanager populations could decline by as much as 23 percent in the Medium Scenario. Black-Throated Blue Warblers are more narrowly distributed in Pennsylvania favoring mature northern hardwood and coniferous forests with a thick understory, frequently in mountain terrain. Since most of their breeding range in Pennsylvania overlaps with likely Marcellus development areas, a higher proportion of their habitat could be affected.

Scarlet tanager © U.S. Fish and Wildlife Service



Map showing estimated percent loss of habitat for Scarlet Tanagers under medium scenario.

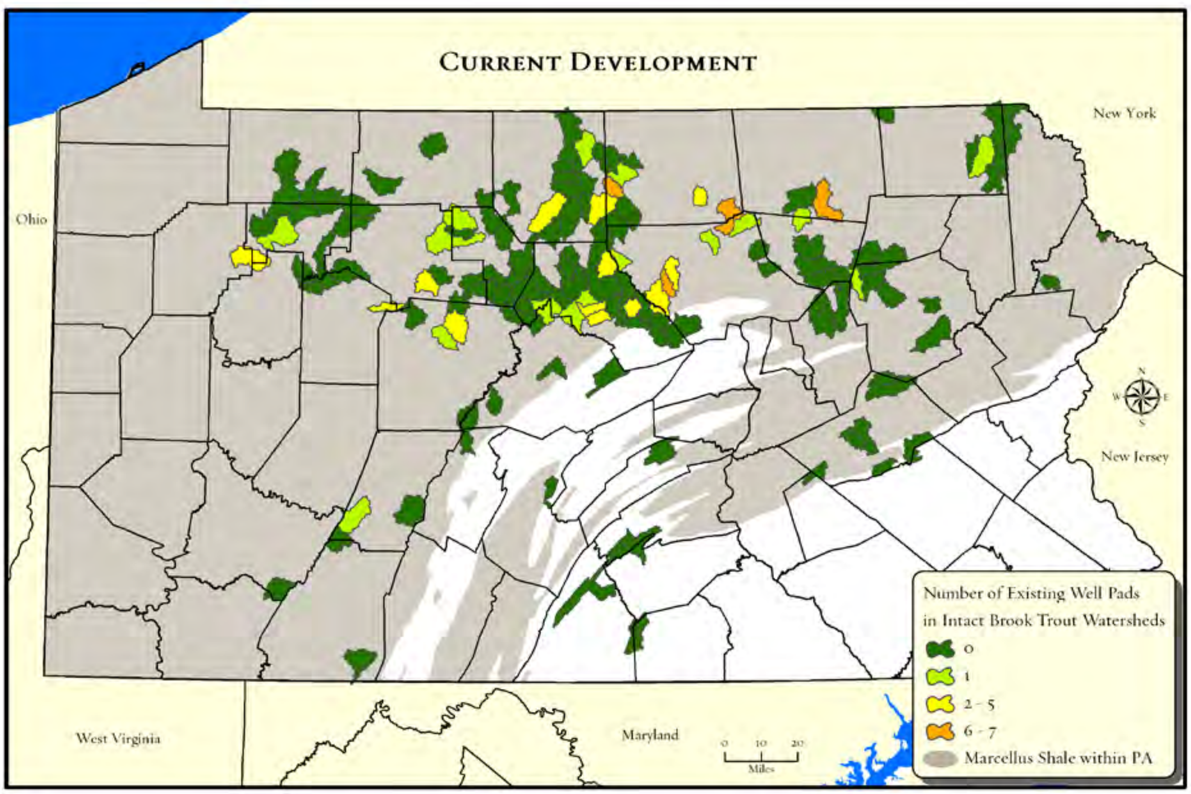


Map showing estimated percent loss of habitat for Black-Throated Blue Warblers under medium scenario.

FRESHWATER

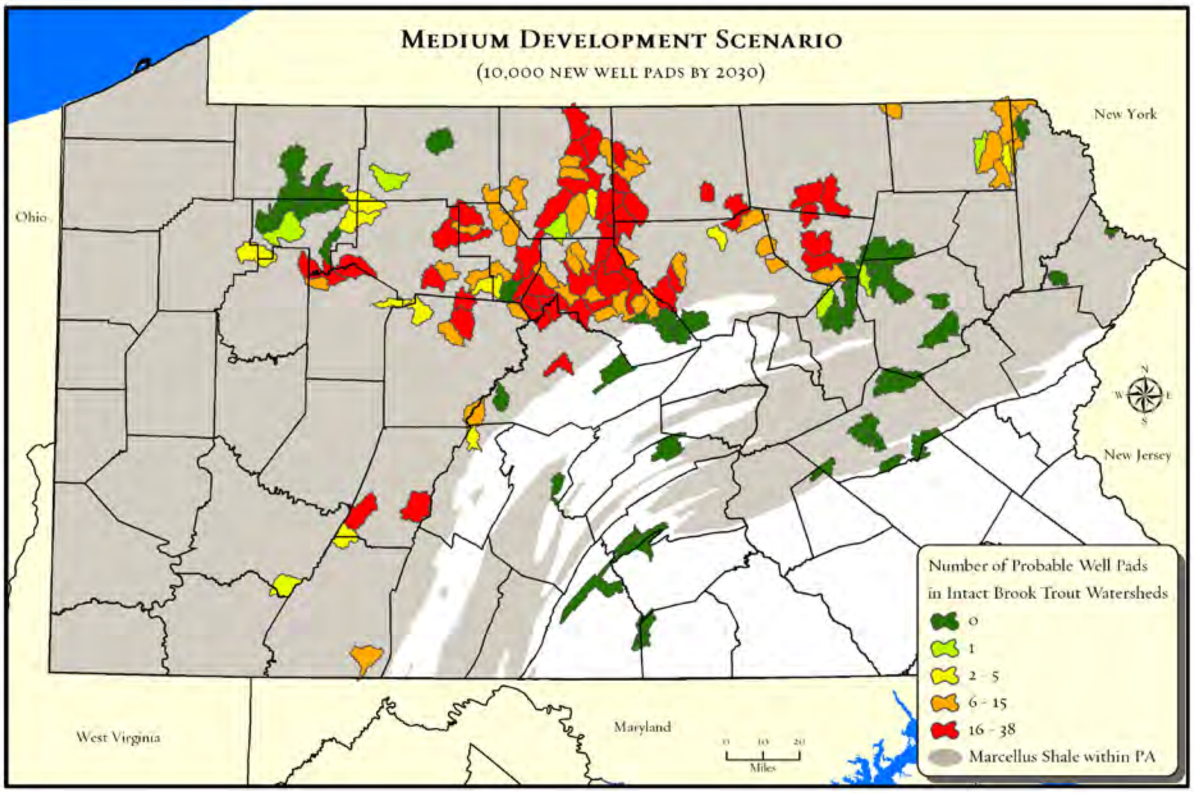
Home to three great river systems and one of the Great Lakes, Pennsylvania's fresh water resources are vital not only to the Commonwealth but to much of the eastern United States. The ***Ohio River*** basin contains the richest fresh water ecosystems in North America. In Pennsylvania, French Creek and parts of the Upper Allegheny River contain some of the most intact aquatic ecosystems in the entire basin. The ***Susquehanna*** **River** is the source of more than half the fresh water that enters the Chesapeake Bay, and most of the water that flows down the Susquehanna River originates in tributary headwaters across a wide swath of central Pennsylvania. Forming Pennsylvania's eastern boundary, the ***Delaware River*** is the longest undammed river in the eastern United States, one of the last strongholds for Atlantic coast migratory fish, and provides the drinking water source for nearly 20 million Americans living in Pennsylvania, New York, and New Jersey. Because of their importance to human health and livelihoods, the potential of Marcellus gas development to affect water flows and quality have received growing attention from regulatory agencies, natural gas companies, and environmental groups.

The intersection of gas development with sensitive watersheds has received less attention. High Quality and Exceptional Value (EV) watersheds have been designated by the Pennsylvania Department of Environmental



Map showing current number of Marcellus well pads in intact and predicted intact brook trout watersheds. Data source: Eastern Brook Trout Joint Venture.

Protection across the state. Our projections indicate 28 percent of High Quality and 5 percent of Exceptional Values streams have or will have Marcellus gas development during the next two decades presence of well pads in these watersheds may not be a problem as long as spill containment measures and erosion and sedimentation regulations are strictly observed and enforced in these areas. More specifically, the projections indicate 3,581 well pads could be located within ½ mile of a High Quality or Exceptional Values streams. Pads within close proximity to High Quality and especially Exceptional Value streams pose more risk than those at greater distances, as there is increased risk for potential spills and uncontained sediments to find their way into streams.



Map showing projected number of Marcellus well pads by 2030 in intact and predicted intact brook trout watersheds under medium scenario. Data source: Eastern Brook Trout Joint Venture.

Native brook trout are one of the most sensitive aquatic species in Pennsylvania watersheds. Brook trout favor cold, highly-oxygenated water and are unusually sensitive to warmer temperatures, sediments, and contaminants. Once widely distributed across Pennsylvania, healthy populations have retreated to a shrinking number of small watersheds. Many of these watersheds overlap with the Marcellus shale formation. A large majority (113) of the 138 intact or predicted intact native brook trout watersheds in Pennsylvania are projected to see at least some Marcellus gas development. Over half (74) are projected to host between 6 – 38 well pads, and the number reaches as high as 64 pads for some intact brook trout watersheds in the high scenario. Rigorous sediment controls and carefully designed stream crossings will be critical for brook trout survival in watersheds, especially upper watersheds, with intensive Marcellus development.

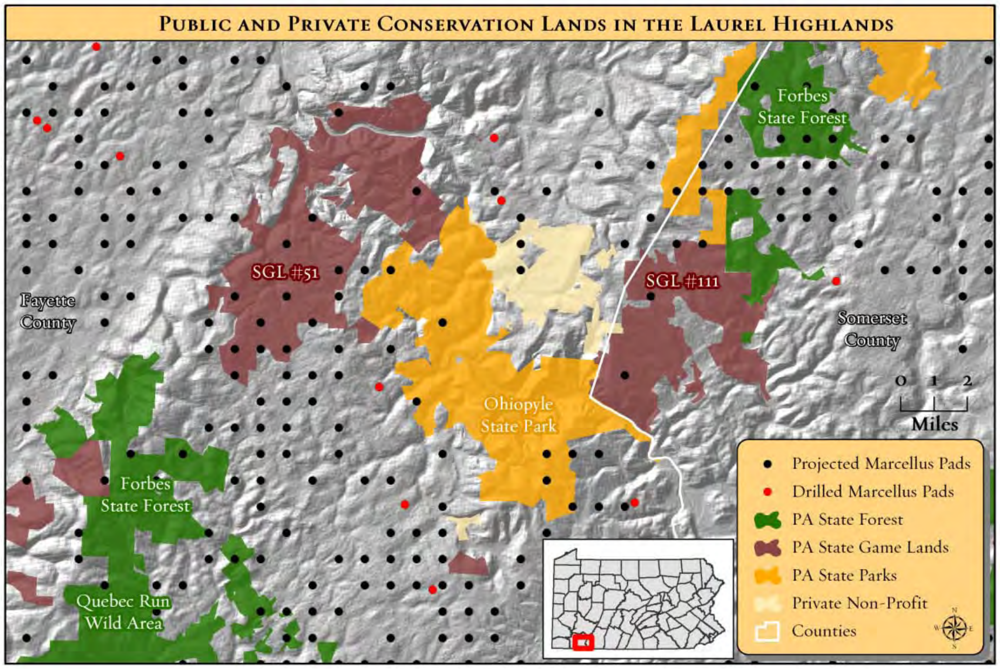
RARE SPECIES

Green salamander © Pennsylvania Fish and Boat Commission

Of the approximately 100,000 species believed to occur in Pennsylvania, just over 1 percent (1052) are tracked by The Pennsylvania Natural Heritage Program (PNHP). Due to low population sizes and immediate threats, these species are rare, declining or otherwise considered to be of conservation concern. PNHP records indicate that 329 tracked species have populations within pixels that have a relatively high modeled probability for Marcellus development. Nearly 40 percent (132) are considered to be globally rare or critically endangered or imperiled in Pennsylvania. Many are found in riparian areas, streams, and wetlands, while others are clustered in unusually biologically diverse areas such as the Youghiogheny Gorge. Some of these species may have only one, two or three populations left in the state. Two examples include the green salamander (*Aniedes aeneus)* with all known populations in relatively high probability Marcellus development pixels and snow trillium (*Trillium nivale*) with 73 percent of known populations in relatively high probability pixels. A well-managed screening system to identify the presence of these species and their preferred habitats will be critical to their survival as energy development expands across the state.

RECREATION

Pennsylvania has built one of the largest networks of public recreation lands in the eastern United States, but much of it could see Marcellus and other natural gas development in coming decades. Of the 4.5 million acres of state and federal lands in the state, we estimate as little as 500,000 acres are permanently protected from surface mineral development, including gas drilling. State and federal agencies do not own mineral rights under at least 2.2 million acres. Most other areas where the state does own mineral rights can be leased, such as the estimated 700,000 acres previously leased for gas development on state forest lands. Severe budget pressures will likely to tempt the legislature to lease additional lands in the future. Our projections excluded state Wild and Natural Areas, National Park lands, and Congressionally-designated Wilderness Areas but otherwise assumed that high probability Marcellus gas pixels on public lands could be developed. The low scenario projects 897 pad locations on State Forest and State Game Lands which expands to 1,438 well pads in the medium scenario and 2,096 pads in the high scenario. The focal area below illustrates what the overlap of future gas development and conservation lands could look like in the medium scenario for the southern Laurel Highlands. It projects 7 well pads in the portion of Forbes State Forest visible in the focal area above, 13 pads on State Game Lands 51, and 3 on State Game Lands 111.



Map showing projected Marcellus well pads under the medium scenario on public and private conservation lands in the Laurel Highlands.

Pennsylvania's state park system, recognized as one of the best in the nation, illustrates the challenge of protecting recreational values in areas of intensive Marcellus development. While the DCNR has a long standing policy of not extracting natural resources in state parks, it does not own the mineral rights under an estimated 80 percent of the system's 283,000 acres. Our projections indicate Marcellus well pads could be located in between 9 and 22 state parks.

AVOIDING FOREST IMPACTS IN THE LAUREL HIGHLANDS

The projected potential impacts of Marcellus gas energy development assume recent patterns of development will continue. Given the relatively large areas drained by Marcellus gas pads (depending on the lateral length and number of wells per pad), there is flexibility in how they are placed. This allows us potentially to optimize between energy production and conservation outcomes. To look at how conservation impacts could be minimized, we examined how projected Marcellus gas pads could be relocated to avoid forest

Projected Well Pads on State Lands (Medium Scenario)	
DCNR State Forests	**1,002**
DCNR State Parks	**41**
State Game Lands	**436**
Total State Lands	**1,479**

patches in the Southern Laurel Highlands in Fayette and Somerset counties. This area is important because it represents a unique ecological region with a large amount of state land as well as private farmland and forest land. The area is also facing great pressure to develop the Marcellus Gas resource. The focus area included approximately 350 square miles and included Chestnut Ridge on its western border and Laurel Ridge on its east. Within the area, there are two state parks (Ohiopyle State Park and Laurel Hill State Park), two State Game Lands (SGL 51, SGL 111), and state forest land (Forbes State Forest).

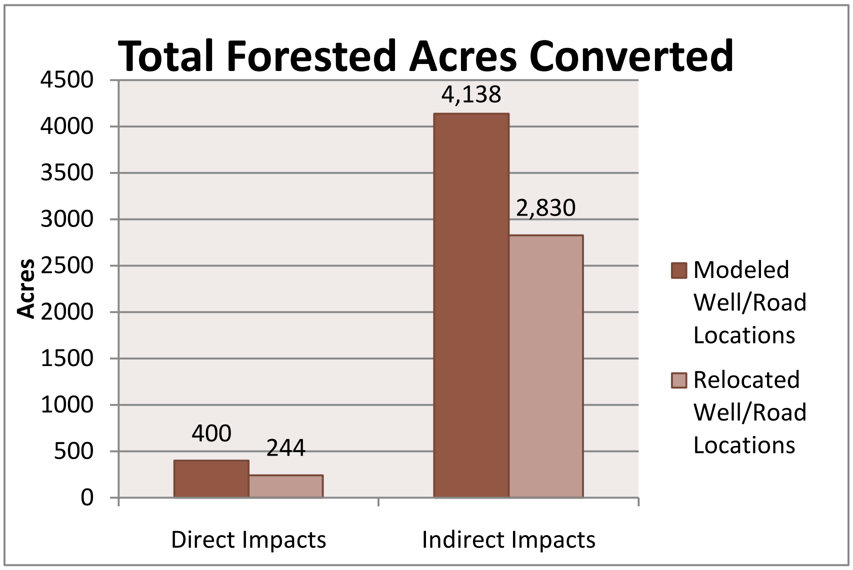
The Medium Scenario projected 127 well pads in the focus area. Fourteen well pads were projected in agricultural fields, 33 were in edge habitat (within 100 m of the forest edge), 11 fell within existing cleared areas (e.g. strip mines), and 69 were in forest. There were five pads on Ohiopyle State Park, and 13 within a mile of its boundary. Laurel Ridge State Park contained two pads. Forbes State Forest had seven modeled pads. State Game Lands 111 had 3 pads, and SGL 51 had 13. It was not clear if DCNR State Parks Bureau or the Game Commission control the sub-surface mineral rights beneath the 23 modeled pads. Given that 80 percent of mineral rights are severed on State Park and State Game Lands (and close to 100 percent in western parts of the state), we have assumed that drilling could happen at those projected locations.

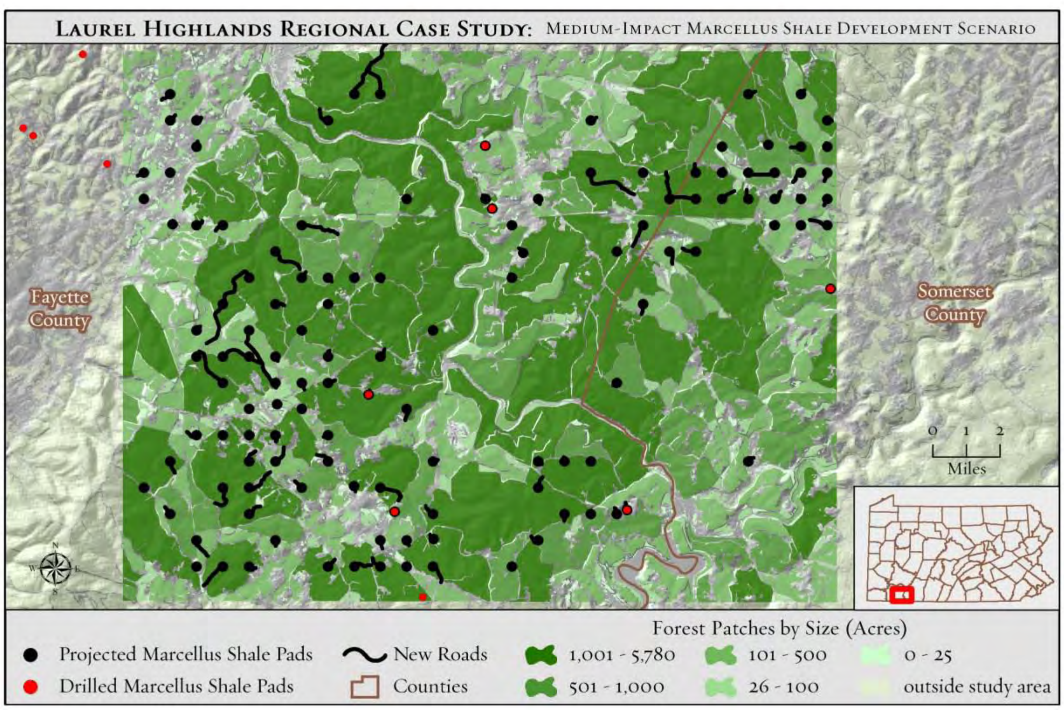
To assess additional impacts beyond the well pad itself, we placed a new and/or improved road from the projected pad to the nearest existing road (ESRI Roads Layer). We placed new roads along existing trails, paths and openings whenever detectable on aerial photo imagery (used Bing Maps and 2005-2006 PA Map imagery), avoiding wetlands, steep slopes, cliffs, rock outcrops, and buildings, and where possible, rivers, streams, and forest patches. The projected pads and roads required clearing 400 acres of forest.

Can a modest shift in the location of well pads reduce impacts to forest patches and conservation lands? To reduce the impacts to forest habitats, the wells were relocated to nearby existing anthropogenic openings, old fields, or agricultural fields. Attempts were made to maintain the 4,200 foot (1,260 m) distance between modeled wells. If nearby open areas did not exist, the locations of the well pads were moved toward the edges of forest patches to minimize impacts to forest interior habitats. A set of rules was developed and followed to minimize bias, including:

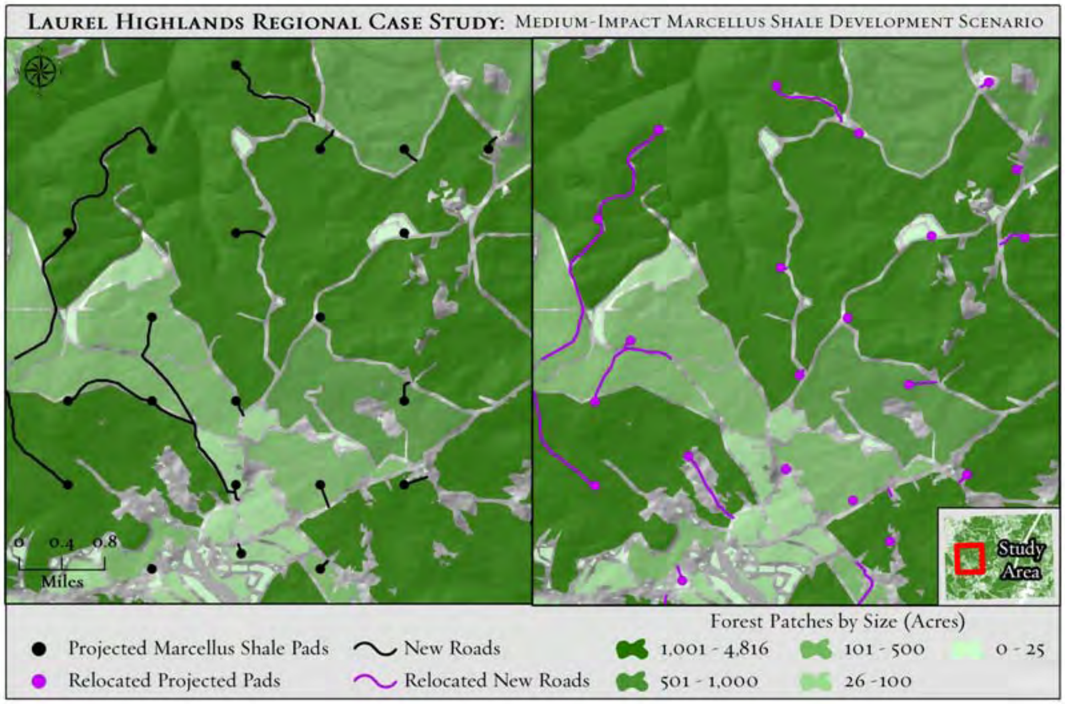
1. Modeled well pads were not relocated if they occurred in old fields or agricultural fields.
2. Modeled well pads that occurred in forest or edge habitat were moved but well pads were placed in the same general areas as the modeled well pad;
3. Attempts were made to avoid placing idealized wells any closer than the minimum distance between pads as specified by the medium scenario (1260 m);
4. Agriculture, cleared land (e.g., former strip mines), or otherwise opened land cover was favored over forest or edge for placing idealized well pads;
5. If the well pad could not be placed in an open area, forest edges were favored over deep interior forest;
6. Residential areas were avoided. Idealized well pads were placed at least 500 feet (150 m) from homes;
7. Wetlands, water, steep slopes, cliffs, rock outcrops, creeks and rivers, buildings and manicured lawns were avoided;
8. Relocated well pads were only placed in areas with similar to those that supported modeled pads.
9. Relocated well pads often were connected to roads using existing trails, paths and openings whenever detectable on aerial photo imagery (used Bing Maps and 2005-2006 PA Map imagery);
10. The same number of relocated well pads were placed on state lands and Western Pennsylvania Conservancy lands as they were in the modeled output;
11. When the modeled well pad occurred within a forest patch with no nearby alternative locations (due to proximity of other wells or environmental constraints), the projected well pad was not relocated.

The relocated wells and roads did not eliminate forest impacts in this heavily forested landscape, but there was a significant reduction. Total forest loss declined almost 40% while impacts to interior forest habitats adjacent to new clearings declined by a third.





Location of 127 projected Marcellus well pads and new roads in the study area in the southern Laurel Highlands.



Relocated well pads (on the right) reduced forest clearing and forest interior habitat impacts by 40 % and 33% respectively compared to the projected well pads (on the left).

Key Findings

Key findings from the Pennsylvania Energy Impacts Assessment for Marcellus Shale natural gas include:

- About 60,000 new Marcellus wells are projected by 2030 in Pennsylvania with a range of 6,000 to 15,000 well pads, depending on the number of wells per pad;

- Wells are likely to be developed in at least 30 counties, with the greatest number concentrated in 15 southwestern, north central, and northeastern counties;

- Nearly two thirds of well pads are projected to be in forest areas, with forest clearing projected to range between 34,000 and 83,000 acres depending on the number of number of well pads that are developed. An additional range of 80,000 to 200,000 acres of forest interior habitat impacts are projected due to new forest edges created by well pads and associated infrastructure (roads, water impoundments);

- On a statewide basis, the projected forest clearing from well pad development would affect less than one percent of the state's forests, but forest clearing and fragmentation could be much more pronounced in areas with intensive Marcellus development;

- Approximately one third of Pennsylvania's largest forest patches (>5,000 acres) are projected to have a range of between 1 and 17 well pads in the medium scenario;

- Impacts on forest interior breeding bird habitats vary with the range and population densities of the species. The widely-distributed scarlet tanager would see relatively modest impacts to its statewide population while black-throated blue warblers, with a Pennsylvania range that largely overlaps with Marcellus development area, could see more significant population impacts;

- Watersheds with healthy eastern brook trout populations substantially overlap with projected Marcellus development sites. The state's watersheds ranked as "intact" by the Eastern Brook Trout Joint Venture are concentrated in north central Pennsylvania, where most of these small watersheds are projected to have between two and three dozen well pads;

- Nearly a third of the species tracked by the Pennsylvania Natural Heritage Program are found in areas projected to have a high probability of Marcellus well development, with 132 considered to be globally rare or critically endangered or imperiled in Pennsylvania. Several of these species have all or most of their known populations in Pennsylvania in high probability Marcellus gas development areas.

- Marcellus gas development is projected to be extensive across Pennsylvania's 4.5 million acres of public lands, including State Parks, State Forests, and State Game Lands. Just over 10 percent of these lands are legally protected from surface development.

- Integration of conservation features into the planning and development of Marcellus gas well fields can significantly reduce impacts. For example, relocating projected wells to open areas or toward the edge of large forest patches in high probability gas development pixels in the southern Laurel Highlands reduces forest clearing by 40 percent and forest interior impacts by over a third.

Additional Information

- Geologic information on the Marcellus shale formation in Pennsylvania:
  http://www.dcnr.state.pa.us/topogeo/oilandgas/marcellus_shale.aspx

- Estimates of Marcellus shale formation gas reserves:
  http://geology.com/articles/marcellus-shale.shtml

- Baker-Hughes weekly oil and gas rig count
  http://gis.bakerhughesdirect.com/Reports/StandardReport.aspx

- Pennsylvania Department of Environmental Protection, Permit and Rig Activity Report:
  http://www.dep.state.pa.us/dep/deputate/minres/oilgas/RIG10.htm

- Copeland, H. E., K.E. Doherty, D.E. Naugle, A. Pocewicz, and J. M. Kiesecker. 2009. Mapping Oil and Gas Development Potential in the US Intermountain West and Estimating Impacts to Species:
  http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0007400

- Overview of forest fragmentation impacts on forest interior nesting species:
  http://www.state.nj.us/dep/fgw/neomigr.htm

- Overview of Pennsylvania High Quality and Exceptional Value Streams:
  http://www.dcnr.state.pa.us/wlhabitat/aquatic/streamdist.aspx

- Pennsylvania Department of Environmental Protection, Chapter 93 Water Quality Standards, Exceptional Value and High Quality Streams: data downloaded from Pennsylvania Spatial Data Access:
  http://www.pasda.psu.edu

- Eastern Brook Trout Joint Venture intact brook trout watersheds:
  http://128.118.47.58/EBTJV/ebtjv2.html

- Overview of Carnegie Museum of Natural History, Powdermill Nature Reserve, and the Pennsylvania Game Commission's 2nd Pennsylvania Breeding Bird Atlas Project:
  http://www.carnegiemnh.org/powdermill/atlas/2pbba.html

- Pennsylvania Natural Heritage Program, including lists of globally rare and state endangered and imperiled species: http://www.naturalheritage.state.pa.us/

- U.S. Department of Agriculture, Natural Resources Conservation Service, National Agriculture Imagery Program: http://datagateway.nrcs.usda.gov/GDGOrder.aspx

- DigitalGlobe, GlobeXplorer, ImageConnect Version 3.1: http://www.digitalglobe.com

Wind

Wind has become one of the country's fastest growing sources of renewable energy. Pennsylvania is a leader in the industry as host to several wind company manufacturing plants and corporate headquarters. Wind energy development has been spurred by its potential to reduce carbon emissions, promote new manufacturing jobs, and increase energy independence. Technological advances have expanded the size and efficiency of wind turbines during the past decade. This, together with state and federal incentive programs, has facilitated wind development in Pennsylvania, which otherwise ranks relatively low among states for its potential wind generation capacity. The eight turbines installed next to the Pennsylvania Turnpike in Somerset County a decade ago have grown to nearly 500 turbines, with more permitted for construction (AWEA, 2010). Topography is a key factor in average wind speeds across Pennsylvania, so nearly all turbines have been built on mountain ridgelines or on top of high elevation plateaus.

Wind energy has become the most symbolic icon of the shift toward a low carbon economy. With no air emissions or water consumption, it is one of the cleanest renewable energy types. Communities across the state benefit economically as rural landowners lease their properties, skilled jobs are created to manufacture turbines, and workers are hired to install and maintain turbines. Wind development has faced controversy in some areas from neighboring landowners and those worried about impacts to migrating birds and bats. The wind industry, government agencies, and independent researchers have invested considerable effort in trying to better understand impacts on birds and bats. For example, 26 wind development companies have signed a cooperative agreement with the Pennsylvania Game Commission to conduct bird, bat and animal surveys using specified protocols in proposed development areas. Among other findings have been the discovery of the Pennsylvania's second largest Indiana bat maternal colony and a variety of previously undocumented foraging and roosting locations for the state's two rarest bats (Indiana and eastern small-footed). Less understood are the potential habitat impacts of wind development in the northeastern United States. This assessment, therefore, focuses on impacts to forest and stream habitats and selected species of conservation concern that may be vulnerable to development of ridgetop habitats.

What is Wind Energy?

Wind mills have powered grain processing and water pumping in agriculture around the world – most famously in the Netherlands – for centuries. The first modern wind facilities to generate electricity were built in California in the early 1980s. Rated at less than 0.5 MW capacity per turbine, the towers were only 50 feet tall. These facilities were poorly designed and generated considerable controversy because they caused significant mortalities to migrating hawks and eagles. Wind energy development did not expand appreciably until the late 1990s when newer turbine designs and federal energy incentives stimulated the development of new facilities. These turbines were rated at 1.0 or 1.5 MW capacity and reached about 200 feet high at the tip of their rotor. Since the power produced by a wind turbine is proportional to the cube of the blade size and how high in the air it is; turbine size, height and power ratings have expanded steadily. The largest turbines installed in Pennsylvania are now rated at

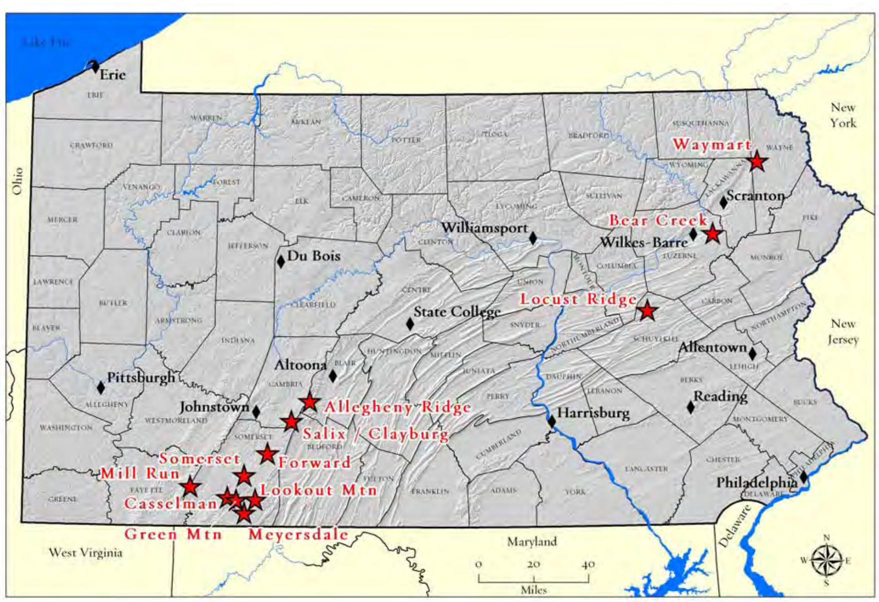
2.5 MW (the average was 1.8 MW in 2009) and reach over 400 feet to the tip of the rotor at the apex of its rotation.

Location is everything for wind development in the northeastern United States. Unlike the vast windswept plains in the Midwest and the intermountain West, high wind speeds in the Northeast are primarily confined to mountain ridgetops, plateau escarpments, and the Atlantic and Great Lake shorelines. Areas that have a wind power class rating of 3 or more (300 watts per m^2) are potentially feasible for wind power development. Wind companies will lease areas that seem to have the most favorable characteristics including wind class, flat pad sites, proximity to transmission lines, and proximity to existing highways. Before development, a wind development company will typically place an anemometer tower on potential development sites to improve knowledge about wind power at the site during a year or longer monitoring period. The turbines are mounted on pads at least 800 feet apart with an access road between towers. The average size of wind facilities has been growing steadily since the first eight were established in 2000. The two largest facilities are now between 75 and 100 turbines.

Several steps have been taken to address potential conflicts between wind development and wildlife in Pennsylvania. The Pennsylvania Game Commission (PGC) has a voluntary agreement in place with most wind companies active in the state to screen proposed facilities for possible impacts to birds and bats and migratory pathways. Participating wind companies carry out pre-construction monitoring for birds and bats. If possible conflicts are identified, PGC works with wind companies to avoid or minimize impacts and to continue monitoring post construction in some cases. Second, the Pennsylvania Wind and Wildlife Collaborative (PWWC) was established in 2005 with a state goal to develop a set of "Pennsylvania-specific principles, policies and best management practices, guidelines and tools to assess risks to habitat and wildlife, and to mitigate for the impact of that development." Several studies on wildlife and habitat issues have been commissioned, though guidelines and Best Management Practices (BMPs) have not been released.

Current and Projected Wind Energy Development

We documented the spatial foot print for 319 wind turbines at 12 wind facilities across the state by comparing aerial photos taken before and after development. Turbine pads, roads, and other new clearings were digitized for all 12 facilities. The ground excavated for turbines,

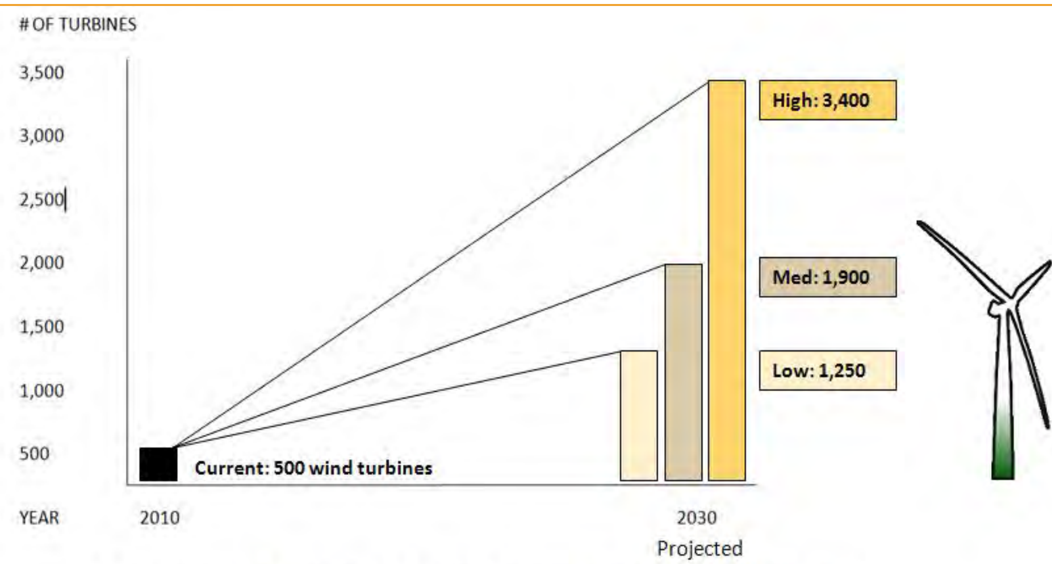


Map showing 12 wind facilities included in the spatial footprint analysis.

roads, and associated infrastructure (e.g., clearings for construction staging areas or electrical sub-stations) is the most obvious spatial impact. For each turbine site, the area for the turbine pad, new roads, staging areas, and sub-stations were digitized and measured. Turbine pads occupy 1.4 acres on average while the associated infrastructure (roads, staging areas and substations) takes up 0.5 acres, or a total of 1.9 acres of spatial impact per wind turbine.

Average Spatial Disturbance for Wind Energy Development in Forested Context (acres)		
Forest cleared for wind turbine	**1.4**	**1.9**
Forest cleared for associated infrastructure (roads, other cleared areas)	**0.5**	
Indirect forest impact from new edges	**13.4**	
TOTAL DIRECT AND INDIRECT IMPACTS	**15.3**	

As with Marcellus gas development, adjacent lands can also be impacted even if they are not directly cleared (See p. 9 for a description of forest edge impacts on forest "interior" species). To assess the potential interior forest habitat impact, we created a 330 foot buffer into forest patches from new edges created by wind turbine and associated infrastructure development. For turbine sites developed in forest areas (about 80% of the 319 turbines), an average area of 13.4 acres of interior forest habitat was lost in addition to the 1.9 acres of directly cleared forest.



Key drivers: Alternative Energy Portfolio Standard (AEPS) and projected contribution of wind to meeting that standard.

We project between 1,250 and 3,400 total wind turbines will be erected in Pennsylvania by 2030.

The number of wind turbines built in Pennsylvania will certainly expand during the next two decades. Various factors will drive exactly how many turbines are ultimately built including electricity prices, state and federal incentives, technological improvements, energy and climate policy, regulatory changes, and social preferences. Our projections assume economic, policy, and social conditions will remain favorable enough to promote steady expansion of wind development in the state since we cannot reasonably forecast energy prices, technological developments, and policy conditions. The key driver in our low scenario is that companies will use wind energy to meet 70 percent of the current Alternative Energy Portfolio Standard (AEPS) Tier 1 standard (8 percent of electric generation). This projection indicates an additional 750 turbines (2 MW average) will be added to the 500 turbines currently operating. The key driver in our medium scenario is that utilities will use wind energy to meet 70 percent of an expanded AEPS 15% Tier 1 standard, as proposed in recent draft legislation. That scenario would add 1,400 new turbines to those already built. The high scenario used in this assessment is based on the 20% wind power electric generation scenario used by the National Renewable Energy Laboratory in the Eastern Wind Integration Study (EWITS). This scenario would require 2,900 additional turbines.

Where are those new turbines in each scenario more and less likely to go? To start, we created a probability surface by looking at a range of variables that might be relevant to a company's decision to develop a wind facility with wind turbines that have already been built. We used the maximum entropy modeling approach used to develop the Marcellus gas probability surface (see p. 13) and built the model using 580 existing and permitted wind turbines. Variables that potentially drive wind energy development were chosen based on data availability and included wind power (W/m^2), distance to transmission lines, percent slope, distance to roads, and land cover. An additional 193 existing and permitted wind turbines were used to test the validity of the model's probability surface and the model was found to be 95.8% accurate in predicting existing and permitted turbines from randomly sampled undeveloped areas. The resulting probability map indicates many long, narrow high probability sites along ridge tops, and several wider areas on high plateaus and along the Lake Erie coastline.

To get a better sense of where wind development is more likely, we searched for the highest probability areas where wind turbine pads in each scenario might be located. The probability raster was re-sampled to 60 meter resolution (0.89 acres) to reflect the actual geographic footprint of wind turbines based on aerial photo assessment. We selected the highest available probability pixel for each scenario and then buffered that pixel by a minimum separation distance of 800 feet (240 meters – the site distance between turbines) between existing turbines before selecting the next highest available probability pixel. The highest probable pixels were then selected until the threshold for each impact scenario was reached (low – 700 turbines; medium – 1,200 turbines; high – 2,700 turbines). Areas incompatible for wind energy development (existing wind turbines, Wild and Natural Areas, and water bodies) were excluded from being selected as probable pixels. The highest probable pixels were then converted into points for map display purposes.

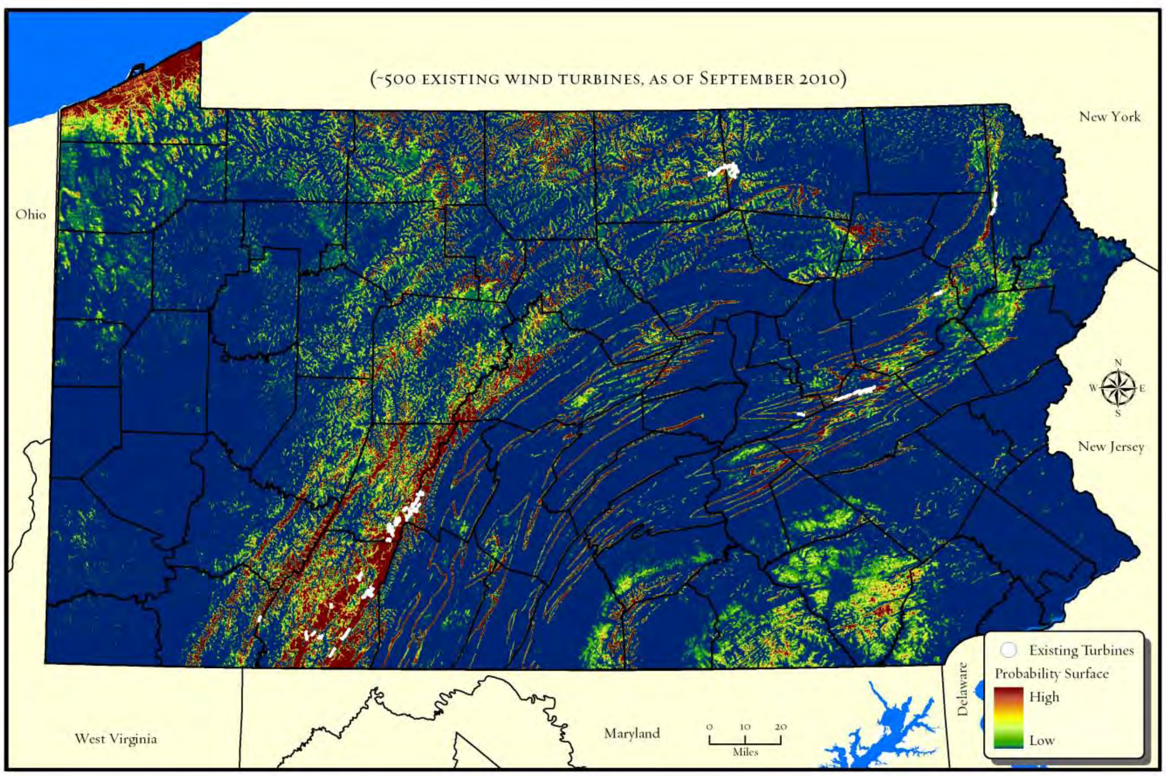
The resulting projected turbine locations occur in strings, groups, and widely scattered single or very small clusters (2-5) of turbines, mostly in southwest, north central and northeastern parts of Pennsylvania.

Wind turbines, however, are almost always located in clusters rather than widely separated locations for individual turbines. In order to represent viable wind farms, we selected clusters of pixels with high probability to represent probable farms based on the results of the model. The following steps were applied to standardize the selection process:

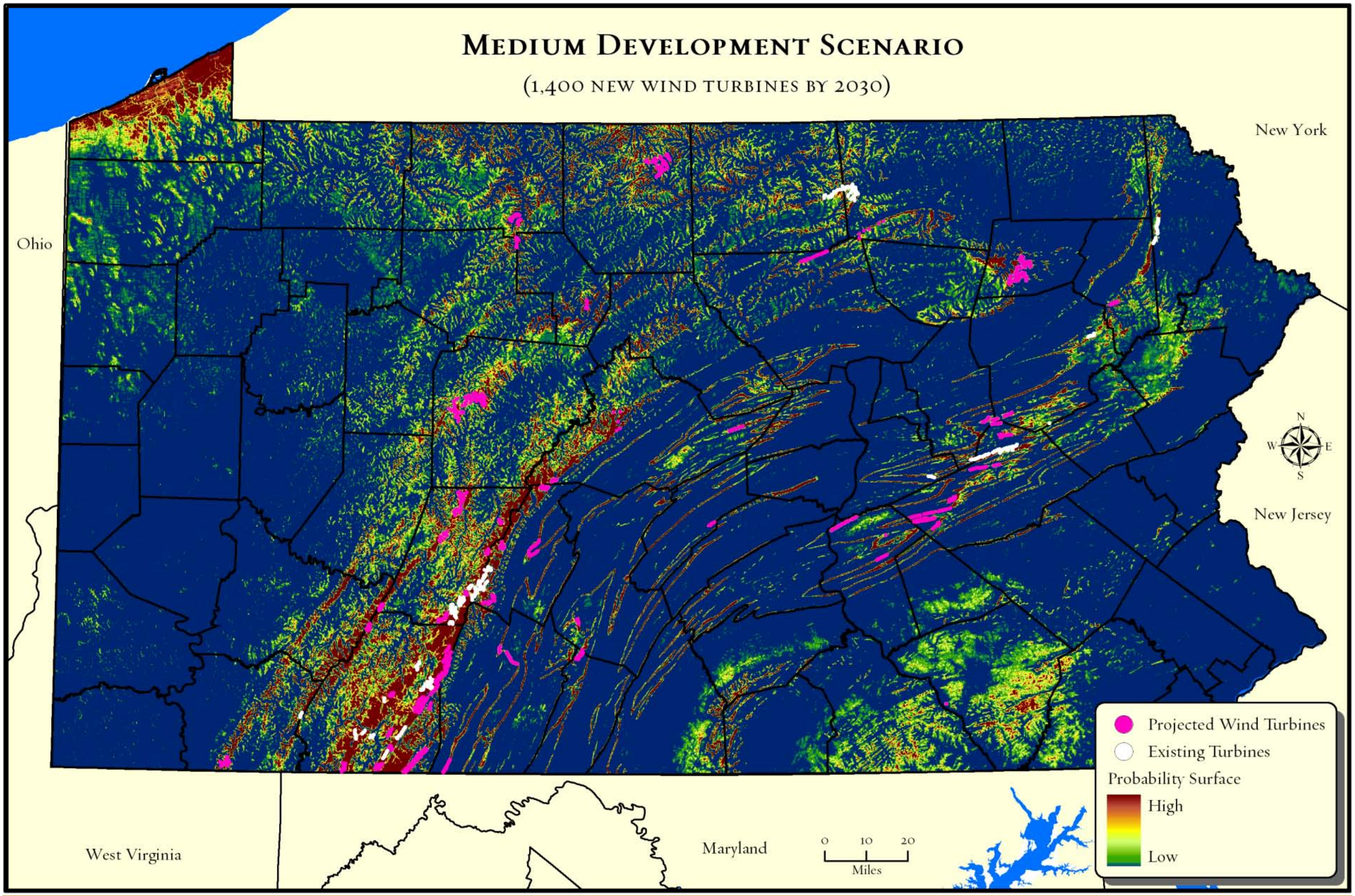
- All selected wind facilities had to be anchored by at least 6 projected wind turbine sites selected by the model

- Buffers of equaling four times the minimum turbine separation distance of 787 ft (totaling 3,148 ft) were applied to existing and permitted wind farms were in order to not 'expand' operating and soon to be operating facilities;
- Setbacks of 500 ft from the boundaries of state and federal lands were applied to exclude turbine placement areas adjacent to public land;
- Existing homes Areas (as visible in aerial imagery) were buffered by approximately 1,000 ft;
- Projected clusters (wind farms) were assigned to the low, medium, or high scenario based on the number of the assigned wind turbines to that scenario within the cluster.
- Solitary and very small clusters of wind turbines were relocated to relatively high probability pixels adjacent to projected wind turbine clusters of at least 6 turbines (an 800 feet buffer was applied to each modeled turbine to maintain proper spacing).

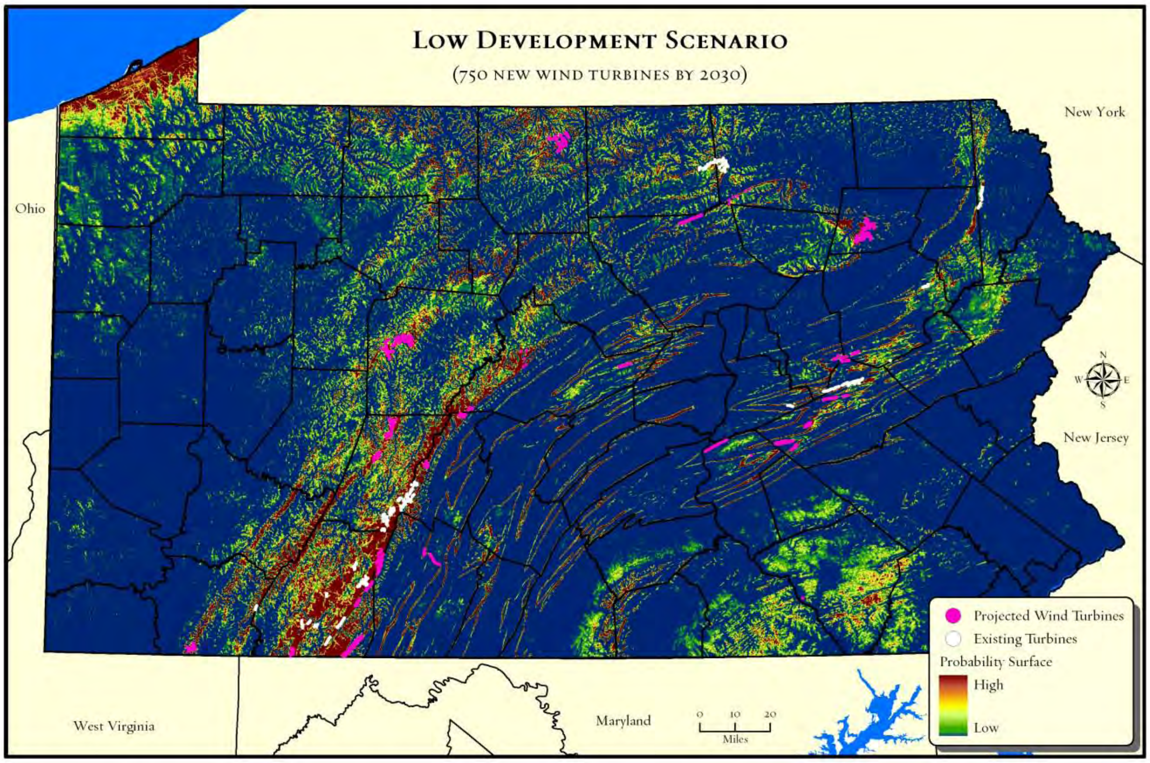
The scenarios are cumulative with the high scenario including the wind facilities for both the low and medium scenarios and the additional turbines needed to meet the high scenario quota.



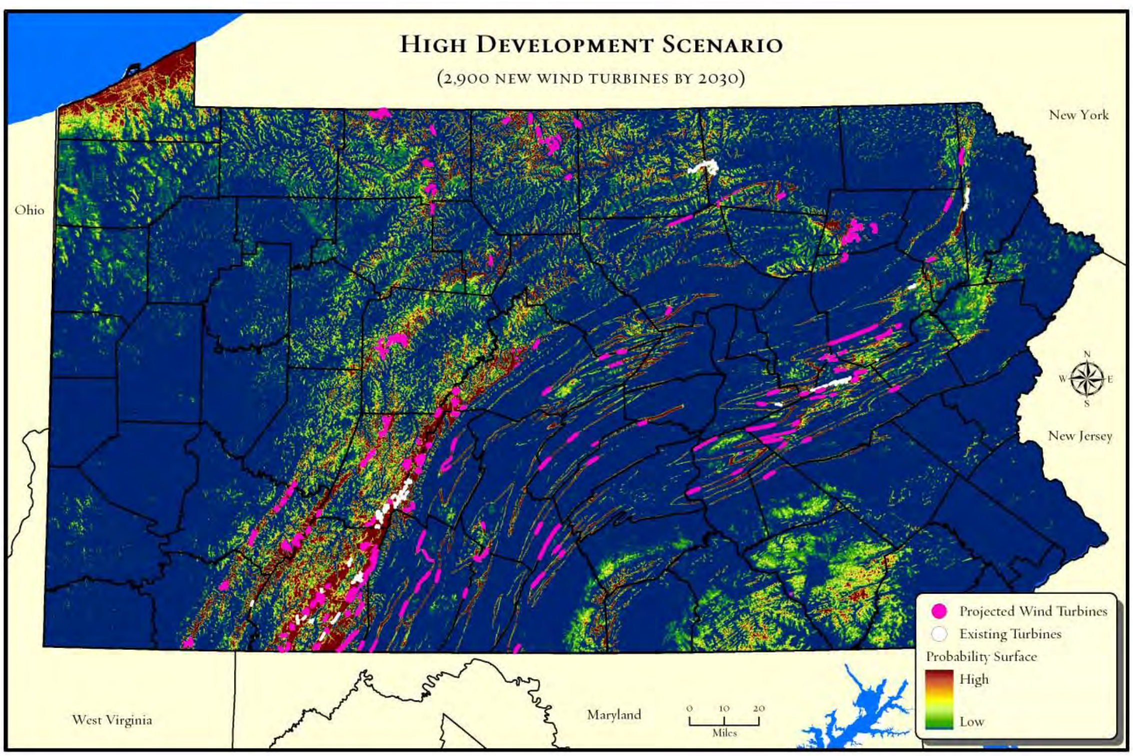
Map showing existing wind turbines with the probability that a given area will be developed indicated by color (dark red is high probability; dark blue is low).



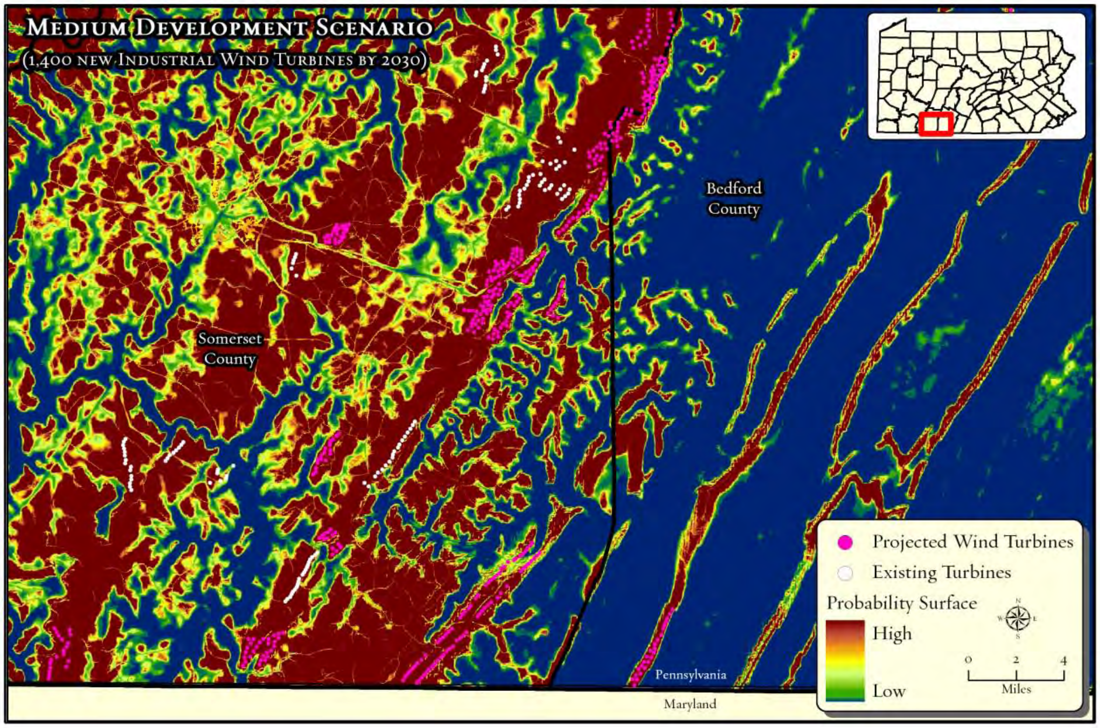
Map showing 1,400 new wind turbines projected by 2030 under the medium development scenario.



Map showing 750 new wind turbines projected by 2030 under the low development scenario.



Map showing 2,900 new wind turbines projected by 2030 under the high development scenario.



Map showing medium wind development scenario within Somerset and Bradford counties.

These geographic projections of future wind energy development are spatial representations of possible scenarios. They are not predictions. We faced several constraints in developing the geographic scenarios:

- We do not have the detailed wind power data that wind companies have developed through anemometer tower monitoring.
- We do not have the detailed location of wind energy leases.

Still, we believe the overall geographic patterns in the projected wind development locations are relatively robust for several reasons. We used over 500 existing or permitted wind turbines to build the model and nearly 200 additional existing and permitted wind turbine sites were used to validate the model. This is typically a sufficient sample size for building predictive models. They are also consistent with Black and Veatch (2010) projected locations for wind facilities under a 15% renewable energy portfolio standard.

Conservation Impacts of Wind Energy Development

What is the overlap of the areas with the highest probability of future wind energy development and those areas known to have high conservation values? To answer this question, we intersected the projected wind energy facilities with high conservation value areas. We looked at several examples from four categories of conservation value, including:

- Forest habitats
- Freshwater habitats

- Species of conservation concern
- Outdoor recreation

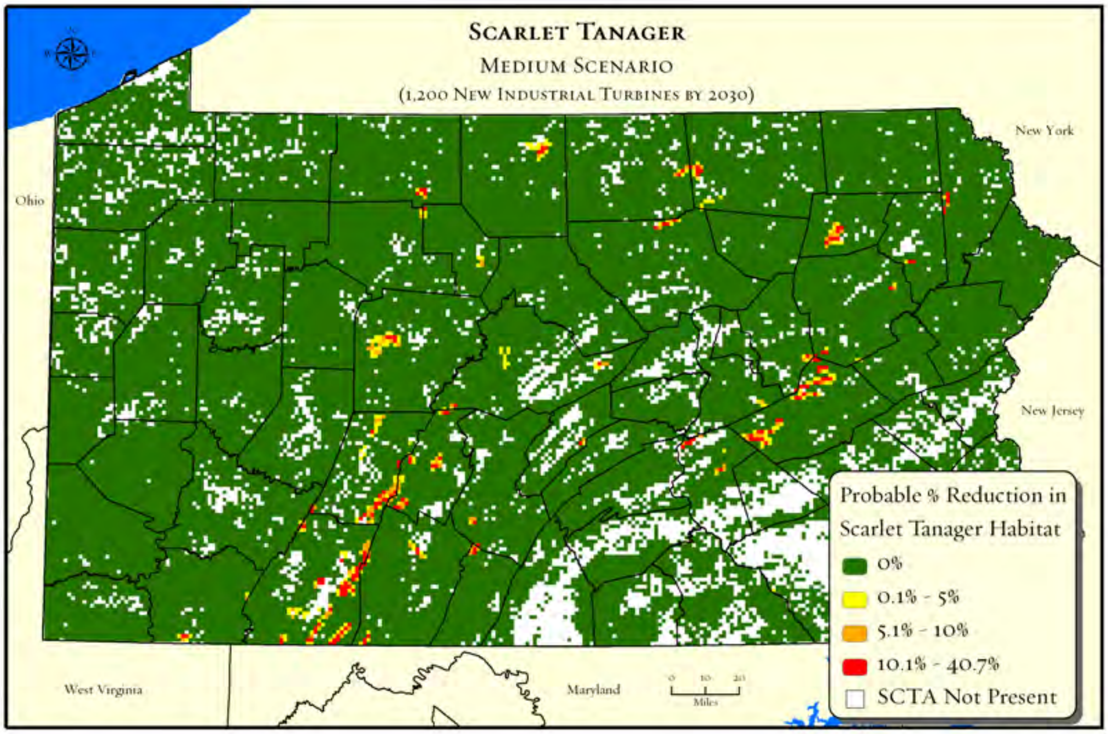
Areas of overlap between likely future wind development areas and priority conservation areas in Pennsylvania are substantially less than the conservation area overlap with likely future Marcellus development areas, largely because the projected foot print will be much smaller.

Forests

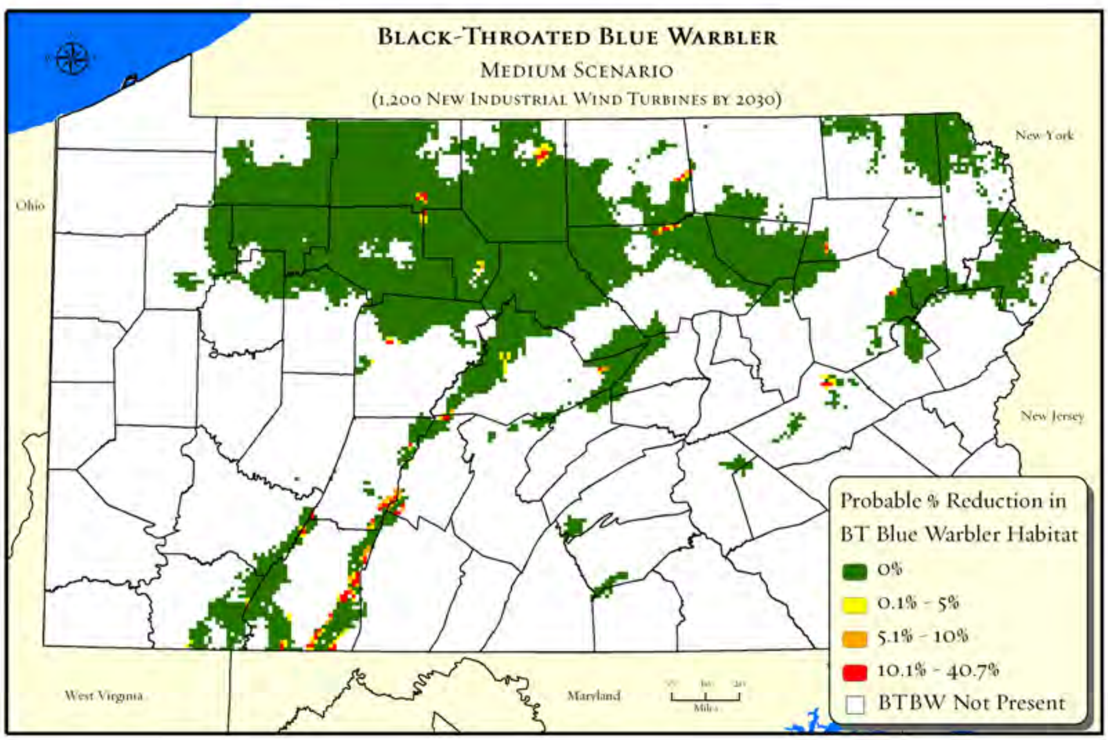
A large majority of projected wind turbines are found in forest patches, about 80 percent for each of the scenarios. The low scenario would see 600 new wind turbines in forest areas. With a cleared forest average of 1.9 acres per turbine (including roads and other infrastructure), the total forest loss would be a modest 1,140 acres. Indirect impacts to adjacent forest interior habitats would total an additional 7,920 acres. Forest impacts from the medium scenario (1,120 projected new turbines in forest locations) would be 2,128 cleared forest acres and an additional 15,840 acres of adjacent forest interior habitat impacts. For the high scenario (2,320 new turbines in forest areas) 4,408 acres would be cleared and an additional 30,624 acres of forest interior habitats would be affected by new adjacent clearings. On a statewide basis, the projected forest losses and accompanying interior forest habitat impacts will be minor given the Pennsylvania's 16 million acres of forest. Locally, these impacts could be significant for individual large forest patches where wind development takes place.

All forests have conservation value, but large contiguous forest patches are especially valuable because they sustain wide-ranging forest species, such as northern goshawk, than small patches. They are also more resistant to the spread of invasive species, can better withstand damage from wind and ice storms, and provide more ecosystem services – from carbon sequestration to water filtration – than small patches. The Nature Conservancy and the Western Pennsylvania Conservancy's Forest Conservation Analysis mapped nearly 25,000 forest patches in the state greater than 100 acres. Patches at least 1,000 acres in size are about a tenth of the total (2,700). The medium projected wind development scenarios indicate 73 patches (3%) greater than 1,000 acres in size are projected to have at least one wind turbine and associated infrastructure. Patches at least 5,000 acres in size are relatively rare (only 316 patches). The medium wind scenario indicates about 21 (7%) of these patches could be affected by future wind turbine development. Most affected large patches have multiple projected wind turbines (as many as 36). Typically, a large patch is split by wind development into two or three smaller patches due the linear pattern of development. Projected gas well pads, by contrast, are more likely to fragment a large patch into multiple smaller patches.

Forest interior bird species could be affected by the clearing of forest and adjacent edge effects that wind turbine facilities create in a forest context. We used data from the 2nd Breeding Bird Atlas Project (see p. 20) to assess the potential impact on forest interior species. The resulting maps show the estimated reduction in habitat for that species in each high wind development gas probability pixel (including both cleared forest and adjacent edge effects). Scarlet Tanagers are perhaps the most widespread forest interior nesting bird in the state. Since they are so widespread, the vast majority of their range in the state is outside of the most likely wind development areas. Scarlet Tanager populations could decline by an insignificant amount due to habitat losses projected in the medium scenario. Black-Throated Blue Warblers are more narrowly distributed in Pennsylvania favoring mature northern hardwood and coniferous forests with a thick understory, frequently in mountain terrain. Likewise, population declines would also be extremely small for Black-Throated Blue Warblers under the medium scenario.



Map showing estimated percent loss of habitat for Scarlet Tanagers under the medium wind scenario.

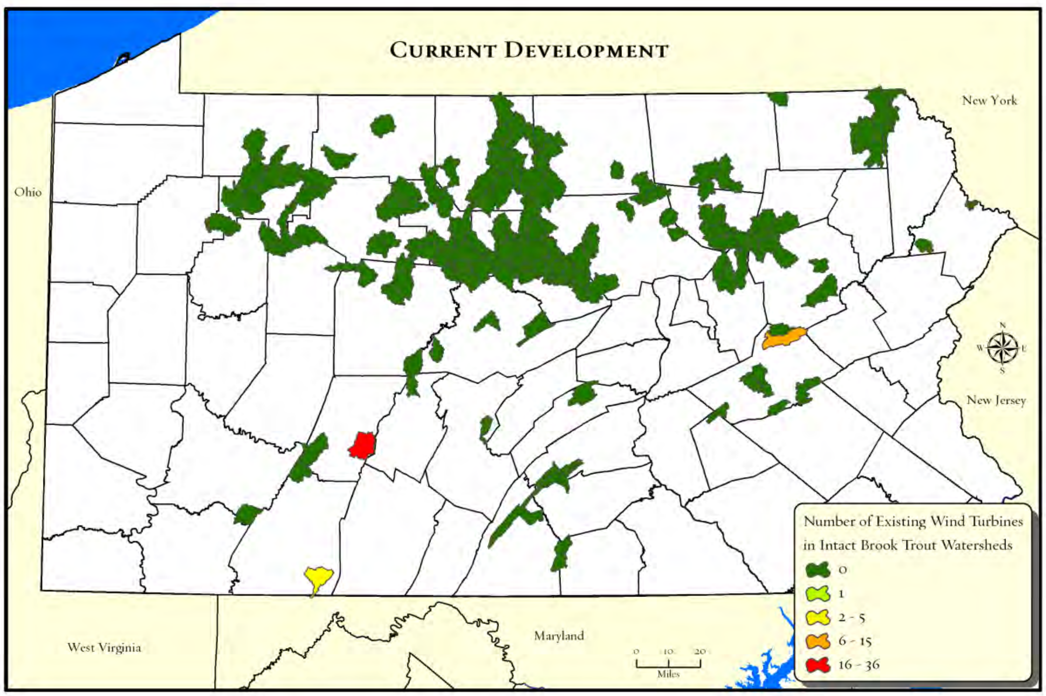


Map showing estimated percent loss of habitat for Black-Throated Blue Warblers under the medium wind scenario.

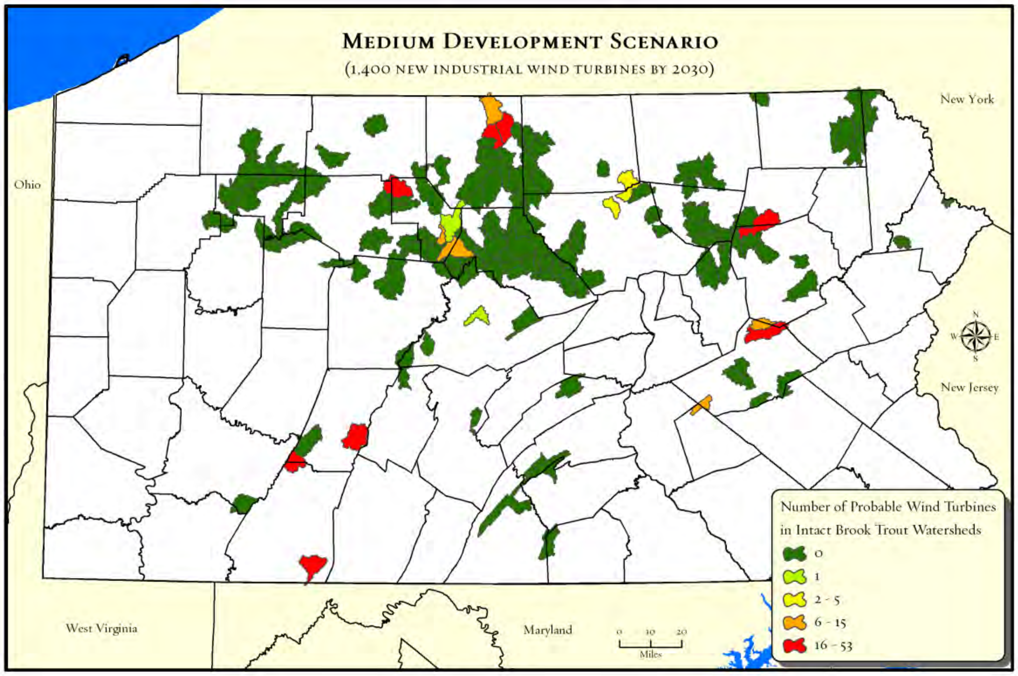
Freshwater

Wind energy and freshwater habitats are not often thought of in the same context since most wind facilities are generally in high elevation areas away from rivers and streams. The exceptions are small headwater streams, some of which may be classified as Exceptional Value watersheds. Our medium scenario projection indicates that 9 percent of future turbine development could be located within ½ mile of an Exceptional Value stream.

Native brook trout are one of the most sensitive species in Pennsylvania watersheds. Brook trout favor cold, highly-oxygenated water and are unusually sensitive to warmer temperatures, sediments, and contaminants. Once widely distributed across Pennsylvania, healthy populations have retreated to a shrinking number of small watersheds. The potential impact on intact brook trout watersheds, however, does increase significantly between the low to high scenarios. Wind turbines have been built in just five of the intact brook trout watersheds identified by the Eastern Brook Trout Joint Venture. That number would expand to 13 in the low scenario, 19 in the medium scenario, and 28 in the high scenario. The presence of wind turbines may pose a limited risk in many of these watersheds, principally from soil disturbance near headwater streams.



Map showing current number of wind turbines in intact and predicted intact brook trout watersheds.



Map showing projected number of wind turbines in intact brook trout watersheds (by 2030) under medium scenario.

Poorly designed or maintained sedimentation measures, especially on road cuts and stream crossings, is the principal risk to these sensitive populations.

Rare Species

Of the approximately 100,000 species believed to occur in Pennsylvania, just over 1 percent is tracked by The Pennsylvania Natural Heritage Program (PNHP). These species are rare, declining or otherwise considered to be of conservation concern. PNHP records indicate that 77 tracked species have populations within pixels that have a relatively high modeled probability for wind development. Most of these species are commonly found in rocky outcrops and scrub oak/pitch pine barrens habitats on ridgetops across the state. Only a handful of species, however, have more than a few occurrences overlapping with the relatively high probability wind development pixels. For example, the eastern timber rattlesnake (*Crotalus horridus*) and Allegheny woodrat (*Neotoma magister*) are strongly associated with rocky outcrops and talus slopes along or near ridgetops. Six percent of the rattlesnake's known rattlesnake breeding/denning sites and three percent of Allegheny woodrat den sites are located in relatively high wind probability pixels. The den sites are very small sites and do not include foraging areas. The Pennsylvania Natural Heritage Program has developed core habitat polygons for each Allegheny woodrat occurrence. Much larger than the den locations, these polygons indicate a much broader overlap – 43 percent – with relatively high probability pixels for wind development. The Northern long-eared Myotis bat (*Myotis septentrionalis*) has about eight percent of its known winter hibernation and summer roosting areas overlapping with relatively high probability wind development pixels. Ridgetop barrens communities in northeastern Pennsylvania have some of the state's largest concentrations of rare terrestrial species. The Nature Conservancy has mapped these communities, and some of these habitats overlap with high wind areas. In general, there appears to be relatively little overlap between tracked species occurrences in Pennsylvania and likely wind development sites. For a handful of species, there is enough overlap to indicate the importance of surveys early in the project planning stage to identify the presence of rare species and their core habitats.

We have not addressed the potential impact of these scenarios on bird migration patterns and bat foraging populations. For more information on wind development impacts on bird and bat species, please see links to the Pennsylvania Game Commission, U.S. Fish and Wildlife Service, American Wind and Wildlife Institute, and Bat Conservation International.

Recreation

Wind development has not occurred on any state or federal lands in Pennsylvania to date. Since our projections assume there will not be a significant change in state land leasing policies for wind development, we have not projected new wind turbines in State Parks, State Forests or State Game Lands. Our projections, however, do indicate that wind turbines will be located in close proximity (sometimes as close as 500 feet) to many state lands. They are likely to be highly visible in some heavily visited areas, such as Blue Knob State Park in Bedford County, where natural landscape vistas are a prime attraction.

Key Findings

Key findings from the Pennsylvania Energy Impacts Assessment include:

- Projections of between 750 and 2,900 new wind turbines developed on ridgetops and high plateaus by 2030, depending on the size of the Pennsylvania Alternative Energy Portfolio standard. There are currently an estimated 500 wind turbines built in the state.
- Wind turbine facilities are likely to be developed in half of the state's counties, especially along the Allegheny front in western Pennsylvania and on high Central Appalachian ridges in central and northeastern parts of the state;
- Nearly eighty percent of turbine locations are projected to be in forest areas, with forest clearing projected to range between 1,140 and 4,400 acres depending on the number of turbines developed. An additional range of 7,900 to 30,600 acres of forest interior habitat impacts are projected due to new edges created by turbine pads and roads;
- On a statewide basis, the projected forest clearing from turbine development is relatively minor, though some of the state's largest forest patches (>5,000 acres) could be fragmented into smaller patches by projected wind turbine development;
- Impacts on forest interior breeding bird habitats appear to be limited, largely because the overall footprint for the projected wind turbine facilities is small in comparison to the typical breeding range of these species in Pennsylvania. The study did not assess impacts to migratory pathways for birds or foraging bats.
- Relatively few watersheds ranked as "intact" by the Eastern Brook Trout Joint Venture are affected by projected wind turbine development. Several intact watersheds, however, could see several dozen wind turbines. In a number of cases, these small watersheds are projected to see significant Marcellus gas development as well. Given the cumulative impact of these activities, rigorously designed and monitored sediment control measures will be needed to protect sensitive brook trout populations.
- A relatively small handful of rare species occurrences tracked by the Pennsylvania Natural Heritage Program are found in areas with high probability for wind development. These species tend to be associated with rocky outcrops and barrens communities typically found on ridge tops, including the Allegheny wood rat, the eastern timber rattlesnake, and the northern long-eared Myotis bat.
- Wind development is not projected to occur on Pennsylvania's public lands. Existing and projected wind turbines, however, will be close to some of Pennsylvania's most heavily visited outdoor recreation areas where scenic natural vistas are a major attraction.

Additional Information

- American Wind Energy Association (2010). U.S. Wind Projects Database. http://www.awea.org/la_usprojects.cfm
- Black and Veatch (2010) Study for the Community Foundation for the Alleghenies: Assessment of a 15 Percent Pennsylvania Alternative Energy Portfolio Standard: http://www.cfalleghenies.org/pdf/aepss.pdf
- Federal Aviation Administration (FAA) permits for wind turbines: https://oeaaa.faa.gov/oeaaa/external/public/publicAction.jsp?action=showCaseDownloadForm
- Federal Aviation Administration (FAA), Obstruction Evaluation / Airport Airspace Analysis (OE/AAA): https://oeaaa.faa.gov/oeaaa/external/public/publicAction.jsp?action=showCaseDownloadForm
- Pennsylvania Wind Farms and Wildlife Collaborative: http://www.dcnr.state.pa.us/wind/index.aspx
- PA Game Commission (2007) Wind Energy Voluntary Cooperative Agreement and First Annual Report for the Wind Energy Voluntary Cooperative Agreement: http://www.portal.state.pa.us/portal/server.pt?open=514&objID=613068&mode=2
- Pennsylvania Department of Environmental Protection, Chapter 93 Water Quality Standards, Exceptional Value and High Quality Streams: data downloaded from Pennsylvania Spatial Data Access: (www.pasda.psu.edu)
- U.S. Department of Energy TrueWind 80 Meter Wind Resource Maps: http://www.windpoweringamerica.gov/wind_maps.asp
- U.S. Fish and Wildlife Service Wind Turbine Advisory Committee: http://www.fws.gov/habitatconservation/windpower/wind_turbine_advisory_committee.html
- U.S. Environmental Protection Agency summary of forest fragmentation effects: http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&lv=list.listByAlpha&r=219658&subtop=210
- Overview of forest fragmentation impacts on forest interior nesting species: http://www.state.nj.us/dep/fgw/neomigr.htm
- Overview of Pennsylvania High Quality and Exceptional Value Streams: http://www.dcnr.state.pa.us/wlhabitat/aquatic/streamdist.aspx
- Eastern Brook Trout Joint Venture intact brook trout watersheds: http://128.118.47.58/EBTJV/ebtjv2.html

- Overview of Carnegie Museum of Natural History, Powdermill Nature Reserve, and the Pennsylvania Game Commission's 2nd Pennsylvania Breeding Bird Atlas Project: http://www.carnegiemnh.org/powdermill/atlas/2pbba.html

- Pennsylvania Natural Heritage Program, including lists of globally rare and state endangered and imperiled species: http://www.naturalheritage.state.pa.us/

- U.S. Department of Agriculture, Natural Resources Conservation Service, National Agriculture Imagery Program: http://datagateway.nrcs.usda.gov/GDGOrder.aspx

Testimony on the Economic and Environmental Impacts of Hydraulic Drilling of Marcellus Shale on Philadelphia and the Surrounding Region

Before The Joint Committees on the Environment and Transportation & Public Utilities of the Council of the City of Philadelphia

David Velinsky, Ph.D.
Vice President for Environmental Research
The Academy of Natural Sciences

Good morning. I appreciate the opportunity to speak on this crucial issue. I am Dr. David Velinsky and I am the Vice President for Environmental Research at the Academy of Natural Sciences. The Academy is Philadelphia's natural history museum, and our environmental research program has been studying human impacts on the environment for over sixty years. I direct an interdisciplinary team of scientists and technical staff that focuses on the ecological processes and environmental health of natural systems, particularly waterways, watersheds, and estuaries.

My colleague, Dr. Boufadel, and I were invited to provide scientific background on the issue of gas drilling in the Marcellus Shale and to discuss its potential impacts on the environment. I'd like to thank the Council for asking Temple University and the Academy of Natural Sciences to speak at this hearing. Our institutions are two of Philadelphia's important scientific resources, and we are pleased to apply our scientific capabilities to a topic of critical interest to our City and the Commonwealth of Pennsylvania. As our institutions propose to collaborate further on studying the Marcellus Shale, it is very appropriate that we are co-presenters today.

Today I'm going to start with some of the basic science of the Marcellus Shale and the natural gas deposited within it; touch on the drilling method known as hydraulic fracturing; and then look at some of the potential impacts of the drilling practice on the aquatic and terrestrial ecosystems. Finally I will discuss some preliminary research that has been conducted on these impacts, and briefly touch upon the further research that we feel is necessary to resolve a variety of uncertainties that surround the potential impacts of gas drilling in the Marcellus Shale. Dr. Boufadel's testimony will then focus on the hydrogeology of drilling and the potential below ground impacts.

I would also note that the Academy of Natural Sciences does not take a position on the overall advantages or disadvantages of obtaining gas from the Marcellus Shale. We recognize the enormous potential of this resource, for both the possible economic benefit of the Commonwealth and as an energy source with reduced greenhouse gas emissions. As environmental scientists, our role is to outline the potential changes to our ecosystem that may result from this process and to point out relative levels of uncertainty.

The Marcellus Shale, as this slide indicates, runs roughly from New York to West Virginia and lies on average about a mile underground (a little less than the distance from City Hall to the Art Museum), although that varies widely and in some places, such as Marcellus, New York, where it protrudes above the surface. As you can see from this map, a significant proportion of the Marcellus Shale is located under Pennsylvania, particularly along the Susquehanna Basin and, to a lesser extent, the Delaware.

What actually is the Marcellus Shale we've heard so much about? Technically, shale is a fine-grained sedimentary rock formed from mud deposited in ancient river bottoms, lagoons or even the continental shelf. There are types of shale formations around the world that occupy regions below the earth's surface. The Marcellus Shale was formed about 300 million years ago in an enclosed sea that once covered part of Pennsylvania. Microscopic algae produced in the surface waters were deposited in the bottom of the ancient sea that had low oxygen, and then were eventually covered over with other types of sediments. The methane gas was formed as the organic rich sediment degraded over time. This process needed the right temperature, pressure and time for methane to form and remain. This gas is now embedded in the tiny pores of the shale.

I would point out that the Marcellus is only one of many classes of shale that were formed by ancient geological processes. As you can see from the diagram, in this region there are shales that lie both above and below the Marcellus, and some of these may also contain gas. In fact, the presence of shale gas has been known for some time and extracting shale gas has been done in other parts of the country.

However until recently, it was believed that most of this shale gas could not be effectively utilized. Many shale gas deposits have low permeability, that is to say, the deposits are trapped in the grain of the rock, and there isn't enough pressure for the gas to be withdrawn by simply boring a well into it. Many of these shales are also located at depths that were not easily reached by conventional drilling technologies.

This was the case until recently with the Marcellus gas. Several recent developments, however, have made it a more promising fuel source. First, new studies, notably by USGS and then Penn State, revealed that the extent and potential volume of the gas was much larger than previously estimated. Secondly, technical advances in drilling, specifically horizontal drilling combined with the older technique of hydraulic fracturing, have now provided a means for economically accessing the gas.

This method is quite simple in principle, although in the past was a daunting engineering task. Wells are drilled down to the level of the Marcellus Shale—as mentioned, roughly a mile—and the drilling tool is turned horizontally into the shale. Explosives are introduced into the horizontal bore, loosening the rocks, and then high-pressure water—a few million gallons per well—is pumped into open factures in the shale. The gas then flows through these fractures and is withdrawn through the vertical shaft.

I will leave it to the representatives of the drilling companies to explain any further details or clarify anything I've missed on the process. The questions we are considering are the potential environmental impacts of the gas drilling.

I would point out that while hydraulic fracturing and it's relationship to water quality has received the most attention, the impacts resulting from the entire process of gas drilling in the shale must be considered. We need to think about whether there are specific impacts on water quality and quantity, but we also have to look at larger impacts on natural resources and the natural services, such as water filtration, that are provided by the existing ecological systems. I will discuss this latter concept, known as ecosystem services, in few moments.

In terms of overall impacts, as these photos show, gas drilling is an industrial process. There is the footprint of the well pad itself, the extraction and transportation of water to be used for fracturing, the disposal of fracturing water once it has been used (about a third of the amount is withdrawn from the well), potential impact of these activities on ground water, and the attendant issues that come from roads, construction, truck traffic, and air and noise issues, to name a few.

I'm not saying that these processes can't be managed or that they are unjustified from a cost-benefit perspective, but it is doubtful that they could be done with zero impact. However careful and conscientious drillers may be—and many are trying to be—it would be simplistic to say you could introduce these sorts of activities into natural or agricultural settings without altering elements of the system.

Let's take a moment and look specifically at the fracturing water, since that has received the most attention. On average about three million gallons of water are used for each well. The effect of this practice on water *quantity* quite simply depends on the source of the water. Three million gallons withdrawn from the Delaware down at Penn's Landing would not have a measurable effect on the flow of the river—it's simply too small a fraction. Three million gallons withdrawn from a small upland waterway—what we call a first- or second-order stream—could have a significant impact on available water locally and its biological diversity.

A number of substances are added to the fracturing water to increase its effectiveness in obtaining the gas. These substances include lubricants to reduce friction, biocides and scale inhibitors to prevent bacterial growth, and coarse substances to assist the fracturing. None of these, for the most part, are found naturally in waterways. While best practices are that none of the fracturing water will ever be released into the environment, the level of risk involved in using these substances must be assessed.

In addition to the chemicals added to the water prior to use, the fracturing process adds a number of substances from the underground environment to the water that is withdrawn. As result, withdrawn fracturing water has very high levels of total dissolved solids.

The measure of *total dissolved solids or* TDS, is simply the amount of material in dissolved form—including minerals, salts or metals—that are in a given volume of water. High total dissolved solids can be a serious impairment to water quality in freshwater systems. As this slide shows, the amount of various dissolved materials in fracturing water exceeds by many orders of magnitude that found in typical river water. Substances such as barium and strontium, normally in trace amounts, are in very high relative concentrations in withdrawn fracturing water.

Is this a potential impact on the environment? Again, it depends on how the water is handled and how and where it is disposed of. The introduction of three million gallons of fracturing water with the TDS noted to the Delaware at Penn's Landing would probably have no measurable effect on the river as a whole. Three million gallons of such water spilled into a first- or second-order stream would have a profound impact on the local aquatic system. It should be noted that there is no economical treatment process for TDS other than dilution. In other words, at some point this water will have to be introduced into larger waterway or injected in deep wells.

So, to summarize there are several potential sources of environmental impact from gas drilling in the Marcellus Shale. First, water withdrawal could have impacts locally on the quantity of water available for natural processes. Second, there could be impacts on water quality. This could happen from accidental spills; treatment of withdrawn water; or other, as yet poorly understood processes. Dr. Boufadel will address some of the potential impacts on groundwater movement and quality.

The third area of potential impact is habitat and land fragmentation. This issue is not directly related to hydraulic fracturing but may be the most significant and least considered of the potential problems. Fragmentation is simply the reduction in the amount of forest cover and natural open space, breaking it up into smaller fragments, and a loss of connectivity between these fragments, in other words reducing the amount of space available for organisms, and interrupting or blocking important ecological processes in an area.

The effects of habitat fragmentation due to human alterations of the landscape have been studied for many years and are well understood. We know that there are critical sizes of contiguous natural systems that must be present for diverse populations of organisms to function, and we know that those sizes and diversities of organisms are necessary for ecological processes to occur.

This latter function—ecological processes—is sometimes called ecological services, because they represent a variety of potentially costly services that human societies get for free from natural ecosystems. I mention this because it is important to understand that we don't preserve natural systems just out of some altruism or fuzzy moral sense. We preserve natural systems because human society depends on them directly, whether it is for water filtration, air quality, or fertile soil.

The combined effects of habitat fragmentation and potential release of fracturing water into natural systems could have significant impacts on aquatic ecosystem services. Changes in TDS can be toxic, both on a chronic and acute scale, to aquatic organisms, reducing the size of biological communities and ultimately impacting human needs such as fisheries and water quality. Studies by Academy scientists, as well as from other local institutions, has shown that headwater forested streams provide the greatest filtration capacity for nutrient removal.

In summary, both loss of forest area and introduction of increased TDS can reduce or impair ecosystem service in small watersheds such as those in the upper Delaware. In particular removal of nutrient pollution, a major environmental stressor in agricultural landscapes, can be impaired by fragmentation and by changes in water chemistry such as increased TDS.

At this time there is very little information available as to the impacts of long-term exposure of a watershed to Marcellus Shale drilling activities, nor do we know if there is a cumulative impact of drilling activity—and in particular of possible exposure to water with elevated TDS—on the ecosystem services of a small watershed.

Let me be clear on this point. The question we believe needs to be addressed is whether there is a threshold point past which a certain density of drilling activity has a impact on the ecological health and services of the watershed regardless of how carefully drilling is conducted. Past studies that have looked at particular well sites or particular incidents fail to give a picture of the chronic impacts that might be expected from drilling and especially hydraulic fracturing.

We are saying that regardless of the practices being followed by drillers, there may be a point at which drilling will have a definite signal in the ecological function of a watershed. Conversely, there may be some level of activity, some maximum number of well pads, below which, drilling doesn't have measurable ecological impact. Right now we have no idea if either of those are valid hypotheses. We are proposing multi-variable cumulative ecological studies that would answer those questions.

One of the ways we measure ecological functioning is to look at certain key chemical indicators and at the abundance of certain types of organisms. Testing the electrical conductivity of a waterway is a good way of assessing the TDS and also a good proxy for human caused disturbance. This is because increases in pollution, erosion, water withdrawal and many other disturbances are often reflected by increased contamination of the water.

There are also certain organisms, notably amphibians and particular orders of insects that are highly sensitive to degraded and contaminated environments. By sampling watersheds for these measures, we are able to get an approximation the relative heath of the watershed and the ecosystem services of which it is capable.

To at least get preliminary assessment of cumulative impact of drilling in the shale, Academy scientists have been working with a University of Pennsylvania graduate student to collect data on water chemistry and indicator organisms. I would now like to briefly review the preliminary results of that research. Let me emphasize, this data is very tentative and will require further review and replication, but it does suggest that the impact of the drilling may be directly connected to density of drilling.

Our researcher looked at measures of ecological function downstream in nine small watersheds - three in which there had been no drilling, three in which there had been a defined low density of drilling activity and three in which there had been a defined high density of drilling activity.

Three indicators were measured: the conductivity of the water, the abundance of certain sensitive insects (also called an EPT index) and the abundance of salamanders. This last measure is particularly important as amphibians are especially vulnerable to changes in the environment and absence of amphibians is often an ecological "early warning" system.

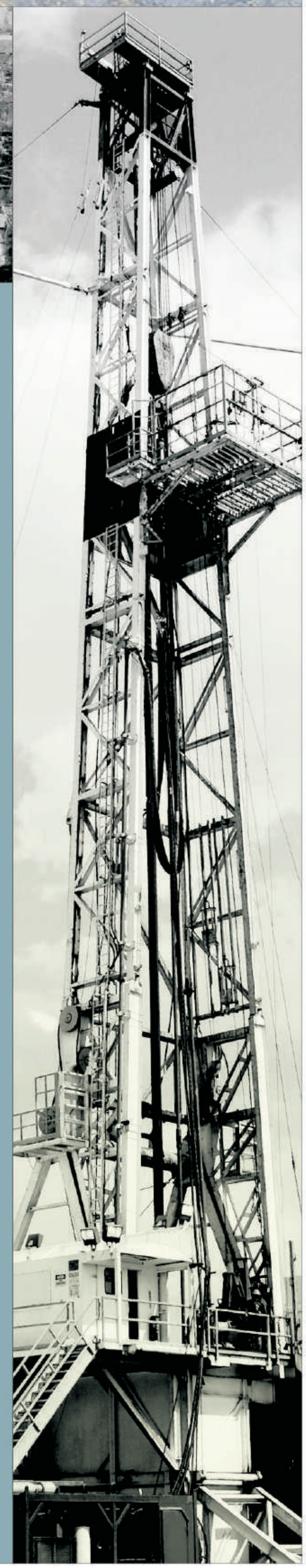
The results of the research can be seen in these graphs. For each of the measures, there was a significant difference between high-density drilling locations and locations with no or low density drilling. Water conductivity was almost twice as high in the high density sites as it was in the low density and reference sites, while number of both salamanders and sensitive insects were approximately 25% reduced. Statistical analysis indicates that there is a less than 5% probability that these differences were the result of random chance.

This suggests that there is indeed a threshold at which drilling—regardless of how it is practiced—will have a significant impact on an ecosystem. Conversely it also suggests that there may be lower densities of drilling at which ecological impact cannot be detected.

With this initial data, which I emphasize remains tentative; we are proposing a comprehensive research plan to the State DEP (i.e., Growing Greener Program), which would develop guidelines and an assessment tool for regulators and managers to minimize the ecological impact of drilling. Our goals are to determine if this apparent threshold in the preliminary data remains valid over a larger sample, and to better understand the interactions between well density, size of the impacted stream and watershed, and the resulting ecological indicators.

We propose to look at four streams in each of three size classes for each of the three levels of well density (none, low and high). We will also use computer modeling to analyze the impact of drilling on deforestation. When this study has been completed, we will be able to indicate with a much higher level of certainty what the ecological risks are of drilling in the shale and how they might be managed. It is this and other types of scientific studies that are needed to provide regulators and drillers the necessary information for environmentally sound gas extraction from Pennsylvania.

In conclusion, I would like to thank the Council for this opportunity to discuss these issues. We believe the gas in the Marcellus Shale could have positive effects on the Pennsylvania economy, and there may be possible ways it could be extracted safely. Again, I'd like to emphasize that the Academy does not take a position on the overall advantages or disadvantages of obtaining gas from the Marcellus Shale. At this time, however, there remain significant uncertainties and we urge a cumulative impact assessment on the scale described above before any large-scale drilling occurs.



FINAL IMPACT ASSESSMENT REPORT

Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed

December 2009

HAZEN AND SAWYER
Environmental Engineers & Scientists

LBG

a joint venture

New York City Department of
Environmental Protection

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Table of Contents

List of Figures

List of Tables

Executive Summary

This report presents the results of an assessment performed by the New York City Department of Environmental Protection (NYCDEP) and its consultants, the Joint Venture of Hazen and Sawyer, P.C., and Leggette, Brashears and Graham, Inc., evaluating potential impacts to the NYC water supply resulting from development of natural gas resources in the Marcellus shale formation. The Marcellus[1] shale is one of the largest potential sources of developable energy in the U.S. and covers an area of 95,000 square miles; the New York State portion is approximately 18,700 square miles. The Catskill and Delaware watersheds that provide 90 percent of New York City's unfiltered drinking water supply are underlain by relatively thick sections of the Marcellus that are expected to have high gas production potential and be targeted for development. Within the watershed, there are approximately 1,076 square miles that are not currently protected and are potentially available for the placement of well pads, impoundments, chemical storage, and other elements of natural gas drilling.

Development Activities

Based on densities of development in other shale gas formations in the United States, the area of unprotected or nominally developable land in the watershed, and the number of wells needed to efficiently exploit the resource, it is estimated that between 3,000 and 6,000 gas wells could be constructed in the watershed in the next two to four decades. Initial rates of development would be relatively low (5 to 20 wells per year), but could escalate rapidly to 100 to 300 or more wells per year under favorable economic and regulatory conditions.

Extraction of natural gas from the Marcellus and other shale formations relies on horizontal drilling and high-volume hydraulic fracturing (fracking). A Marcellus well in the New York City (NYC) watershed region would likely be drilled vertically to a depth of 4,000 to 6,000 feet, and extend horizontally a comparable distance through the target shale formation. Natural gas extraction requires that the shale be hydraulically fractured along the lateral portion of the well to increase the permeability of the shale and allow gas to flow into the well at economically viable rates. The fracturing process involves pumping three to eight million gallons (MG) of water and 80 to 300 tons of chemicals into the well at high pressures over the course of several days. Roughly half the injected solution returns to the surface as "flowback" water containing fracturing chemicals plus naturally occurring and often very high levels of total dissolved solids, hydrocarbons, heavy metals, and radionuclides. Flowback water is not amenable to conventional wastewater treatment, and must be disposed of using underground injection wells or industrial treatment facilities. The region currently has insufficient treatment and disposal capacity to handle the expected wastewater volumes.

Water for the fracturing process is typically drawn from surface water bodies and trucked to the drill site; local groundwater supplies may also be used if available. Hauling of water, wastewater, and equipment to and from the drill site requires on the order of 1,000 or more truck trips per well. The entire process, from site development through completion, takes approximately four to ten months for one well. Multiple horizontal wells are typically drilled from a common well pad roughly five acres in size. One multi-well pad can accommodate six or more wells and can

[1] It should be noted that there are other gas-bearing formations such as the Utica Shale that may be targeted for development in the future.

recover the natural gas from a spacing unit covering a maximum of one square mile. New York requires that all wells from a pad must be drilled within three years of the first well, so sites will experience a relatively high and constant level of heavy industrial activity for at least one and up to three years. The fracturing process may be repeated multiple times over the life of a well to restore declining gas production rates. Wells will generally discharge poor quality brine water from the target formation over their useful life.

Table ES-1, described in more detail in Section 4.1, illustrates the magnitude of cumulative water, wastewater, and chemical volumes associated with large-scale hydraulic fracturing operations for a 6,000 well "full build-out" scenario, with and without refracturing.

Table ES-1: Cumulative Water, Wastewater, and Chemical Volumes Associated with Hydraulic Fracturing

Parameter (units) *Estimate (source)*	Without Refracturing	With Refracturing	
		10-Year Interval	5-Year Interval
Total Number of Wells	6,000	6,000	6,000
CUMULATIVE BASIS			
Total Number of Frack Jobs *Full build-out, high scenario*	6,000	24,000	48,000
Frack Chemicals Used (tons) *1.0% of fracture fluid*	1,000,000	4,000,000	8,000,000
Waste TDS (tons) *100,000 mg/l TDS (dSGEIS)*[2]	12,510,000	27,522,000	47,541,000
ANNUAL BASIS[1]			
Water Demand (mgd) *4 MG per frack job*	3.6 to 5.5	5.5 to 8.2	11.7 to 14.2
Wastewater Production (mgd) *50% Flowback + 0.075 MG/yr Produced Water*	2.6 to 3.5	3.9 to 5.3	6.7 to 8.4
Waste TDS for Disposal (tons/day) *100,000 mg/l TDS in waste (dSGEIS)*[2]	1,100 to 1,500	1,600 to 2,200	2,800 to 3,500
Water Req'd to Dilute TDS to 500 mg/l (mgd)	500 to 700	800 to 1,100	1,300 to 1,700
Frack Chemicals (tons/day) *1.0% of fracture fluid*	150 to 230	230 to 340	490 to 590

Notes:
1. Ranges describe the median and the maximum of the annual average values for each development year. Data for the no-refracturing scenario are drawn from the 20-year period of well development. Data for the refracturing scenarios are drawn from the full 60-year period of development and refracturing.
2. The dSGEIS reports median and maximum values of TDS as 93,200 mg/l and 337,000 mg/l, respectively. The concentration of TDS in flowback reportedly increases with time. The determination of median value may include relatively low concentration samples from initial flowback.

Potential Impacts

The West-of-Hudson watershed is a pristine, largely undisturbed landscape, with only minimal industrial activities. These natural and land use factors combine to yield water of very high quality with little or no chemical contamination. Natural gas well development in the West-of-Hudson watershed at the rates and densities observed in comparable formations will be accompanied by a level of industrial activity and heightened risk of water quality contamination that is inconsistent with the expectations for unfiltered water supply systems.

Intensive natural gas well development in the watershed brings an increased level of risk to the water supply: risk of degrading source water quality, risk to long-term watershed health and the City's ability to rely on natural processes for what is accomplished elsewhere by physical and chemical treatment processes, risk of damaging critical infrastructure, and the risk of exposing watershed residents and potentially NYC residents to chronic low levels of toxic chemicals. In addition to surface risks to the watershed, extensive hydraulic fracturing of horizontal wells will present subsurface contamination risks via naturally occurring faults and fractures, and potential alteration of deep groundwater flow regimes, as indicated by the geological cross-section presented as Figure ES-1.

Each of these risks is discussed in greater detail in this document. They have been identified based on review of the progression of natural gas development in other areas, documented incidents of surface water and shallow groundwater contamination associated with natural gas resource development, and review of regional geological features. NYC operates over 100 miles of water supply tunnels west of the Hudson River, the construction of which provided direct experience with respect to faults and deep fluid migration through bedrock. The assessment of risks to the City's water supply system takes into account seepages of methane and deep formation water, and faults and other natural geological features encountered during tunnel construction. As shown in Figure ES-2, water supply tunnel routes intersect numerous geological faults and fractures, many of which extend laterally for several miles, and vertically through several underlying geological strata. Each of these features represents an existing potential pathway for fluid migration.

The difficulty of remediating diffuse contamination and other risks once allowed into the environment, and the potentially catastrophic consequences of damage to critical water supply infrastructure, make clear that a conservative approach towards natural gas drilling in the NYC watershed and in the vicinity of infrastructure is warranted. In short, the rapid and widespread industrialization of the watershed resulting from natural gas drilling would upset the balance between watershed protection and economic vitality that the City, its State and federal regulators, and its upstate partners have established over the past 15 years.

Development of natural gas resources using current technologies thus presents potential risks to public health and would be expected to compromise the City's ability to protect the watershed and the continued, cost-effective provision of a high-purity water supply. A robust assessment of risks from drilling would consider site-specific factors assessed on a well-by-well basis and would consider detailed knowledge of local fracture, infrastructure, hydrologic, and other conditions at a finer scale than watershed-level analysis. In recognition of the possibility that horizontal drilling and hydraulic fracturing may one day be allowed to proceed, measures for reducing some, but not all, risks to water quality and water supply infrastructure are summarized in an appendix.

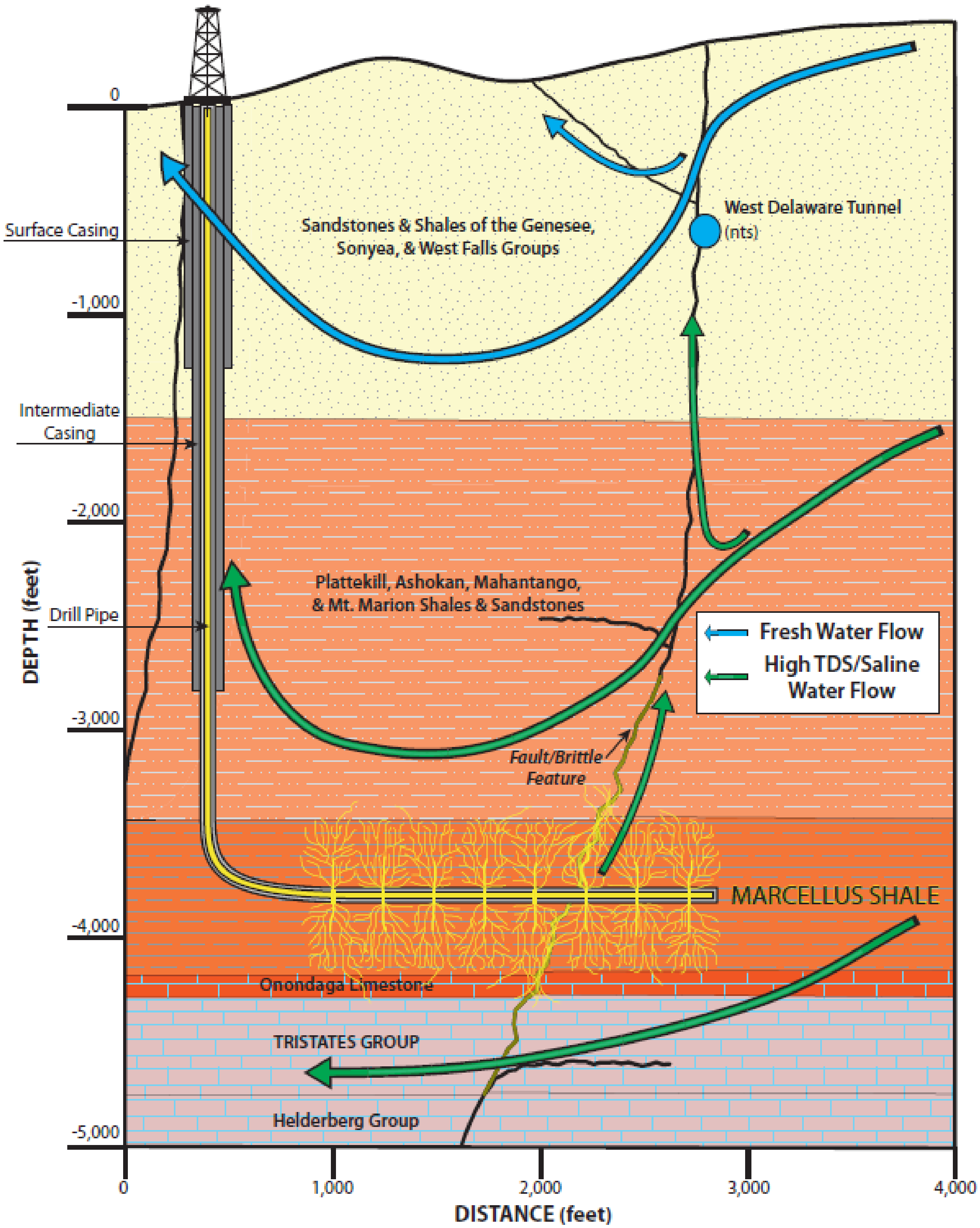


Figure ES-1: Potential Flow Disruption and Contamination Mechanisms

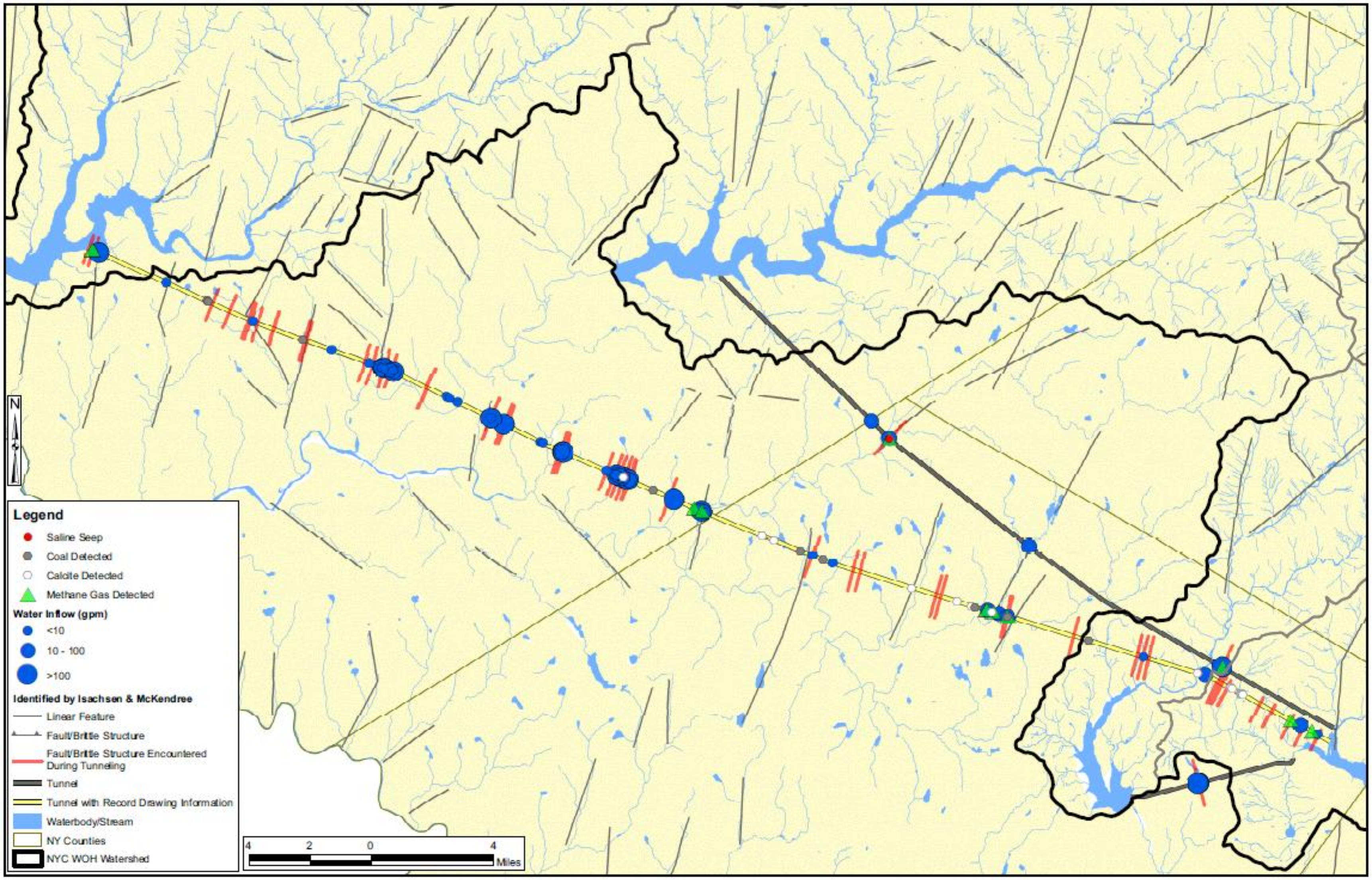


Figure ES-2: Map of the East and West Delaware Tunnels and Neversink Tunnel

Section 1: Introduction

1.1 Project Background

In recognition of increased natural gas development activity in New York State and its potential to impact New York City's water supply, the NYCDEP has undertaken the project, *Impact Assessment of Natural Gas Production in the NYC Water Supply Watershed*. Natural gas development activities have the potential to impact the quality and quantity of NYC's water supply through land disturbance, toxic chemical usage, disruption of groundwater flow pathways, water consumption, and waste generation. The overall goal of the project is to identify potential threats to the continued reliability and high quality of New York City's water supply by providing an assessment of the potential impacts of future natural gas development activities in or near the NYC watershed on water quality, water quantity, and water supply infrastructure.

NYCDEP retained the Joint Venture of Hazen and Sawyer, P.C., an environmental engineering firm, and Leggette, Brashears & Graham, Inc., a hydrogeologic and environmental consulting firm, to assist in performing this assessment. The first phase of the project included evaluation of regional hydrogeology and development of a conceptual hydrogeologic model of the region, characterization of activities and impacts associated with natural gas well development, review of a database of drilling and fracturing chemicals, examination of case studies from other formations, and preparation of a preliminary infrastructure assessment. Results from the first phase were summarized in a Rapid Impact Assessment Report issued in September 2009.

The current Final Impact Assessment Report incorporates the previous work into a cumulative watershed risk assessment and provides further evaluation of subsurface migration pathways and risks to NYC infrastructure.

1.2 New York City Water System and Source Protection Measures

The New York City water system is comprised of three separate supply systems – the Catskill, Delaware, and Croton systems. Approximately 90 percent of the City's water supply (more than one billion gallons per day) is drawn from the Catskill and Delaware systems located west of the Hudson River in upstate New York. As such, it is NYCDEP's mission and responsibility to protect both the NYC water supply system and public health and safety, ensuring continued reliability in serving nine million consumers within New York City and upstate communities (in Westchester, Putnam, Orange, and Ulster Counties) who depend on the New York City system as the primary source of their drinking water. The NYC watershed is a working watershed that supports multiple uses. The 1997 Watershed Memorandum of Agreement signed by New York State Department of Environmental Conservation (NYSDEC), NYCDEP, Environmental Protection Agency (EPA), environmental parties, and numerous local governments committed the parties to foster economic development within the watershed that is consistent with principles of watershed protection.

The City's decision to pursue source water protection was based in part on the existing quality of the water and in part on the belief that keeping pollutants out of the water was in the long term a more sustainable strategy than the more conventional approach used by most water suppliers – employing treatment technologies to remove pollutants after they get in the water.

The West-of-Hudson watershed is a pristine, largely undisturbed landscape, characterized by high rates of forest cover (78 percent) and predominantly rural land uses. Development has historically been confined to the river valleys and impervious surfaces cover a mere 1.2 percent of the land area. Dairy farms are a common part of the rural landscape, particularly in the far western reaches of the watershed, and there are minimal industrial activities. These natural and land use factors combine to produce a very high quality water from the Catskill/Delaware watershed.

Beginning in the early 1990s, NYCDEP initiated development and implementation of a suite of programs designed to preserve and enhance the existing quality of the Catskill/Delaware source waters. Prior to undertaking design of protection programs, NYCDEP initiated a comprehensive water quality monitoring program. Samples were taken at various locations and frequencies to accurately characterize water quality conditions throughout the watershed. Data acquired through this effort was used to identify existing and potential pollution sources and to identify pollution control strategies. Based on monitoring data, NYCDEP identified the primary threat to water quality as coliforms, pathogens, nutrients and turbidity. To this day, those pollutants – which largely derive from natural sources, limited residential development, and agriculture – remain the primary pollutants of concern for the New York City water supply.

DEP's watershed protection program is based on water quality science supported by extensive monitoring and water quality data. Various program elements seek to either remediate existing sources of pollution or to prevent future sources. The overall program has been tailored to be mindful of and support the economic vitality of the communities and the residents of the Catskills. The major elements of the watershed protection program include:

- Land Acquisition – increasing the amount of land to be preserved in its natural condition;
- Watershed Regulations – primarily targeting stormwater and wastewater pollution from development;
- The Watershed Agricultural Program – working with watershed farmers to implement pollution control practices on farms;
- The Stream Management Program – working with riparian landowners to restore degraded streams to more natural conditions;
- The Wastewater Treatment Upgrade Program – funding the upgrade of all pre-1997 WWTPs in the watershed to state-of-the-art tertiary treatment;
- The New Infrastructure and Community Wastewater Management Programs – designing and constructing new wastewater infrastructure for communities with concentrations of failing or likely-to-fail septic systems;
- The Septic Rehabilitation Program – funding the repair or replacement of failing septic systems for individual residences and small businesses;
- The Stormwater Retrofit and Future Stormwater Controls Control Programs – seeking to address pollution from stormwater runoff, either by retrofitting existing sites or funding compliance with the Watershed Regulations; and
- The Watershed Forestry Program – working with owners of forested land to promote a vigorous forest landscape and forestry practices that are protective of water quality.

Taken together, these programs effectively address the current range of human activity in the watershed that could threaten water quality. Instrumental to the success of the City's program has been the strong collaboration between a multitude of stakeholders – watershed representatives and residents, environmental groups, regulatory agencies and NYCDEP. These partnerships are key to the success of the programs because certain elements have the potential to modify individual property rights and community growth goals. The City has worked to develop programs that strike an appropriate balance between water quality preservation and community interests.

Due to the high quality of the West-of-Hudson water supplies and the extensive watershed protection efforts of NYCDEP and numerous stakeholders, EPA has determined in successive Filtration Avoidance Determinations that NYC's Catskill and Delaware supplies satisfy the requirements for unfiltered surface water systems established in the Surface Water Treatment Rule and the Interim Enhanced Surface Water Treatment Rule. The most recent Filtration Avoidance Determination was issued in 2007 and establishes requirements for continued watershed protection efforts through 2017. A core requirement for filtration avoidance is a watershed control program that can identify, monitor, and control activities in the watershed which may have an adverse effect on source water quality.

Proof of the effectiveness of the City's approach lies in the fact that water from the Catskill/Delaware system continues to be of exceptionally high quality and is virtually free of chemical contaminants. Water supply monitoring is extensive and far exceeds regulatory requirements, both in the watershed and in the distribution system. NYCDEP operates five modern water quality laboratories throughout the watershed and distribution system, and processes approximately 50,000 samples from 1,400 sample locations for up to 240 contaminants and 600,000 analyses per year. Analyses performed include those for basic physical parameters, nutrients and metals, and tests for disease-causing organisms such as bacteria, viruses and protozoans. Additionally, the water supply is routinely scanned for synthetic organic compounds at watershed locations and throughout the distribution system. Extensive monitoring is used to ensure that NYCDEP delivers the highest quality water to the consumer and helps to instill a high degree of public confidence in the water supply system.

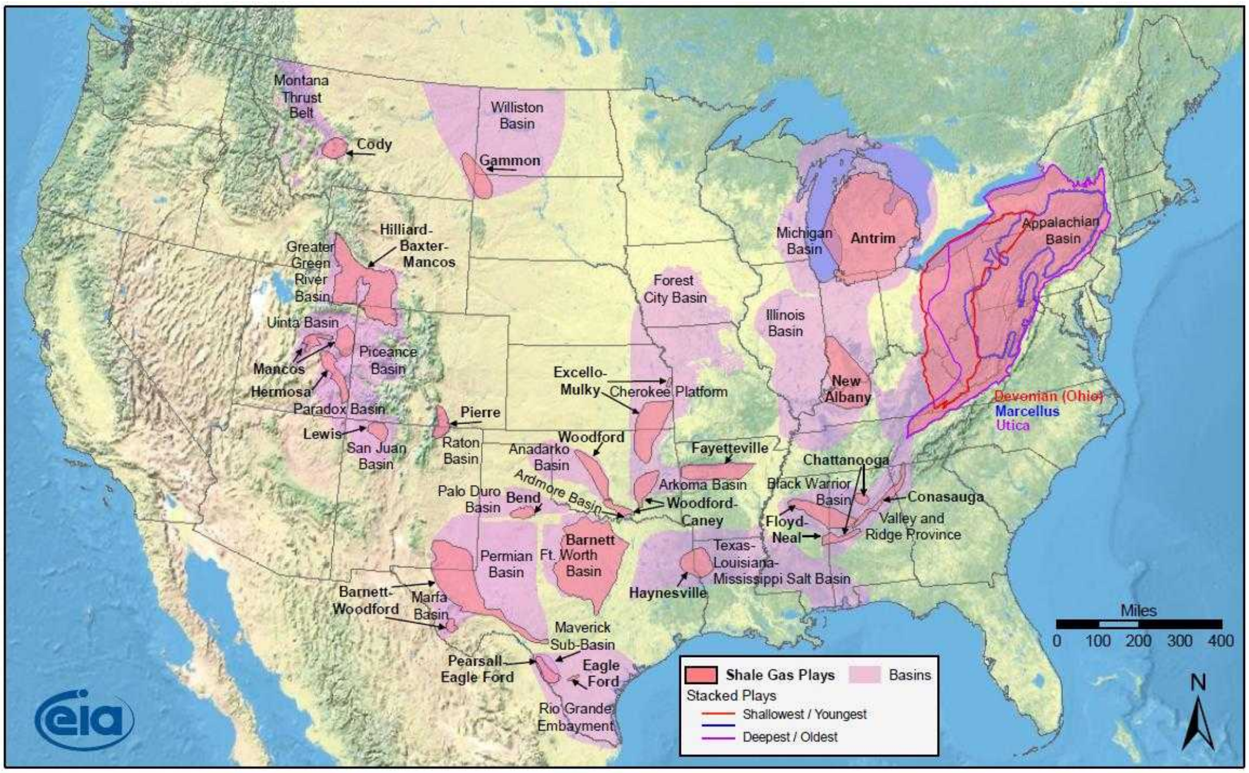
1.3 Trends in Drinking Water Regulations

Currently, the federal Safe Drinking Water Act requires the monitoring of about 90 contaminants in water supply systems. Additionally, the Unregulated Contaminant Monitoring Rule and the Candidate Contaminant Listing process require EPA to establish criteria for expanding the number of contaminants subject to monitoring requirements, and require EPA to make determinations on regulating additional contaminants. As a result of these rules and listing processes, as public health concerns associated with chemical contaminants continue to increase, and as analytical techniques improve, the trend will be toward more stringent drinking water regulations in the future. The number of regulated contaminants will expand and the maximum contaminant levels (MCLs) of contaminants are likely to decrease. The recent heightened national concern over pharmaceuticals and emerging contaminants, and most recently the Environmental Working Group's report on chemical contamination in water supply utilities in the United States,[2] gives a clear indication that the public's expectation is for contaminant-free drinking water. This expectation is consistent with NYCDEP's mission to deliver the highest quality water possible to the consumer.

[2] Available at http://www.ewg.org/tap-water/home.

1.4 Overview of Natural Gas Well Development

Shale formations with gas producing potential are distributed throughout much of the United States (Figure 1-1). Recent technological advances such as hydraulic fracturing and horizontal drilling, in combination with market forces, have made the development of shale gas resources economically viable. The most heavily developed shale gas "play" is the Barnett in Texas and dates back only to the late-1990s. The Fayetteville in Arkansas and the Haynesville in Louisiana and Texas are other major plays that have been more recently developed. There is currently substantial interest in the Marcellus formation because of its size and gas-producing potential.



Source: Energy Information Administration based on data from various published studies
Updated: May 28, 2009

Figure 1-1: Gas-Producing Shale Formations in the US

Shales are generally considered geologically "tight" formations with limited permeability and primary porosity.[3] Hydraulic fracturing is employed to increase permeability and porosity of the rock mass and enhance the movement of gas to the well bore. Horizontal drilling is employed to increase the areal extent from which gas can be drawn to a single well location. The Marcellus and other potential gas-producing formations underlie most of New York, and the state is currently in the process of approving horizontal drilling and high-volume hydraulic fracturing for exploiting these resources.

The natural gas development process using horizontal drilling/high-volume hydraulic fracturing is initiated in a similar manner to traditional gas exploration and includes mapping and geologic

[3] Primary porosity is the void space that remains between grains of sediment deposits after initial deposition and rock formation. Sedimentary rocks, such as the Marcellus Formation, are formed from the compaction of sediments. Secondary porosity results from fractures or other post-depositional physical changes to the formation.

analysis, seismic testing, leasing of mineral rights from landowners, and submission of well permit applications. Each well is assigned to a spacing unit, which roughly corresponds to the area of land from which the well is assumed to be extracting natural gas. For multiple horizontal wells drilled from a common well pad, as is expected for most Marcellus wells, a spacing unit of up to 640 acres (one square mile) is allowed.[4] Spacing unit requirements do not limit the number of horizontal wells that may be drilled from a multi-well pad. Instead, the total number of wells per spacing unit is governed by the number of wells needed to efficiently and economically extract the natural gas resources within a given spacing unit. Industry reports cited in the draft Supplemental Generic Environmental Impact Statement[5] indicate that six to ten wells will be developed per well pad in the Marcellus.

Initial site activities include clearing, grading, and construction of site access road, well pad, and utilities. The size of the pad is expected to be on the order of five acres. Total area requirements including well pad and related features such as roads and pipelines are estimated at seven acres per well pad based on data from the Fayetteville shale.[6] Once the site is prepared and the drill rig and ancillary equipment are set up, operators begin drilling the well. In the New York area, wells will likely consist of a 3,000- to 7,000-foot deep vertical section that extends from the surface to the target formation, plus a horizontal section that extends laterally for an additional 2,000 to 6,000 feet. The lateral section is not allowed to extend beyond a specified setback distance from the spacing unit boundary.

Construction of gas wells in the Marcellus formation requires drilling through shallow freshwater aquifers and penetrating deeper geologic formations that contain naturally-occurring contaminants such as hydrocarbons, metals, radionuclides, and high salinity. The well borehole creates a conduit for fluid to flow between these previously isolated geologic formations. To prevent such flow, the annular space between the well casing and the formation is filled with grout.

After the well is drilled, cased, and grouted, the operator proceeds with hydraulic fracturing operations to stimulate gas production. The process entails injecting a mixture of water and chemicals into the well at high pressure to create fractures in the gas-bearing formation, thus increasing its permeability and enhancing the release of gas for collection. Sand or other inert materials (i.e., proppants) are injected with the fluid mixture to prop open the fractures. A typical fracturing operation may require on the order of three to eight million gallons of water, depending on formation characteristics, lateral length, and fracture design. Water may be obtained from surface or groundwater sources; to date most fracking operations have used fresh or low salinity water.

A variety of chemical additives are added to fracking fluid to control fluid properties. Chemicals are often cited as making up 0.5 to 2.0 percent of the fracking fluid. For a four million gallon fracture operation, this translates to 80 to 330 tons (160,000 to 660,000 lbs) of chemicals per

[4] Natural gas well spacing unit requirements are defined in ECL §23-0501.
[5] Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program – Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs.
[6] U.S. Department of the Interior. 2008. *Reasonably Foreseeable Development Scenario for Fluid Minerals: Arkansas*. Prepared for the Bureau of Land Management Eastern States Jackson Field Office. March 2008.

well. The exact chemical composition of many additives is not known. Of the known chemical components, many are toxic to the environment and human health.

The active drilling and fracturing process requires on the order of four to eight weeks per well. When support activities such as site clearing and grading, pad construction, mobilization and demobilization of drill rigs and other equipment, water delivery, and waste disposal are included, the time during which a drill site can be considered active is on the order of four to ten months for one well, depending on site-specific conditions. For a multiple well pad, site activities may be sequenced such that multiple wells are under various stages of concurrent development. All wells from a multi-well pad must be completed within the three year permit period. A high volume of heavy truck traffic (approximately 800 to 1,200 trips per well) is required during the development process to convey equipment, chemicals, water, and waste to and from the site.

Wastewater disposal is a critical feature of hydraulic fracturing operations. A sizeable fraction (approximately 10 to 50 percent or more) of the original fracturing fluid volume is returned to the surface as "flowback" over a period of several weeks. Flowback water contains chemical additives and naturally occurring formation materials, including high levels of total dissolved solids, metals and naturally occurring radioactive material (NORM). Flowback water is trucked off-site for disposal at underground injection wells, certain municipal wastewater treatment plants (WWTPs), or industrial WWTPs.

When drilling and stimulation operations are complete, the drill rig and equipment are removed and the site is partially restored. If the well produces gas, pumping and treatment equipment are installed at the site and pipelines are constructed to connect the well to the regional transmission network. Tanks are also constructed for temporary storage of the "produced" water that the gas well discharges during the course of normal operation.

As the well ages and the gas production rate declines, the well may be re-fractured to boost productivity. Limited data from the Barnett shale indicates the interval between re-fracturing operations could range from one to more than ten years. The useful life of a well may be on the order of 20 to 40 years; at the end of this time the well is plugged and abandoned. For locations overlying "stacked" shale plays, which appears to be the case in the NYC West-of-Hudson watershed, it is unclear whether multiple gas-bearing formations in the "stack" would be developed simultaneously, or if development of other formations would ultimately require the service life of the site to be extended. Once there are no longer other wells or collection facilities operating on the same well pad, the site can be fully restored.

1.5 Regulatory Context for Gas Exploration and Development

Federal Regulations

Many of the activities associated with natural gas development have the potential to pollute air or water and therefore fall under the nominal jurisdiction of a number of federal environmental regulations, including the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act and the Toxic Release Inventory reporting requirements of the Emergency Planning and Community Right to Know Act. However, each of these regulations currently contain important exemptions regarding the definition, reporting, use, and disposal of the toxic chemicals required during hydraulic fracturing and other gas development activities. At this time there are few constraints on natural gas development at the federal level, and related activities are generally regulated at the state level.

State Regulations

Natural gas development in New York is regulated by the NYSDEC, which under the Environmental Conservation Law (ECL) is charged with conserving, improving and protecting natural resources and the environment, preventing water, land and air pollution, and authorizing the development of gas properties to increase the ultimate recovery of oil and gas resources.

In 1992, NYSDEC finalized a Generic Environmental Impact Statement (GEIS) on the Oil, Gas and Solution Mining Regulatory Program as part of the State Environmental Quality Review Act (SEQRA) process. At the time the GEIS was drafted, the use of horizontal drilling and high-volume hydraulic fracturing for oil and gas extraction in shale and tight sandstone reservoirs was not technologically feasible. Since that time extraction technologies have matured and led to commercially viable development of the Marcellus and other formations. In 2008, Governor Paterson directed NYSDEC to prepare a supplemental GEIS (SGEIS) to review potential additional impacts related to these technologies.

The draft SGEIS was released on September 30, 2009, and included analysis of potential impacts and established a number of permit conditions for drilling applications. Several salient conditions established in the dSGEIS include:

- A requirement for site-specific SEQRA reviews for wells within 1,000 feet of NYCDEP infrastructure, well pads within 300 feet of a reservoir, or well pads within 150 feet of other surface waters. Outside of these setbacks, no additional watershed-specific review is required (i.e., wells may be drilled anywhere else in the NYC watershed or adjacent to tunnels without additional review).
- Baseline and periodic ongoing groundwater water quality testing is required for private wells within 1,000 to 2,000 feet of a gas well.
- Operators are required to disclose to NYSDEC the fracturing products (i.e., additives) that will be used for a given well.
- Surface water withdrawals must allow a specified passby flow to maintain stream habitat.
- Various mitigation plans are required for visual impacts, noise impacts, invasive species, and greenhouse gases.

The dSGEIS is presently under review and is not anticipated to be finalized until 2010. Therefore the proposed permit conditions and mitigation requirements included in the final SGEIS may differ from those described herein.

NYC Watershed Regulations

With the exception of requiring NYCDEP approval of stormwater management plans for activities meeting certain impervious surface or disturbance thresholds, the NYC Watershed Rules and Regulations have little or no applicability to horizontal drilling and high-volume hydraulic fracturing activity in the watershed.

1.6 Report Organization

- Section 2 describes regional geology and hydrogeology and discusses pathways for subsurface migration of fracturing chemicals and formation water;
- Section 3 describes the rates and densities of natural gas well development in comparable formations, and estimates the number of wells that could be constructed in the NYC watershed on an annual basis and under a full build-out scenario;
- Section 4 presents an assessment of cumulative impacts of natural gas well development in the NYC watershed;
- Appendix A provides more detail on the geology and hydrogeology of the region;
- Appendix B provides more information on rates and densities of well development;
- Appendix C provides more detail on the analysis of surface spills; and
- Appendix D identifies potential mitigation measures for reducing the risk of impacts to the water supply.

Section 2: Area Geology

This section presents an overview of the subsurface conditions in the NYC watershed region, including evaluation of gas-producing potential, description of rock strata and geologic features, analysis of water resources, and a summary of data provided by tunnel construction records.

2.1 Shale Gas Potential and the NYC Watershed

The Marcellus formation is one of a series of "stacked" Appalachian plays that also include the Utica Shale. These formations underlie an area of approximately 95,000 square miles[7] that extends from eastern Kentucky, through West Virginia, Ohio and Pennsylvania and into southern/central New York. The Marcellus formation is estimated to contain 200 to 500 trillion cubic feet (tcf) of total natural gas reserves and is considered one of the largest potential sources of developable energy in the U.S.[8]

In New York, the Marcellus formation (Figure 2-1) lies beneath all or part of 29 counties and the entirety of the 1,585 square miles of NYC's West-of-Hudson watersheds. The maximum depth (ca. 6,500 feet) occurs along the Delaware River at the New York - Pennsylvania border, and the formation is shallowest to the east and north. The NYC watershed area is underlain by relatively thick areas of the Marcellus formation that are estimated to have relatively high gas production potential. Within the West-of-Hudson watersheds, 1,076 square miles are not protected and are subject to gas exploration and development activities. This area represents less than six percent of the approximately 18,700 square miles of the Marcellus formation that are in New York State.

Analysis of the depth, thickness, organic content, thermal maturity, and other characteristics of the Marcellus formation has been performed as part of an ongoing study by the New York State Museum.[9] Figure 2-1, which is drawn from the New York State Museum study, shows the approximate depth to the top of the Marcellus formation (top portion) and the approximate thickness of the formation (lower portion). The dotted contours also indicate the transformation ratio associated with the formation, which is an estimate of the thermal maturity of the organic material.[10] The higher the ratio, the more gas that is potentially available.

While acknowledging uncertainties that prevent precise delineation of areas with the highest gas production potential, the authors of the study suggest that drilling in New York is likely to start in the thickest and deepest areas of the formation, which includes southern Tioga, Broome, Delaware and Sullivan Counties, which border the northeast corner of Pennsylvania, before progressing north and west. These areas are also attractive for gas production because of their proximity to the Millennium pipeline and other regional natural gas transmission infrastructure.

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[7] ALL Consulting, Groundwater Protection Council. (2009). *Modern Shale Gas Development in the United States: A Primer.* Prepared for: U.S. Dep't of Energy Office of Fossil Energy and National Energy Technology Laboratory.

[8] Navigant Consulting, Inc. (2008). *North American Natural Gas Supply Assessment*, Prepared for: American Clean Skies Foundation.

[9] Smith, T. and J. Leone. New York State Museum. *Integrated Characterization of the Devonian Marcellus Shale Play in New York State*. Presented at the Marcellus Shale Gas Symposium of the Hudson-Mohawk Professional Geologists' Association, April 29, 2009. Accessed from www.hmpga.org/Marcellus_presentations.html.

[10] Transformation ratio refers to the percentage of Kerogen (an organic solid, bituminous mineraloid substance) occurring in the unit, that has been destructively converted to oil or gas by ambient geological forces (i.e., pressure, temperature) .

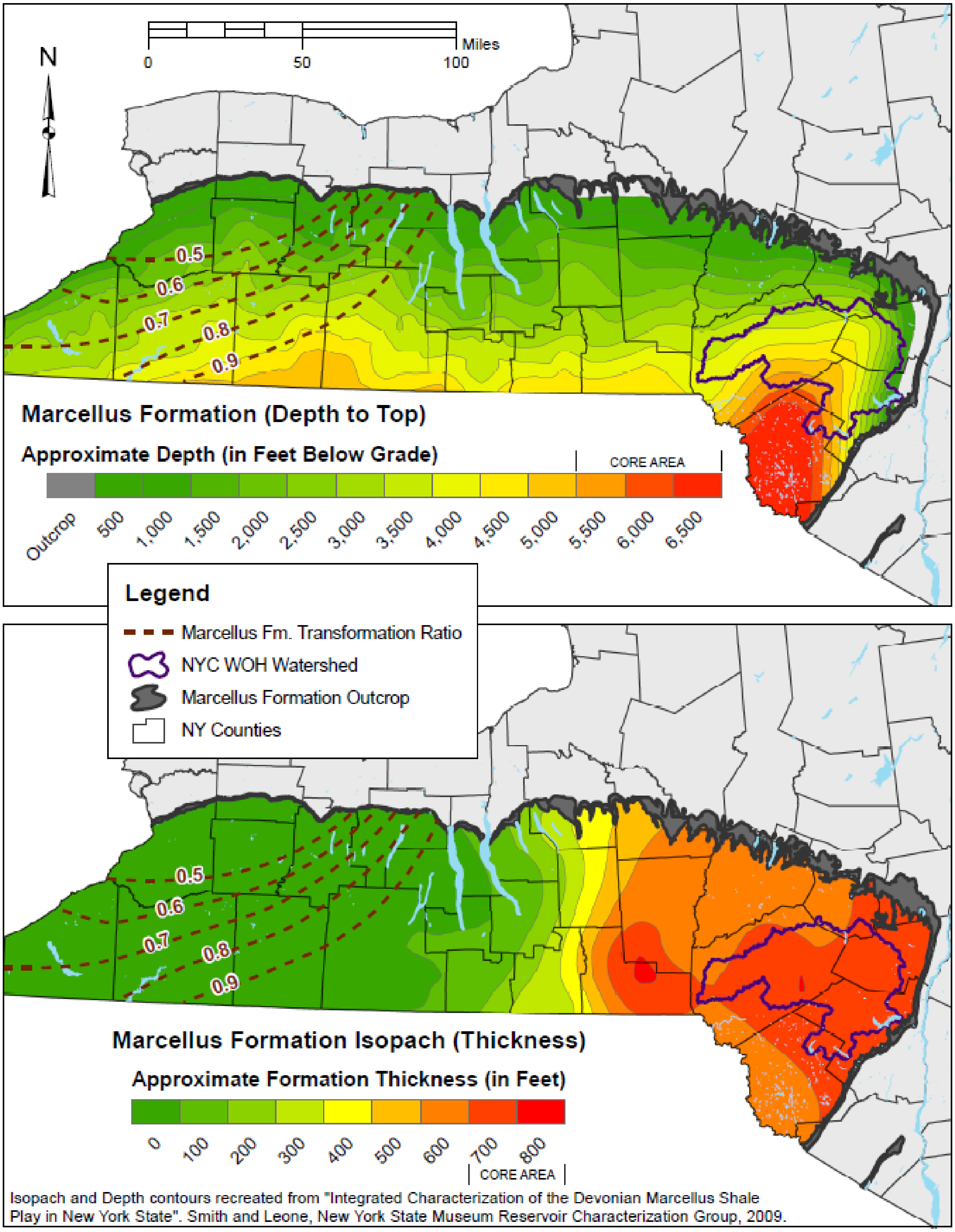

Figure 2-1: Extent and Characteristics of Marcellus Formation in New York

The supposition that the area identified in the New York State Museum study may be highly productive is supported by the intense leasing activity observed in this area and in neighboring counties in northeast Pennsylvania, as well as the ongoing development of a major regional drilling services facility in Horseheads (Chemung County), New York. County locations and additional detail on drilling activity in the region are presented subsequently in Figure 3-4.

2.2 Regional Geology

Figure 2-2 shows the bedrock geology underlying the West-of-Hudson components of NYC's water supply system (Appendix A). It identifies the uppermost layer of underlying bedrock, locations of mapped geologically brittle structures in relation to watershed boundaries, reservoirs, aqueducts, streams and rivers. The contours mapped in Figure 2-2 show the approximate depth to the top of the Marcellus formation. These contours indicate that the formation dips steeply westward in the eastern portion of the watershed, while the dip from north to south is less steep.

The uppermost layer of bedrock is identified in Figure 2-2 by color-coding keyed to the geologic cross-section of Figure 2-3. These figures indicate that virtually the entire watershed is underlain by rock of the West Falls, Sonyea and Genesee Groups, which are Upper (or Late) Devonian period in age (over 360 million years old). The Upper Devonian Groups are in turn underlain by Middle Devonian aged rocks of the Hamilton Group. The orange-shaded band framing the east boundary of the watershed corresponds to Middle Devonian formations and defines the extent of Upper Devonian rock.

The Marcellus formation occurs at the base of the Middle Devonian Hamilton Group and is primarily composed of organic-rich shale units. It is overlain and underlain by sedimentary rock units (e.g., sandstone, shale, siltstone and limestone) of varying natural gas and fossil fuel resource potential. As indicated by Figure 2-3, the Utica Shale, which is part of the Lorraine Group, underlies the Marcellus as well as the entirety of the West-of-Hudson watersheds.

2.3 Water Resources and Hydrogeologic Conditions

The topography of the region comprises six major drainage basins occupied by a NYC reservoir and its tributaries. The three western-most (Cannonsville, Pepacton, and Neversink) are sub-watersheds of the Delaware River Basin; the remaining three (Rondout, Schoharie, and Ashokan) are hydrologically within the Hudson River Basin.

Surface water in the region generally originates as precipitation, which is either captured directly within the waterbody itself, or indirectly, as runoff and groundwater discharge (known as "baseflow"). There is a hydraulically continuous relationship between groundwater and surface water in the region developed from a series of interdependent flow regimes. Under natural conditions, these flow regimes are in hydrogeologic equilibrium as evidenced by major ionic chemical signatures reflective of the comprising water types (i.e., shallow versus deep), indicating that groundwater in very deep geologic formations is typically older and chemically distinct from groundwater in overlying flow regimes.[11] Typically, groundwater from deep formations and flow regimes is not potable, due to high total dissolved solids, and does not mix directly with shallow, fresh groundwater and surface water.

[11] A Conceptual Hydrogeologic Model for the West-of-Hudson watershed region is developed and described in the September 2009 *Rapid Impact Assessment* report.

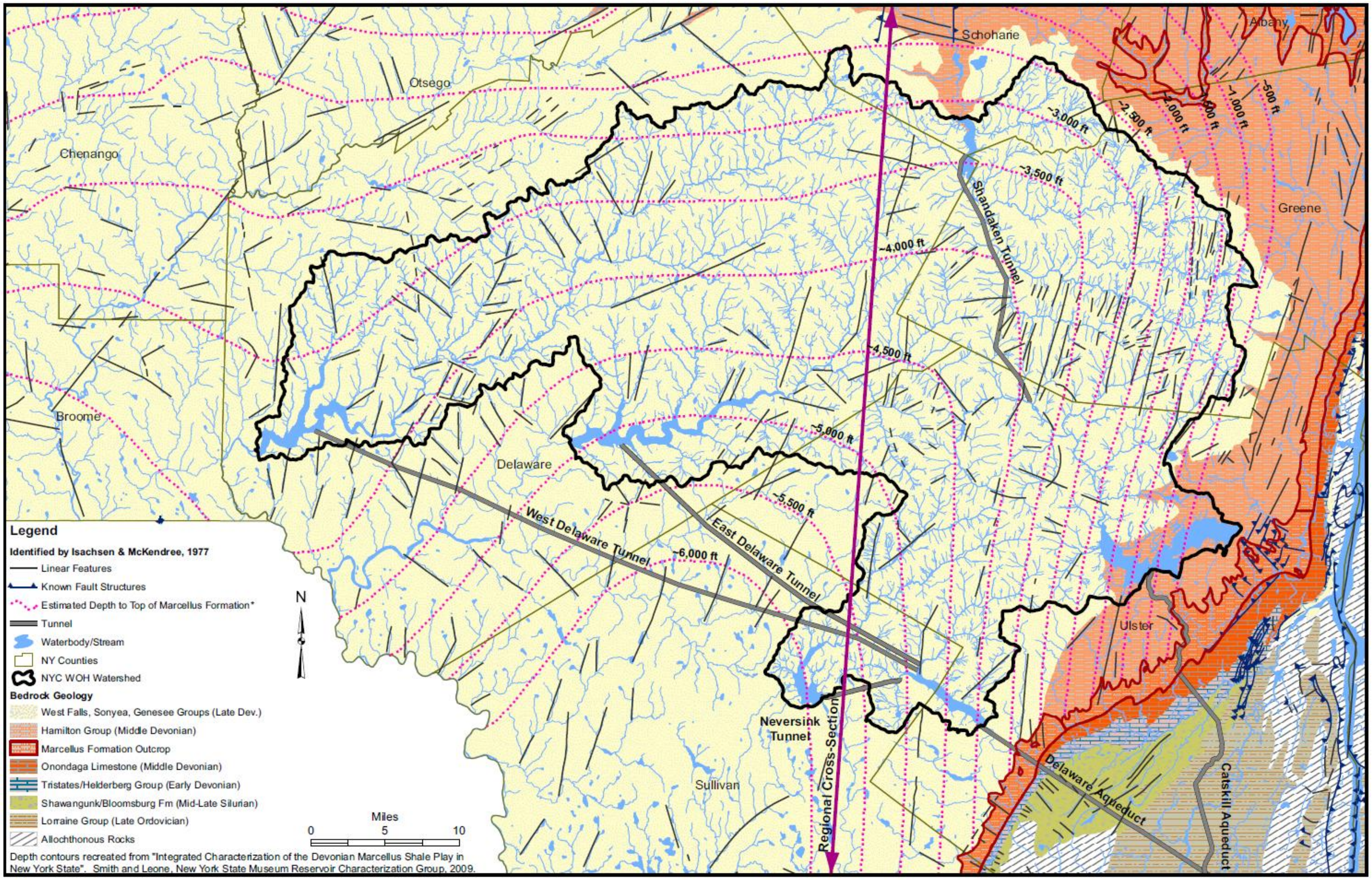

Figure 2-2: Bedrock Geology of the Catskill Region

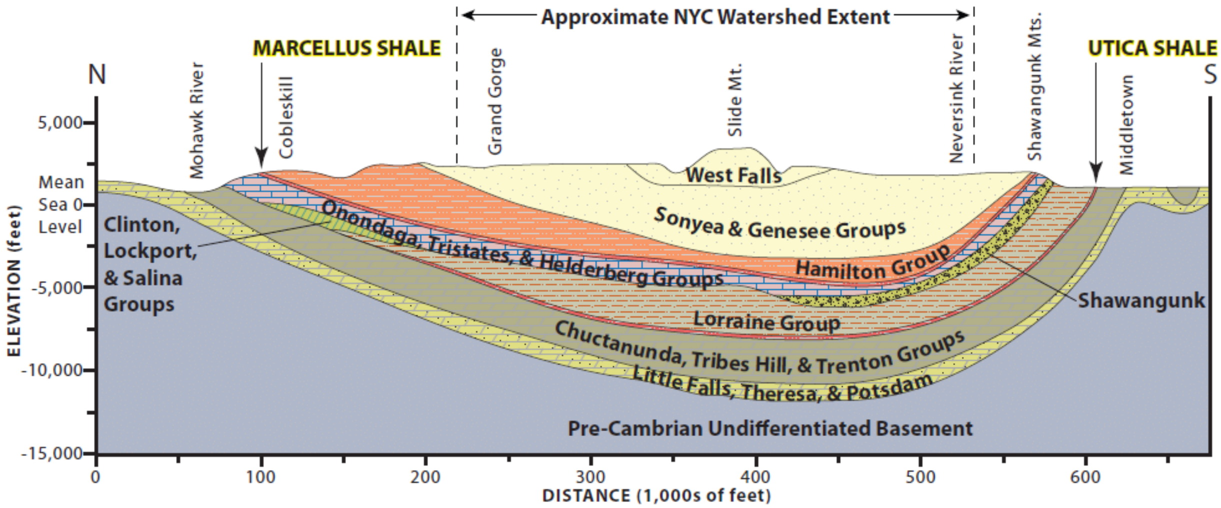

Figure 2-3: Cross-Section of Catskill Region Bedrock Geology

Limited inter-regime flow can be compromised by naturally-occurring, vertically extensive brittle structures as well as the interception of such structures during gas well drilling and stimulation. Abandoned or improperly sealed wells, casing or grouting failures, existing geologic fractures, and new fractures (generated during well development and stimulation) that propagate beyond the target formation can create or enhance hydraulic pathways between previously isolated formations. These hydraulic pathways can permit fluids within geologic formations (such as methane or brine water) to contaminate shallow groundwater, surface water, and subsurface infrastructure. In the case of the Marcellus formation, which is characterized as "overpressurized," fluids in the formation will follow the path of least resistance which, in addition to traveling toward the wellhead, will also follow any existing fractures and be forced upward toward the surface.[12]

2.4 Faults and Other Brittle Structures

The development of natural gas resources using hydraulic fracturing and horizontal well drilling technology relies upon vertical separation distance and low permeability of the intervening rock strata to prevent hydraulic communication between shallow aquifers and deeper gas bearing formations. Given the reliance on overlying rock to isolate hydraulically fractured strata from near-surface flow regimes, an evaluation of the presence and potential extent of geologically formed faults and fractures in the region has been performed. These geological features and other brittle structures can and do serve as conduits that facilitate migration of contaminants, methane, or pressurized fluids from deep formations towards the surface, potentially impacting aquifers and subsurface infrastructure.

Figure 2-4 presents faults, shear zones and other brittle structures as mapped by Isachsen and McKendree (1977) in New York State. The blue-colored features correspond to faults and shear

[12] The dSGEIS (pg. 5-131) reports a pressure gradient in the Marcellus formation of 0.55 to 0.60 psi per foot of depth (i.e., 1.27 to 1.39 feet of pressure per foot of depth). Gas reservoirs that exhibit greater than 0.4 to 0.5 psi per foot of depth (ranging up to 0.7 to 1.0 psi per foot) may be characterized as “overpressurized” (Craft, B.C. and Hawkins, M.F., 1991, *Applied Petroleum Reservoir Engineering*, Prentice Hall).

zones, and the gray features correspond to "Topographic and Tonal Linear Features." Many of these features represent breaks or fractures in the bedrock. The faults and shear zones identified in this study have been mapped on the basis of direct observation in outcrop or boreholes and are associated with movement of the comprising rock masses parallel to the feature. Such movement is commonly associated with "seismic events" such as earthquakes. The "linear features" are typically identified using aerial photographs, maps, and other related methods and may correspond to the suspected locations of faults (although not directly observed in outcrop). In some cases, these features are continuations of known, mapped faults and brittle structures. This data is not likely to present all faults and fractures that might exist at depth

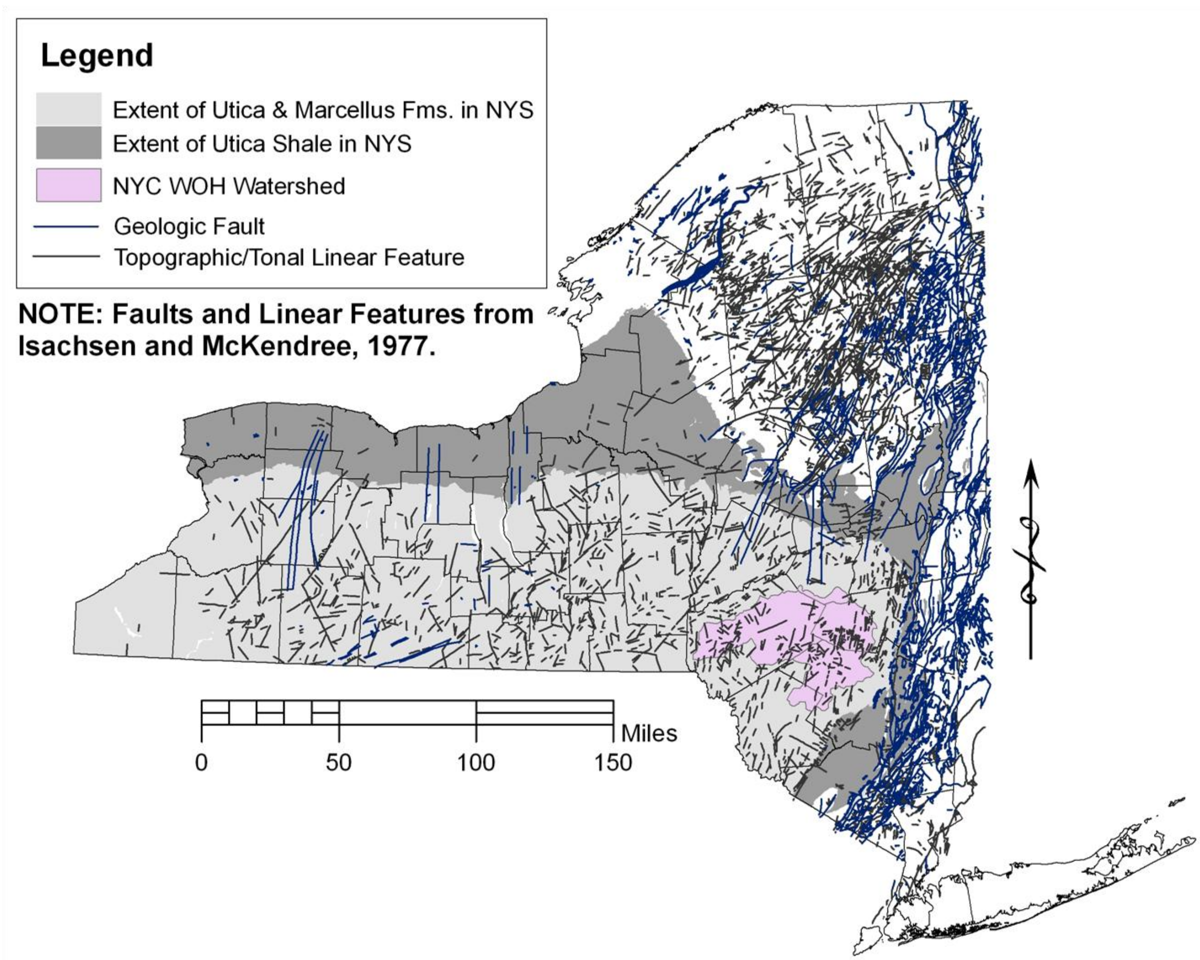

Figure 2-4: Map of Geologic Faults and Linear Features in New York State

Recognizing the significance of brittle structures (i.e., faults, shear zones, fractures and other linear features) to act as migration pathways for fluids from deeper formations, a statistical analysis of the lengths of these reported features in the vicinity of NYC's West-of-Hudson water system has been performed as part of this assessment. The brittle structures in the region commonly extend laterally for distances in excess of several miles and vertically to depths in excess of 6,000 feet. Some of these features intersect one another and some cross NYC infrastructure components. Given that the process relied upon by Isachsen and McKendree to identify the brittle structures concentrated on a large-scale area and recognized only those observable at the land surface, a reasonably conservative assumption is that even more such features and intersections with infrastructure are present. The lengths of identified fractures provide a guide for establishing buffer distances needed to ensure separation of water system components and natural gas drilling activities affecting deep formations.

Based on a statistical analysis of identified fractures and brittle structures in the region, 50 percent of the mapped features have lengths in excess of three miles, and more than 10 percent exceed seven miles in length (Appendix A).

Based on Isachsen and McKendree, the area within and around the NYC watershed is dominated by numerous "linear features" that typically correspond to fractures, both mapped and un-mapped. As such, the intervening rock masses (both horizontally and vertically) between the Marcellus formation and fresh water aquifers or subsurface infrastructure should not be considered as an impermeable barrier, since they are fragmented by a significant number of fractures. The existence of vertical fractures is evident in local rock outcroppings. A local example of such vertically persistent fractures that typify the bedrock character is presented in Figure 2-5, which shows two photos of Plattekill formation outcrops near Ashokan Reservoir. Evident in each photo are vertical fractures that extend across multiple layers of the formation. The Plattekill formation is part of the Hamilton Group of interbedded shales, siltstones and sandstones that overlie the Marcellus formation and underlie NYC tunnels and fresh groundwater and surface water sources.

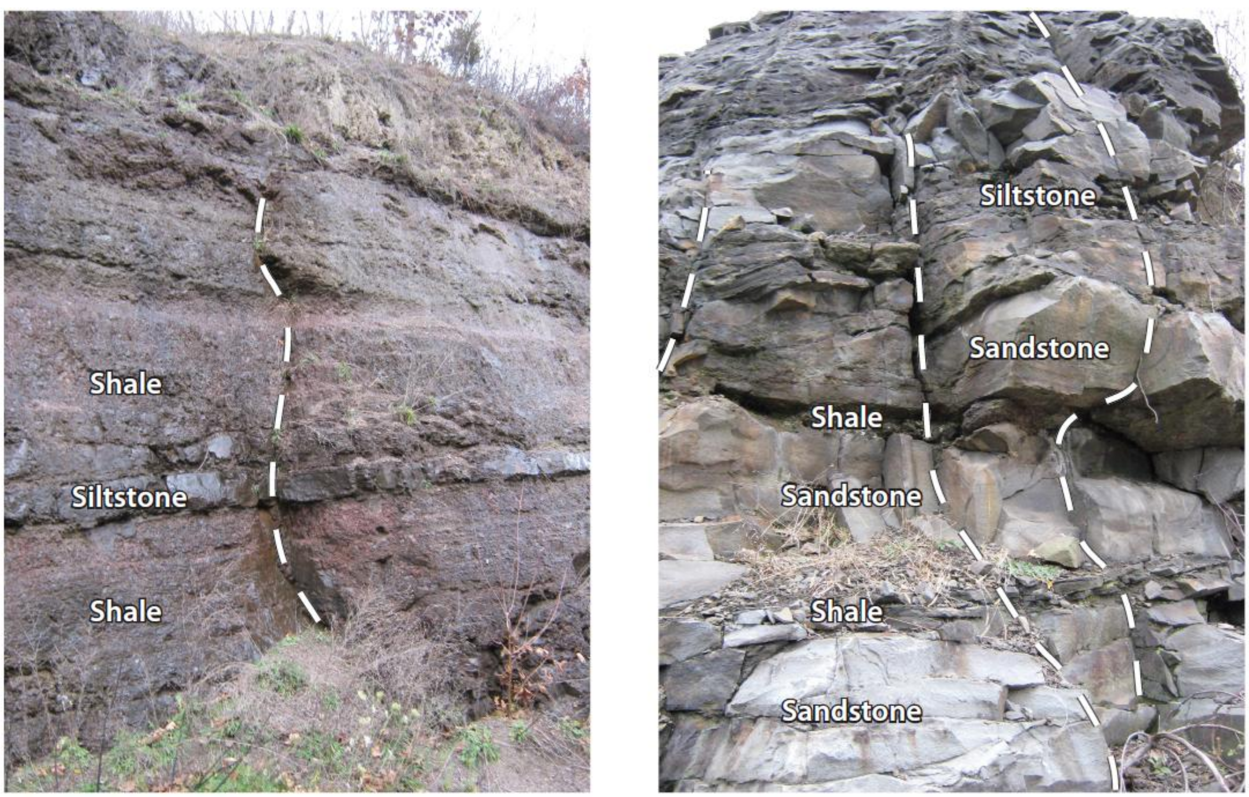

Figure 2-5: Outcrops of the Hamilton Group (Plattekill Formation) near Ashokan Reservoir Showing Persistence of Vertical Fractures across Lithologic Units

2.5 NYC Water Supply Infrastructure Relative to Geological Features

NYC's West-of-Hudson water supply infrastructure has been evaluated in relation to local and regional geologic features. This evaluation has included a review of record drawings and construction documentation, and focused on vertical separation from the Marcellus formation as well as geological features documented during tunnel construction.

Infrastructure Depth and Vertical Separation from Marcellus Formation

The West-of-Hudson water supply tunnels are constructed from several hundred to about 1,000 feet below grade. Regional surface topography ranges from about elevation 1,000 to 2,500 feet. The tunnels upstream of the Rondout and Ashokan Reservoirs are located approximately 1,000 feet above sea level; the tunnels leading from these reservoirs are about 500 feet below sea level. The vertical distance between the Marcellus formation and NYC water supply infrastructure varies from direct contact at the eastern edge of the formation's occurrence, to about 4,500 feet in the western portion of the watershed. Portions of the Shandaken Tunnel, the Catskill Aqueduct, and the bottom of Ashokan Reservoir are separated by as little as 500 feet from the underlying Marcellus formation. Separation increases for infrastructure and reservoirs to the west and the south with increasing depth of the formation. To the west, vertical separation between Delaware system reservoirs and tunnels and the Marcellus ranges from about 2,000 to 4,500 feet.

Geological Features Documented During Construction

Evidence of naturally occurring fluid migration associated with brittle features is reported on record drawings that document the construction of NYC's infrastructure. NYCDEP records indicate that the East and West Delaware Tunnels and Neversink Tunnel construction encountered numerous groundwater seeps, saline water seeps, subsurface fractures, and methane inflows corresponding to the locations of mapped brittle structures. In 1957, methane that had seeped into the West Delaware Tunnel ignited, injuring three miners.[13] Construction of the Rondout-West Branch section of the Delaware Aqueduct also encountered numerous methane seeps. Frequent groundwater and saline water seeps were also encountered during construction of Shandaken Tunnel, sections of the Catskill Aqueduct, and the Rondout-West Branch tunnel.[14] These occurrences substantiate that fractures in the bedrock are naturally providing pathways for the movement of deep formation fluids.

Figure 2-6 highlights a section of the West Delaware Tunnel, where a linear feature identified from regional mapping was encountered as a fault at tunnel depth during construction, as documented in the accompanying excerpt from a tunnel geology drawing. Geological features encountered during construction, including faults and other geological brittle structures, and various seeps, are located on the geologic map of the Delaware system tunnels presented as Figure 2-7. Figure 2-8 shows the geologic features located along a profile of the West Delaware Tunnel, in relation to local surface topography and surficial features, and estimated depth of the Marcellus formation.

[13] The Delaware Water Supply News, April 1, 1964, 23:189, p. 1063.
[14] New York City geologic record drawings.

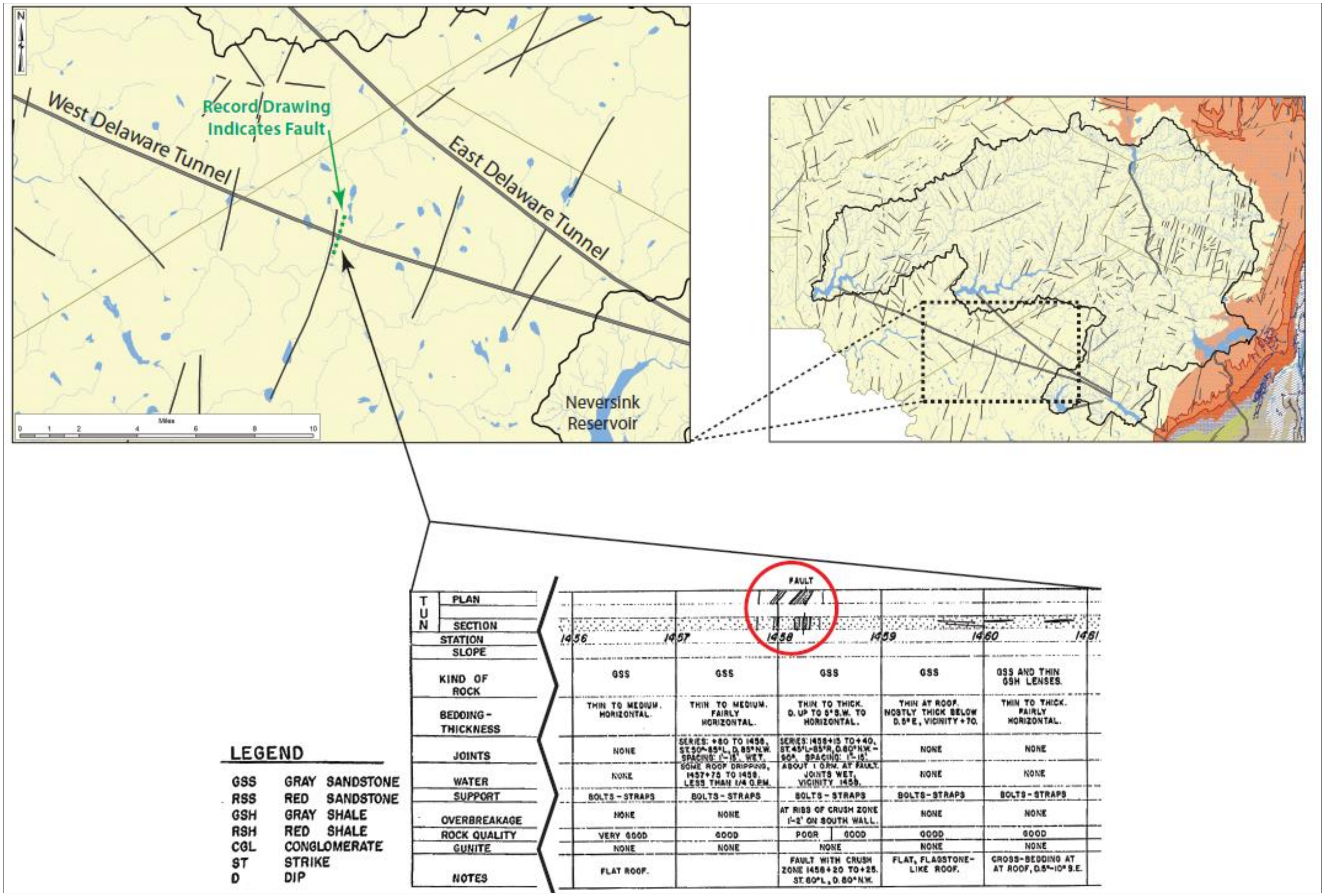

Figure 2-6: Example from West Delaware Tunnel Showing Correlation of Surface Linear Features with Faults Observed During Construction

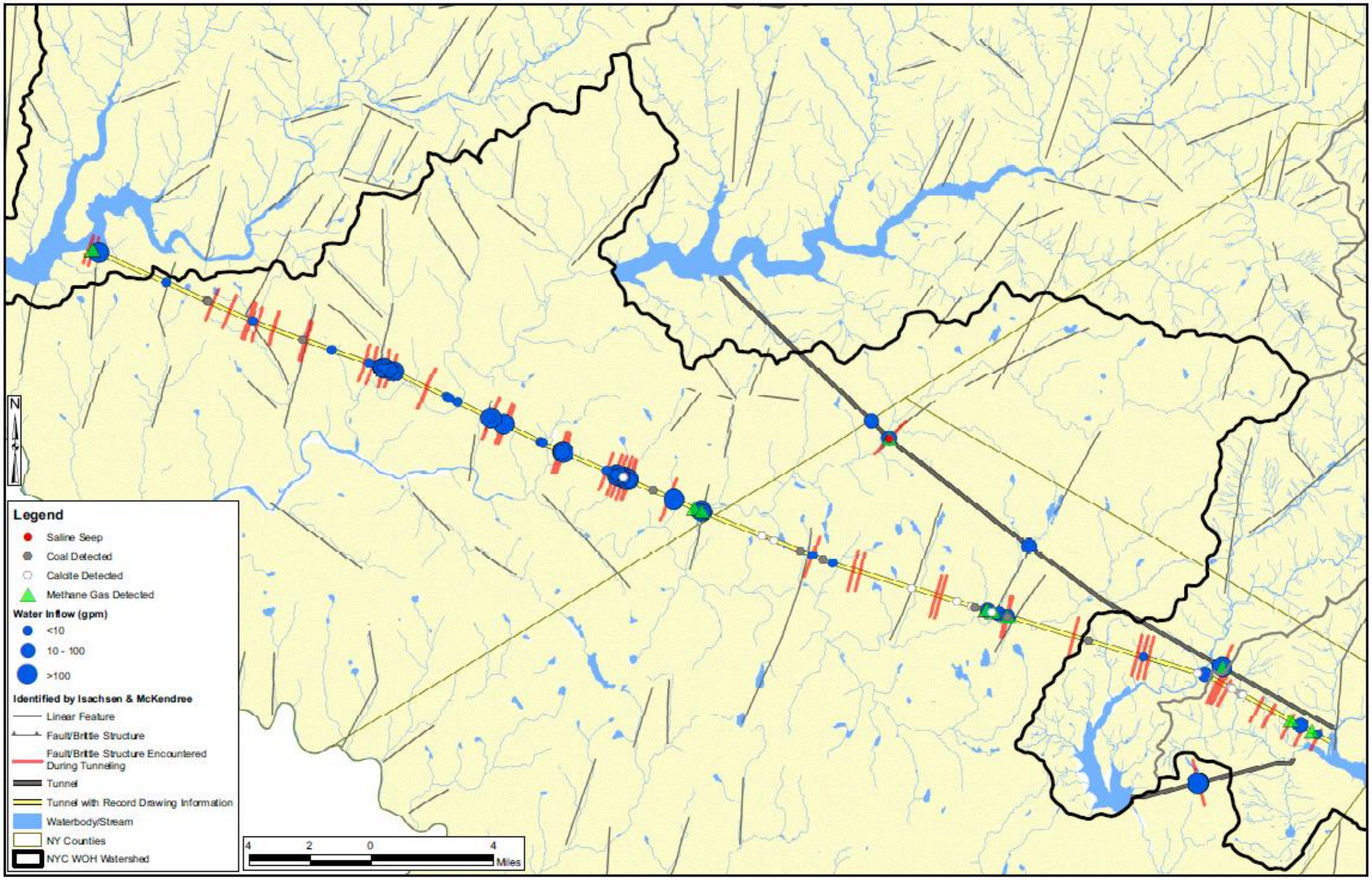

Figure 2-7: Map of the East and West Delaware Tunnels and Neversink Tunnel

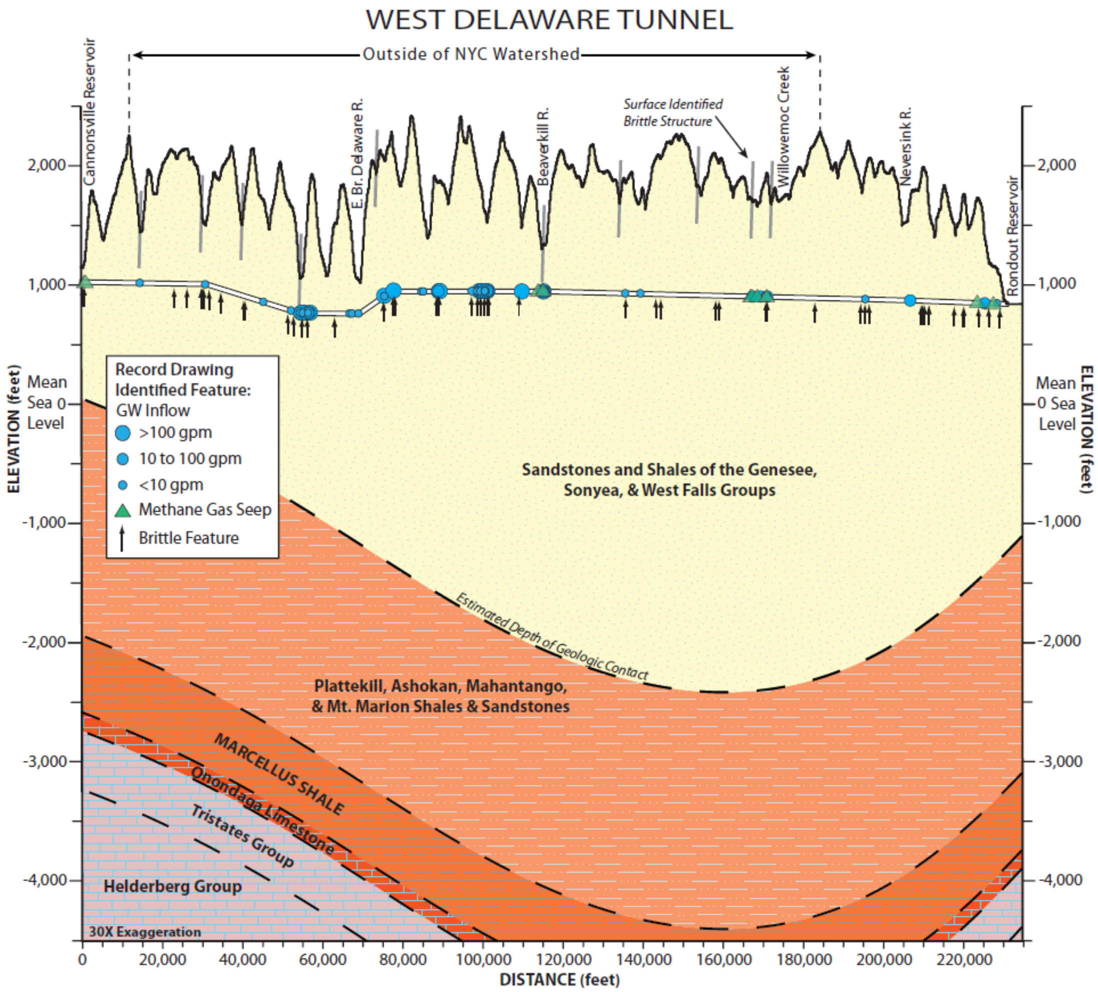

Figure 2-8: Geologic Cross Section of the West Delaware Tunnel

2.6 Summary

Available data, ongoing research performed by the New York State Museum, and comparison with natural gas development progress in northeast Pennsylvania suggests that the NYC watershed is underlain by relatively thick portions of the Marcellus formation with presumably high gas production potential. In addition to the Marcellus, other gas-bearing shale strata underlie the watershed and could be developed in the future. Overall, the NYC watershed area can be expected to be the focus of gas resource development activity comparable to or exceeding that of other contemporary shale gas plays, and this activity can be expected to last for decades.

Under natural conditions, upper geological strata are largely isolated from both methane and water in deep geological strata (formation water). Formation water is typically not potable, even before the addition of chemicals used in the hydrofracturing process. The saline water and methane seeps encountered at grade and in shallow formations near NYC infrastructure during the construction of water system tunnels provide the most reliable evidence that existing fracture systems and pressure gradients will transmit fluid from deeper formations. Taken together with the expected rate and development of gas drilling quantified in Section 3, this evidence of natural migration leads to the conclusion that there is a reasonably foreseeable risk to water supply operations from methane, fracking chemicals, and/or poor quality, saline formation water migrating into overlying groundwater, watershed streams, reservoirs, tunnels, and other infrastructure.

For these reasons, any evaluation of subsurface migration potential associated with future gas development must fully consider all known and foreseeable linear features and fractures. Extensive subsurface fracture systems and known “brittle” geological structures exist that commonly extend over several miles in length, and as far as seven miles in the vicinity of NYC infrastructure (Appendix A). In addition, the net hydraulic conductivity of a formation must be considered, including the influence of faults and fractures, not just the bulk properties of the rock matrix. Naturally occurring fractures in the rock can result in relatively high localized hydraulic conductivity values; these would be several orders of magnitude greater than those considered in analyses provided as technical support of the dSGEIS.

Section 3: Rates and Densities of Natural Gas Well Development

The Marcellus formation is an extensive resource that occurs beneath much of the State and will require tens of thousands of wells to fully exploit. The risks and impacts from any given individual well may be negligible and acceptable, but when evaluated in the context of hundreds or thousands of other wells, the risks and impacts may be significant and unacceptable. As such, cumulative impacts from many wells constructed throughout the watershed must be evaluated in order to fully characterize the potential risk from concurrent activities at multiple locations. Consistent with this understanding, the dSGEIS establishes the *aggregate* and not the *individual* as the appropriate basis for analysis of regional impacts: "*The level of impact on a regional basis will be determined by the amount of development and the rate at which it occurs.*"[15]

This section provides estimates for the annual rate and ultimate density of natural gas wells that could be developed in the NYC watershed under proposed regulations. These rates and densities are then combined with quantity estimates for various activities associated with one individual well to develop cumulative values (Section 4).

Sufficient data is available from shale gas plays that have been under development in other areas over the last two to ten years to develop reasonable ranges of annual rates of well construction (Appendix B). Since these other plays are still under development, the data from these plays underestimates the expected full build-out density. Therefore, estimates for the total number of wells to be constructed in the watershed are derived from estimates of developable area within the NYC West-of-Hudson watershed combined with average expected well densities per square mile.

3.1 Rates and Densities of Well Development in other Formations

Four major shale gas plays were identified for comparison purposes: Barnett (Texas), Fayetteville (Arkansas), Haynesville (Louisiana), and Marcellus (Pennsylvania) (Figure 1-1). These formations are all gas-bearing shales that require hydraulic fracturing for economic production and have been developed using a combination of horizontal and vertical wells.

Data on New York's Marcellus formation depth, thickness, organic content, thermal maturity, and other factors that have been analyzed by the New York State Museum's Reservoir Characterization Group indicate that the NYC watershed is underlain by portions of the Marcellus with high gas production potential. As such this assessment focuses on counties in other formations that have similarly high potential for gas production. Salient features of these formations and the counties selected for comparison are summarized in Table 3-1.

Well development rates and density for the four shale gas formations and their selected counties are summarized in Figure 3-1, Figure 3-2, and Figure 3-3. Figure 3-1 shows the annual rate of development in the other shale gas plays. Figure 3-2 depicts the density trends noted in the four comparable shale gas plays over the past decade, and Figure 3-3 presents current densities (2009).

[15] dSGEIS Chapter 6.13.2.

Table 3-1: Areas of Major Shale Gas Plays Comparable to Marcellus formation in NYS

Formation (State)	Approximate # Years under Development	Total Formation Area (mi2)	Selected Counties	Area (mi2)	% of Formation Area in Selected Counties
Barnett (TX) (Newark East field)	13	5,000	Denton, Johnson, Tarrant, Wise	3,512	70%
Fayetteville (AR) (B-43 field)	6	9,000	Cleburne, Conway, Faulkner, Van Buren, White	3,589	40%
Haynesville (LA)	3	9,000	Bossier, Caddo, De Soto, Red River	3,100	34%
Marcellus (PA)	2	95,000	Bradford, Lycoming, Susquehanna, Tioga	4,374	5%

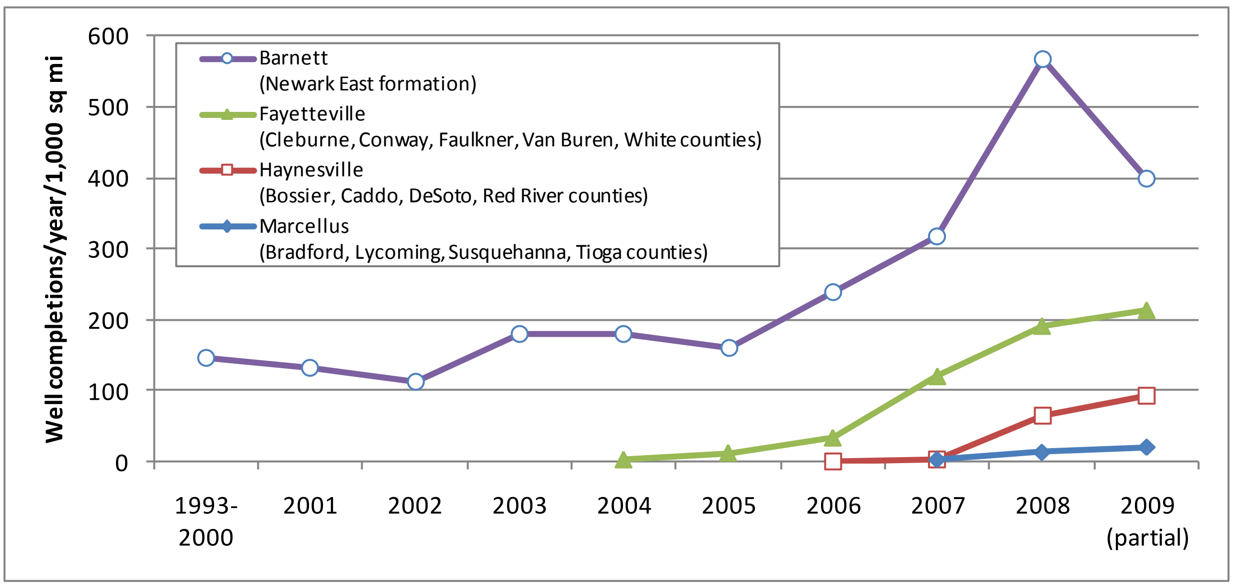

Figure 3-1: Annual Well Completion Rates in Core Counties of Comparable Shale Gas Plays (2001-2009)

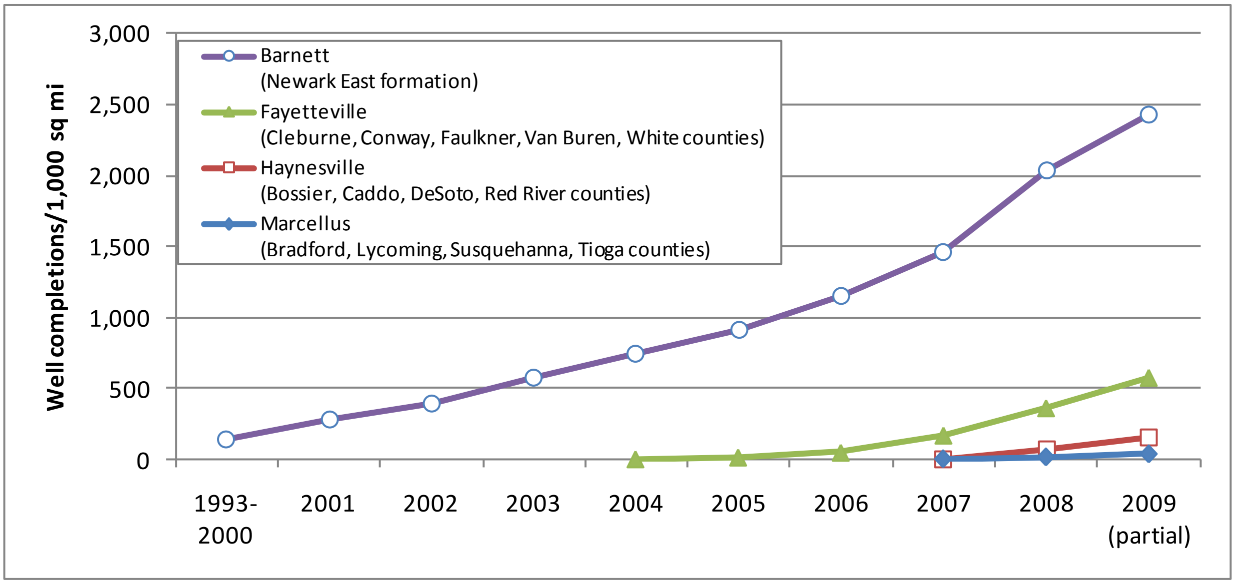

Figure 3-2: Well Density in Comparable Shale Gas Plays (2001-2009)

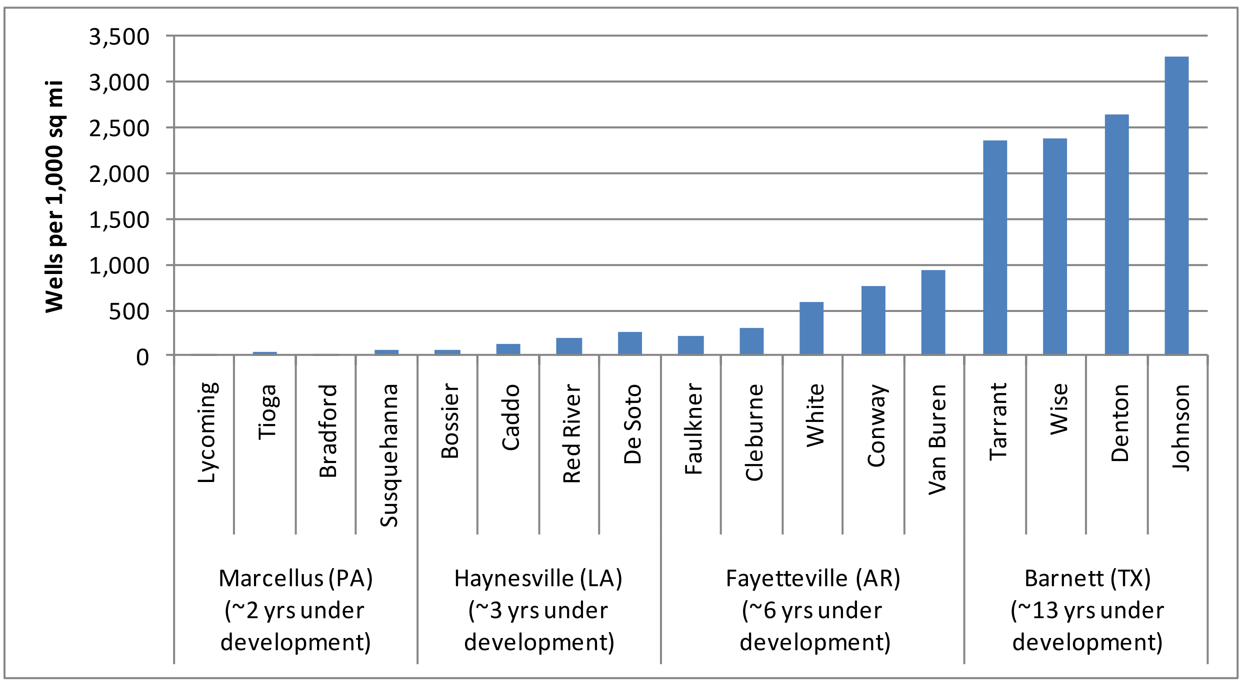

Figure 3-3: Current Well Density in Core Counties of Comparable Shale Gas Plays (2009)

Mapping of natural gas exploration activities in the Marcellus formation in eastern Pennsylvania reveal an accelerating rate of well construction over the two-year period from 2007 to 2009, as shown in Figure 3-4. NYSDEC Notices of Intent to issue well permits in neighboring portions of New York State are also shown. It is reasonable to expect that the pattern and pace of development that could occur in New York State would be similar to that experienced in eastern Pennsylvania. It is important to note that the level of well development shown in the bottom figure reflects the very early stages of development of the formation, and that a roughly one order of magnitude increase in well density should be anticipated.

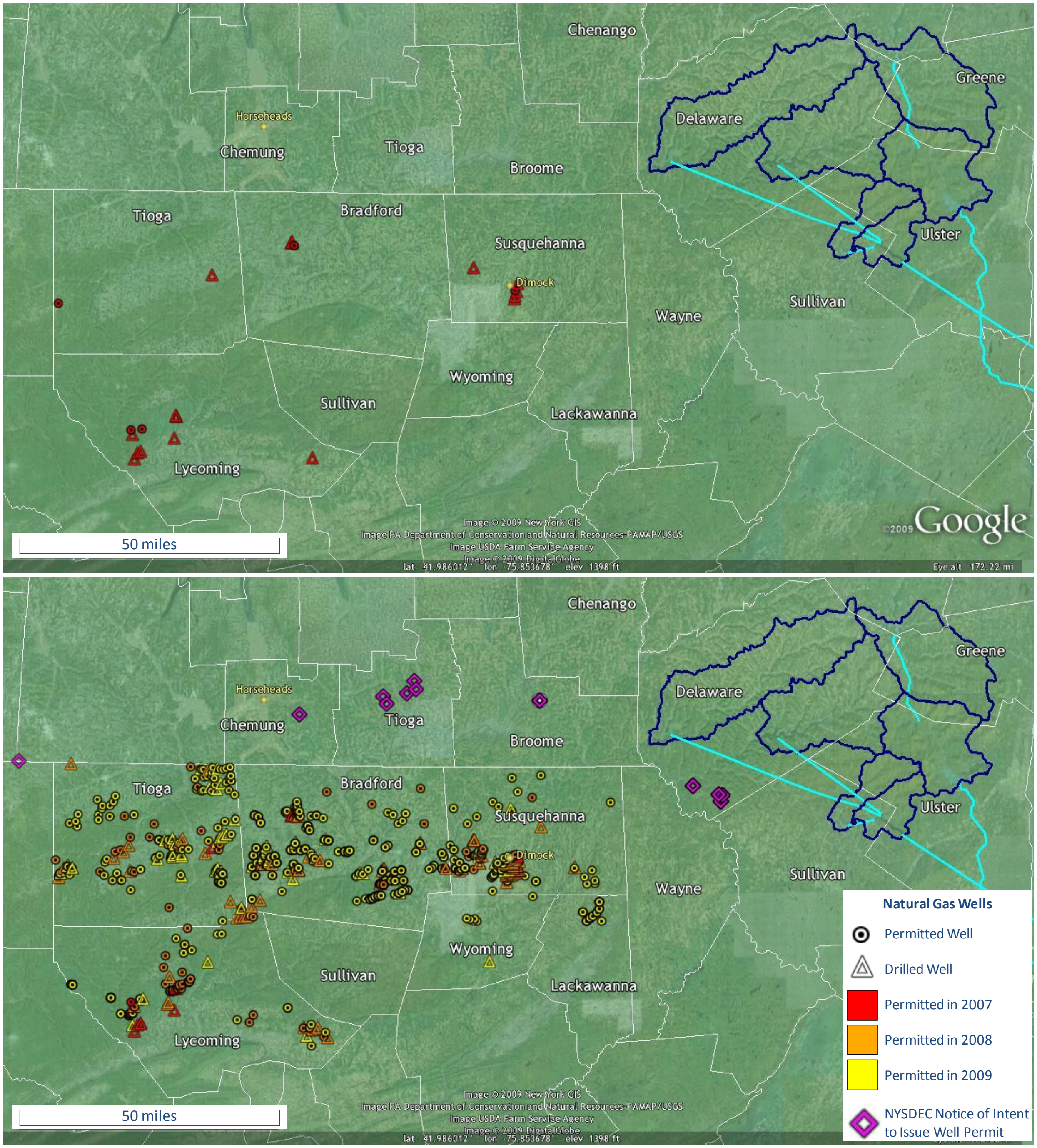

Figure 3-4: Marcellus Formation Gas Well Permitting and Completion in New York and Pennsylvania Core Counties in 2007 (Top) and 2009 (Bottom)[16]

[16] Pennsylvania Department of Environmental Protection Well Data as of 9/30/09 (http://www.dep.state.pa.us/dep/deputate/minres/oilgas/RIG09.htm, accessed 10/21/09). NYSDEC data on Notices

Rates of natural gas well development in the comparable major shale gas formations provides the basis for the scenarios presented in Table 3-2 and are consistent with well development patterns observed to date. Therefore, the scenarios provided are reasonable for estimating potential impacts within the NYC watershed even though the actual rate of development is uncertain due to numerous factors, including natural gas prices, regional economic conditions, State regulations, and formation productivity.

Table 3-2: Annual Natural Gas Development Scenarios

Rate Scenario	Average Annual Well Completions per 1,000 Square Miles	Description
Low	5 to 20	Drilling rate during the early years of the play as operators refine their understanding of the resource and continue to lease land and apply for permits.
Moderate	100 to 300	Rate of well completion that has been sustained for a number of years in other shale gas plays
High	500, based on well completions (potentially as high as 800, based on permit applications)	Rate of development that could potentially occur in the most profitable areas under favorable conditions (e.g., gas prices are very high).

3.2 Rate and Density of Well Development in the NYC Watershed

To calculate the total number of wells that could be developed in the NYC watershed, an average well density was estimated and then applied across the total developable area within the watershed.

In estimating the developable area within the watershed, state forest preserve area[17] and lands controlled by NYC through ownership and conservation easements (shown in Figure 3-5 and Figure 3-6) were excluded.[18] The remaining "uncontrolled" area (1,076 square miles, or 68 percent of the watershed) was then assumed to be between 50 and 100 percent developable. This range of development is consistent with other nearby areas of the Marcellus formation region, such as Bradford County, which has experienced mineral leasing of nearly 85 percent of the total county land area. The resulting estimate of the land area in the NYC watershed available for natural gas development is thus on the order of 500 to 1,000 square miles.

Although New York regulations allow up to 16 wells per square mile, the dSGEIS indicates a lower density, approximately six to nine wells per square mile, is more likely. This estimate is corroborated by recent permit applications in Sullivan County, which are based on five to six wells per square mile.[19] Well densities to date in excess of three wells per square mile over areas comparable in size to the NYC watershed have been documented in other shale gas plays with significantly higher localized densities (e.g., Denton County, TX has a well density of 5.5 wells

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of Intent to Issue Well Permits in Spacing Units Which Conform to Statewide Spacing in New York State as of 10/26/2009 (http://www.dec.ny.gov/dmndata/Well_Reports/Unit_Spacing_SW_Rpt.html, accessed 10/27/2009)

[17] The estimates of State forest preserve land in Figure 3-6 only include land in the Catskill State Forest Preserve, which cannot be leased or sold without a constitutional amendment. The estimates do not include other state land in the NYC watershed which is not afforded a similar level of protection.

[18] Compulsory integration may bring peripheral areas of NYC-controlled or state lands under development.

[19] NYSDEC. 2009. *Notices of intent to issue well permits in spacing units which conform to statewide spacing in New York state*. (http://www.dec.ny.gov/dmndata/Well_Reports/Unit_Spacing_SW_Rpt.html, accessed 9/2/09).

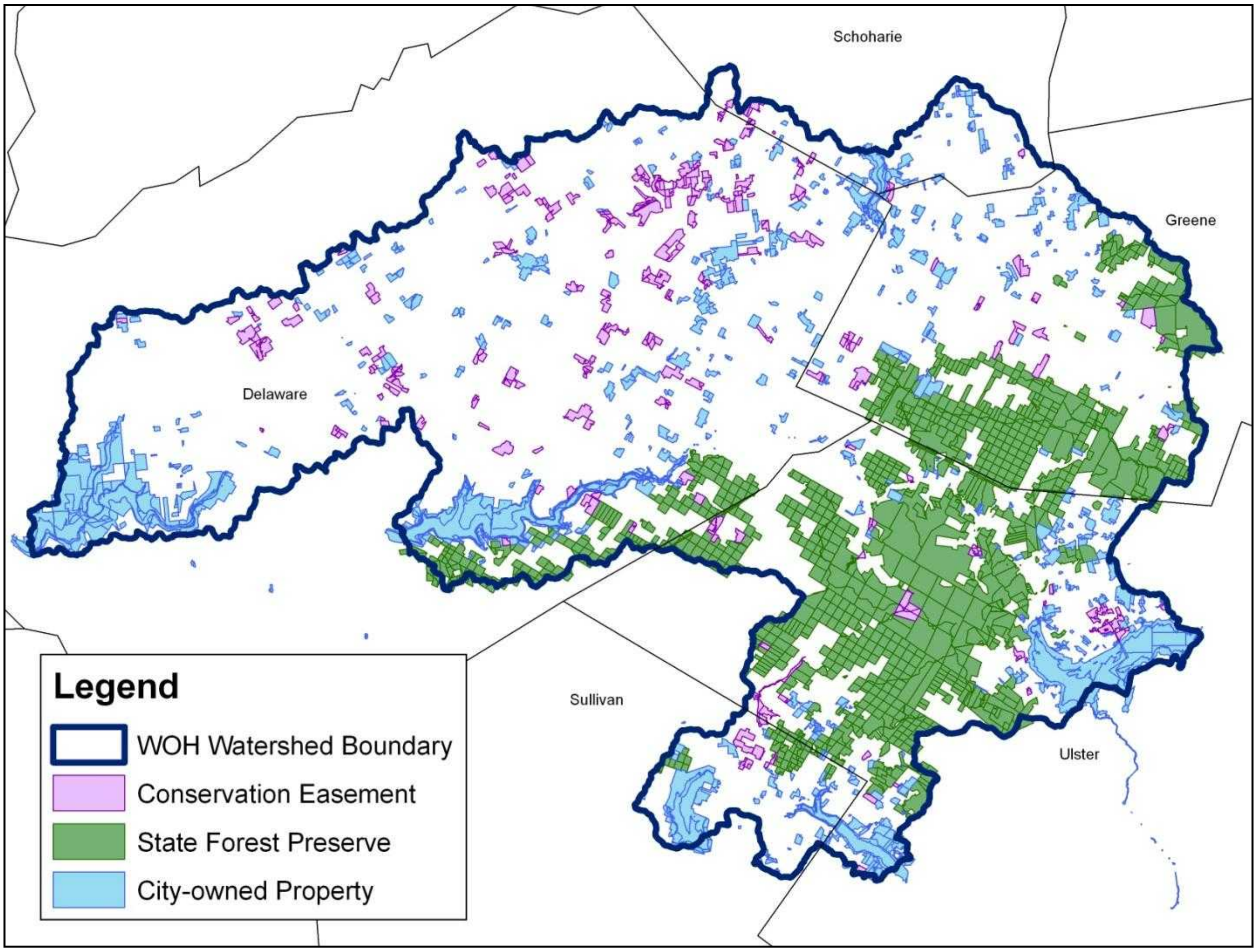

Figure 3-5: NYC West-of-Hudson Watershed Land Ownership (April 2009)

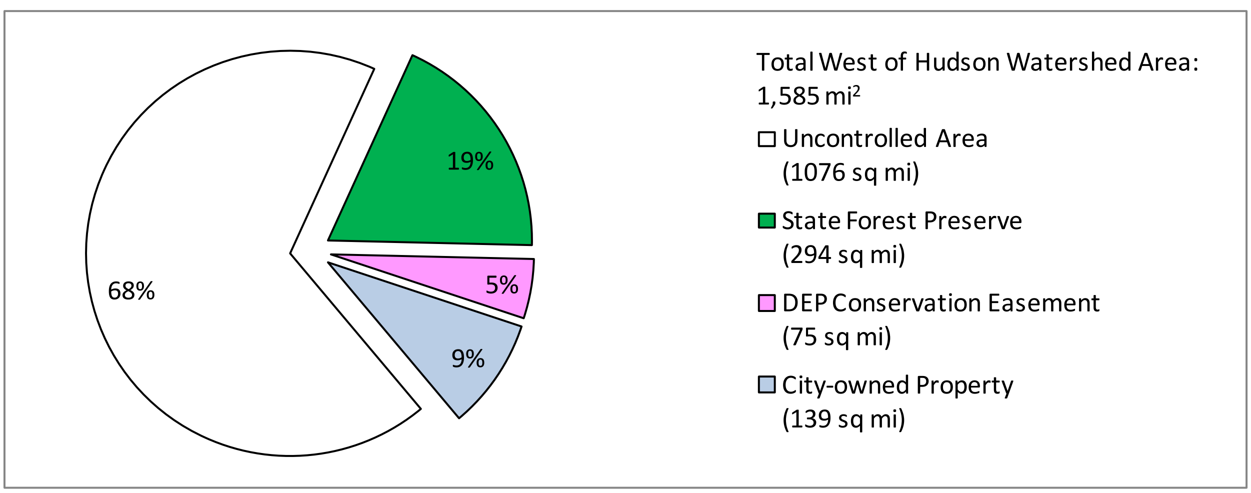

Figure 3-6: Ownership Status of West-of-Hudson Watershed Land (April 2009)

per square mile over approximately 400 square miles [40 percent] of the county area). It has not been established that these areas have been completely developed so still higher densities are possible. Similarly, annual well completion rates in excess of five wells per square mile have been documented, and permit applications suggest that these rates could be higher also. Given the available data, a working estimate of six wells per square mile over the developable area within the watershed is reasonable.

At six wells per square mile, and assuming that 50 to 100 percent of the currently uncontrolled land is ultimately developed, it is estimated that on the order of 3,000 to 6,000 wells could potentially be drilled in the watershed. This estimate is based on the best available data on industry intent for developing the resource in conformance with New York state regulations at this time, and presents a range of development within the watershed that is consistent with that observed in comparable plays.

3.3 Summary

Reasonably foreseeable natural gas well development scenarios for the NYC watershed can be calculated based on experience in comparable formations. Annual well completion rates would likely be 5 to 20 wells per year initially, but could accelerate rapidly under favorable economic and regulatory conditions, averaging 100 to 300 wells per year, and potentially peaking at 500 wells per year. Consistent with NYSDEC spacing unit requirements and development in other formations, it is estimated that between 3,000 and 6,000 wells could ultimately be drilled and fractured in the NYC watershed. This does not include re-fracturing of the same wells, nor does it include drilling and fracturing of wells to tap natural gas in the Utica, Oriskany, or Trenton/Black River formations underlying the NYC watershed.

Section 4: Cumulative Impacts

This section presents an assessment of cumulative impacts associated with natural gas well development in the NYC watershed. The primary focus of the analysis is on drinking water quality, water supply reliability, and infrastructure integrity. This section does not address other potential impacts (e.g., noise, air pollution, habitat disruption, induced growth), though such impacts may occur and deserve full consideration. A summary of estimates of quantifiable gas well development activities is presented for an individual well, for well development on an annual basis, and for a "full build-out" scenario. Subsequent subsections review cumulative impacts in greater detail.

4.1 Quantification of Gas Well Development Activities

Table 4-1 quantifies several critical activities that occur during well drilling and fracturing operations, including site disturbance, water usage, chemical usage, flowback and produced water generation, and truck trips. Estimates for each of these activities are presented for one individual well, based on data presented in the Rapid Impact Assessment Report and the dSGEIS and supporting technical reports. These individual well estimates are then applied to multiple wells to develop order of magnitude estimates of cumulative quantities on an annual basis and a full build-out basis. Assumptions for the annual and total number of well completions under low and high development scenarios are based on estimates presented in Section 3.

Table 4-1 does not account for impacts associated with refracturing that may be conducted to restore declining gas well production rates. Experience in the Barnett shale provides some guidance with respect to the frequency of re-fracturing that may occur in the Marcellus. Based on data in the dSGEIS,[20] two re-fracturing intervals, five and ten years, were examined for the purpose of developing a screening-level assessment of impacts associated with refracturing (Table 4-2).

To develop these estimates, it was assumed that the natural gas wells are constructed over the course of a 20-year development period, and that each individual well has a service life of 40 years.[21] As such, natural gas development and production activities occur over the course of 60 years. Alternative scenarios describing the rate of well completion during the 20-year development period were developed; in all cases the peak annual rate of well completion was limited to 500 wells per year. For the high (6,000 well) build-out scenario and a five year refracturing interval, an additional 42,000 hydrofracturing operations would occur in the watershed over the life of the gas play. For a ten-year interval, an additional 18,000 hydrofracturing operations would occur.

[20] The dSGEIS states that "*Hydraulically fractured wells in tight gas shale often experience production rate declines of over 50% in the first year. Fractured Barnett shale wells generally would benefit from refracturing within 5 years of completion, but the time between fracture stimulations can be less than 1 year or greater than 10 years*." (dSGEIS, ICF Task 1 Report - Technical Analysis of Hydraulic Fracturing).

[21] The typical well-life expected for horizontally drilled wells in the Marcellus Shale has not yet been established or identified in the dSGEIS. The 40-year service life assumption is made in light of reported estimates for Barnett Shale wells. As an example, a recent article concerning potential royalty estimates assumed a 30-year well life without re-fracturing, but also indicated that it was expected that most Barnett wells would be re-fractured within 7 years, and that continuous re-fracturing could double or even triple the life of the wells. Other sources also estimate Barnett well-life in excess of 30 years. Source: *2008 Tarrant County Barnett Shale Well Revenue Estimate for Neighborhoods* by Gene Powell. Excerpt from May 5, 2008 *Powell Barnett Shale Newsletter.*

Table 4-1: Summary of Individual and Cumulative Impact Estimates

Parameter (units) *Estimate (source)*	Quantity for One Well (range)	Annual Well Development (Quantity/year)		Full Build-out (Total Quantity)	
		Low	High	Low	High
Developable Area (sq mi)	--	--	--	500	1,000
Percent of Total Watershed Area *Total Watershed area is 1585 sq. miles*	--	--	--	32%	63%
Number of Wells *Assume 6 wells/square mile*	1	20	500	3,000	6,000
Site Disturbance (acres) *4 – 6 wells/pad (dSGEIS)*	7	28	700	4,200	8,400
Water Consumption (MG) *Industry and dSGEIS*	4 (3 to 8)	80	2,000	12,000*	24,000*
Chemical Usage (tons) *0.5 to 2% of fracture fluid; assume 1% (dSGEIS)*	167 (83 to 334)	3340	83,500	500,000*	1,000,000*
Flowback (MG) *10 to ~70% of fracture fluid; assume 50%* [1]	2 (0.4 to 2.8)	40	1,000	6,000*	12,000*
Produced Water (MG /yr) *Industry and dSGEIS*	0.075 (0.015 to 0.15)	1.5	37.5	225	450
Truck trips *800 – 2000 per well (RIA)* *890 – 1340 per well (dSGEIS)*	1,200 (800 to 2000)	24,000	600,000	3,600,000*	7,200,000*

Notes:
1. Flowback volume estimates vary widely. The dSGEIS cites flowback as 9% to 35% of fracture fluids for horizontal Marcellus wells in Pennsylvania, but also assumes flowback as 50% of fracture fluid in its estimates of truck trips. NETL cites 25% to 100%.[22] Annual well development calculations use 0.4 MG and 2.8 MG for the low and high estimates, respectively.
* These totals do not include allowance for re-fracturing operations.

Related quantities of water, wastewater and chemicals are summarized in Table 4-2 for the high (6,000 well) development scenario with and without refracturing. Estimates for wastewater quantities assume the same values for fracturing fluid volume, fracture fluid flowback and produced water as for the initial fracturing job, as indicated in Table 4-1. Flowback and produced water estimates are combined to estimate total wastewater production. Waste disposal requirements are represented by calculation of the total dissolved solids (TDS) load assuming a TDS concentration of 100,000 mg/l for both flowback and produced water, which is based on the median reported in the dSGEIS. In order to provide an initial assessment of the feasibility of disposal through dilution with other waste streams, dilution calculations have also been performed that assume that the maximum permissible effluent concentration would be limited to 500 mg/l. Lastly, the total mass of fracturing chemicals is totaled, assuming that these constitute one percent by weight of hydro-fracturing fluid. The resulting estimates are summarized in Table 4-2.

[22] National Energy Technology Laboratory (NETL). 2009. Project description for *Sustainable Management of Flowback Water during Hydraulic Fracturing of Marcellus Shale for Natural Gas Production*.

Table 4-2: Impact of Refracturing on Cumulative Water, Wastewater, and Chemical Volumes

Parameter (units) *Estimate (source)*	Without Refracturing	With Refracturing	
		10-Year Interval	5-Year Interval
Total Number of Wells	6,000	6,000	6,000
CUMULATIVE BASIS			
Total Number of Frack Jobs *Full build-out, high scenario*	6,000	24,000	48,000
Frack Chemicals Used (tons) *1.0% of fracture fluid*	1,000,000	4,000,000	8,000,000
Waste TDS (tons) *100,000 mg/l TDS (dSGEIS)*[2]	12,510,000	27,522,000	47,541,000
ANNUAL BASIS[1]			
Water Demand (mgd) *4 MG per frack job*	3.6 to 5.5	5.5 to 8.2	11.7 to 14.2
Wastewater Production (mgd) *50% Flowback + 0.075 MG/yr Produced Water*	2.6 to 3.5	3.9 to 5.3	6.7 to 8.4
Waste TDS for Disposal (tons/day) 100,000 mg/l TDS in waste (dSGEIS)2	1,100 to 1,500	1,600 to 2,200	2,800 to 3,500
Water Req'd to Dilute TDS to 500 mg/l (mgd)	500 to 700	800 to 1,100	1,300 to 1,700
Frack Chemicals (tons/day) *1.0% of fracture fluid*	150 to 230	230 to 340	490 to 590

Notes:
1. Ranges describe the median and the maximum of the annual average values for each development year. Data for the no-refracturing scenario are drawn from the 20-year period of well development. Data for the refracturing scenarios are drawn from the full 60-year period of development and refracturing.
2. The dSGEIS reports median and maximum values of TDS as 93,200 mg/l and 337,000 mg/l, respectively. The concentration of TDS in flowback reportedly increases with time. The determination of median value may include relatively low concentration samples from initial flowback.

The calculations summarized in Table 4-2 indicate that a 5-year refracturing interval would require sustained water diversion needs on the order of 12 to 14 mgd and approximately 10 mgd of wastewater disposal capacity on an annual average basis. Even without including re-fracturing quantities, sustained water demands of 5.5 mgd and wastewater generation of 3.5 mgd can be anticipated within the watershed. Given the expected development of gas drilling and therefore wastewater services across the entire region, it is reasonable to assume that wastewater generated locally may be disposed of locally. Fracturing chemical usage is estimated to range from 150 tons per day without refracturing to nearly 600 tons per day for refracturing at a 5-year interval.

Note that the analysis summarized in Table 4-2 presents annual average rates; shorter-term variations can be expected to exceed these estimates. The analysis includes well drilling activities for Marcellus spacing units only; additional drilling to develop other formations, if these prove feasible, would be in addition to these estimates. Finally, these estimates are only for wells which are assumed to be located within roughly two-thirds of the NYC West-of-Hudson watershed. Water, wastewater and disposal requirements for wells elsewhere in NYS would be in addition to the quantities summarized above.

Impacts of the estimates presented in Table 4-1 and Table 4-2 are discussed further in the following sections.

4.2 Land Disturbance, Site Activity, and Truck Traffic

Land Disturbance

Site development for a natural gas well begins with clearing and grading land for the well pad, water and wastewater storage area, access road, and utility corridor. Most Marcellus wells are expected to be drilled on multi-well pads; industry estimates cited in the dSGEIS suggest these pads will be on the order of five acres in size. These estimates do not include the area required for access roads, gas transmission lines, or centralized impoundments. The total site disturbance including pad and related features such as road and pipelines is estimated at seven acres per well pad based on data from the Fayetteville Shale.[23]

Once all wells are drilled and completed on a pad, the site is partially restored, leaving an area of roughly one to three acres for maintenance access, produced water storage, and gas production equipment. The site will remain in a partially restored state for the duration of the well's productive life (~20 to 40 years). Full surface restoration of the site occurs after the well is plugged and abandoned.

Assuming a pad size of seven acres and four to six wells per pad, the total land disturbance associated with 3,000 to 6,000 wells in the watershed is on the order of 4,200 to 8,400 acres (6.5 to 13.1 square miles). The total amount of land disturbance on an annual basis will depend on the number of active drill pads in a given year. This is expected to range from less than five active pads per year (fewer than 35 acres per year) in the early years of development to 100 or more (700+ acres per year) during peak years.

Impacts associated with site development activities include habitat loss and fragmentation, conversion of forest or pasture land to gravel or other low permeability compacted material, and increases in stormwater runoff and erosion potential due to reduced infiltration rates, increased flow velocities, and lack of vegetative protection. Drilling sites will likely require a NYCDEP-approved stormwater pollution prevention plan that can be expected to help reduce some of the impacts associated with site disturbance. Review and inspection of stormwater plans/facilities will increase the workload of NYCDEP personnel compared to current levels.

Site Activity

Though well sites and associated disturbance are generally described as temporary impacts, it is important to note that sites will remain active for much longer than the nominal four to eight weeks required to drill and fracture one well. When the time required for initial pad construction, mobilization and demobilization of drill rigs and other equipment, water delivery, flowback time, and waste disposal is considered, the total duration of pre-production activities during which a drill site can be considered active is on the order of four to ten months for one well, depending on site-specific circumstances.[24] During this time, activities may be staged so that multiple wells are under various stages of concurrent development at any given time.

[23] U.S. Department of the Interior. 2008. *Reasonably Foreseeable Development Scenario for Fluid Minerals: Arkansas*. Prepared for the Bureau of Land Management Eastern States Jackson Field Office. March 2008.
[24] See dSGEIS Table 5-15.

Given that six to ten wells are expected to be required to fully exploit the natural gas resources in a 640-acre spacing unit, and given that ECL §23-0501 requires all horizontal wells in a multi-well shale unit to be drilled within three years, it is reasonable to expect that a given well site will be undergoing a relatively high and constant level of industrial activity for at least one and up to three years. This same level of activity can be expected to recur periodically over the life of the well, depending on the frequency of subsequent re-fracturing operations.

Truck Traffic

Development of natural gas resources in the watershed will be accompanied by a significant increase in the level of heavy truck traffic compared to current conditions. The dSGEIS estimates the number of truck trips per well at roughly 900 to 1,300, approximately two-thirds of which are for water and wastewater hauling. On an annual basis, the number of additional truck trips per year could range from 24,000 to 600,000, depending on the number of wells drilled in a given year (Table 4-1). The increased number of travel cycles in the area will increase the risk of accidents.

NYCDEP owns and maintains 94 miles of secondary two-lane highways and 32 bridges in the West-of-Hudson watershed. Large volumes of truck traffic will stress these and other local roads and bridges, thus increasing maintenance and capital costs but also increasing the risk of accidents that result in leakage or spillage of hazardous materials. The risks associated with such spills are quantified in Section 4.5.

Other Drilling Infrastructure

In addition to trucking activity, gas well development in the watershed will be accompanied by provision of equipment and material supply systems (warehouses, garages, support services), gas gathering and pipeline systems, compressor stations, and waste disposal systems.

4.3 Water Withdrawals

The volume of water required to fracture a horizontal well depends on a variety of factors, including characteristics of the target formation, the length of the lateral, and fracture goal. Industry data cited in the dSGEIS indicates that on the order of three to eight million gallons of water may be required to fracture a horizontal well in the Marcellus formation. Assuming an average of four million gallons per well, the estimates presented in Table 4-2 indicate that on the order of one to two billion gallons per year of additional demand could be placed on the watershed’s resources. Note that these estimates do not include possible diversions of water from the NYC watershed for fracturing of wells outside the watershed. Withdrawals of this magnitude may appear insignificant; however, given current and future demands for water from the NYC system any reduction in system yield is of concern. Extrapolating from OASIS modeling done to support the development of the current Delaware Reservoirs Flexible Flow Management Program (FFMP), a reduction of system inflows on the order of four million gallons per day would require the expansion of system storage by approximately 1 billion gallons to maintain safe yield.[25]

[25] Flexible Flow Management Program, Agreement of the Parties to the 1954 U.S. Supreme Court Decree, Effective December 10, 2008 (http://water.usgs.gov/osw/odrm/documents/FFMP_FINAL.pdf).

Excessive surface water withdrawals could reduce inflow to NYC reservoirs, reduce available supplies, and decrease the probability of refilling reservoirs prior to drawdown. Excessive groundwater withdrawals could deplete aquifers, resulting in reduced baseflow in watershed streams or wetlands. The severity of such impacts will depend heavily on the total amount of withdrawals from the West-of-Hudson watersheds, as well as the timing of such withdrawals. Withdrawals during periods when reservoirs are full and spilling would likely have little or no impact on supply reliability. In contrast, withdrawals during dry periods could increase the length of time spent under drought watch, warning, or emergency conditions.

Excessive withdrawals could also impact water system operations by requiring increased reservoir releases to meet in-stream flow requirements. For example, large volume water withdrawals downstream of Pepacton, Cannonsville, or Neversink Reservoirs could necessitate additional releases from those reservoirs to satisfy Delaware Basin release requirements. Similarly, withdrawals from the Upper Esopus Creek could require increased releases from Schoharie Reservoir to meet Esopus Creek minimum flow requirements. Excessive water withdrawals may also impact aquatic habitat and biota.

It has been reported that in the absence of control mechanisms, a number of streams in Washington County in southwestern Pennsylvania (outside the jurisdiction of the Delaware and Susquehanna River Basin Commissions) have been nearly drained or pumped dry from excessive withdrawals for Marcellus wells.[26] Such a scenario in the NYC watershed could result in adverse impacts to water supply reliability.

4.4 Chemical Usage

Water and sand have been reported to comprise 98 to 99.5 percent of the fracturing fluid mixture, with the remaining 0.5 to 2.0 percent consisting of an array of chemical additives used to control fluid properties during the various stages of the fracking process.[27,28,29] Though the *proportion* of chemicals in fracturing fluid is indeed low relative to the large amounts of water required by the fracturing process, meaningful assessment of potential water quality impacts requires that chemicals additives be expressed on a mass basis.

Table 4-3 summarizes the proportion and the mass of water, proppant (sand), and each of 12 major classes of chemical additives required for a single four million gallon fracture operation. The proportions in this mixture are based on data from the Fayetteville Shale, as presented in the dSGEIS.[30] Chemical additives make up 0.446 percent of this mixture, or roughly 82 tons. For a frack mix with one to two percent chemicals, the mass of chemical additives would be approximately 167 tons and 324 tons, respectively. Chemical usage estimates presented in Section 4.1 assume that chemical additives make up one percent of the fracturing fluid mixture. Under this assumption, development of 6,000 wells over a 20 year period would entail fracturing

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[26] Parsons, J. (2008). *Pa. Streams Drained Dry By Drillers*. WTAE, Pittsburgh, November 13, 2008.
[27] Arthur, J.D., B. Bohm, B.J. Coughlin, and M. Layne. (2008). *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs*. ALL Consulting, Tulsa OK.
[28] Fortuna Energy (2009). *Marcellus Natural Gas Development*. Presented at NYWEA 2009 Spring Technical Conference, West Point, NY, June 2, 2009.
[29] U.S. Department of Energy, Office of Fossil Energy. (2009). *Modern Shale Gas Development in the United States: A Primer*, prepared by the Ground Water Protection Council and ALL Consulting, Washington, DC.
[30] dSGEIS, URS Technical Report *Water-Related Issues Associated With Gas Production in the Marcellus Shale*, Figure 2-1.

chemical usage at a rate of 150 to 230 tons per day, or up to 590 tons per day with refracturing at 5-year intervals.

Table 4-3: Mass of Water, Sand and Major Classes of Fracturing Fluid Chemical Additives Required for one 4 MG Fracture Operation

	Percent by mass[1]	Mass required for one 4 MG fracturing operation (tons)
Water	90.6%	16,690
Proppant	8.96%	1,651
Acid	0.11%	20.3
Surfactant	0.08%	14.7
Friction Reducer	0.08%	14.7
Gelling Agent	0.05%	9.2
Clay Stabilizer/Controller	0.05%	9.2
Scale Inhibitor	0.04%	7.4
pH Adjusting Agent	0.01%	1.8
Breaker	0.01%	1.8
Crosslinker	0.01%	1.8
Iron Control	0.004%	0.7
Bactericide/Biocide	0.001%	0.2
Corrosion Inhibitor	0.001%	0.2
Total (all constituents)	100.0%	18,423 tons
Total (chemicals only)	**0.446%**	**82.2 tons**

Notes:
1. dSGEIS, URS Technical Report *Water-Related Issues Associated With Gas Production in the Marcellus Shale*, Figure 2-1.

Chemicals in drilling and fracturing fluid may be introduced into surface waters and ultimately into the water supply as a result of vehicle accidents during transport of raw chemicals to a drill site or removal of wastes from the site, via spills resulting from improper chemical storage and handling at drill sites, and via airborne and subsurface pathways. Chemicals introduced into the ground during the hydraulic fracturing process are not fully recovered. Based on data from horizontal Marcellus wells in northern Pennsylvania reported in the dSGEIS, on the order of 65 to 90 percent of the fracturing fluid may remain in the subsurface. As described in Section 2 and subsequently in Section 4.6, these chemicals can migrate beyond the fracture zone into overlying groundwater, watershed streams, reservoirs, and directly into tunnels and ultimately enter the water supply.

Chemical usage is a significant concern for watershed water quality because many drilling and fracturing fluid additives contain chemicals that are known to be toxic to the environment and hazardous to human health. This concern is heightened by the fact that the exact chemical composition of many additives is not disclosed. Well drilling and fracking products are proprietary and typically protected by trade secret laws, thereby limiting disclosure requirements. Consequently data is limited on the identity and amounts of specific chemicals that could be used during drilling and fracturing operations in or near the NYC watershed.

The fracturing chemical data obtained by NYSDEC from service companies and chemical suppliers during the dSGEIS preparation process highlights the difficulty in obtaining full chemical composition data. Data was received for 197 products, 23 percent of which were not characterized by full chemical composition data. The 197 products were composed of 260 unique chemical components and another 40 components which are mixtures or otherwise not fully characterized. This challenge is also evidenced in a database of fracturing products and chemicals developed by The Endocrine Disruption Exchange (TEDX, Paonia, CO) and reviewed in connection with this project. The database identifies 435 products composed of over 340 individual chemical constituents. The exact chemical composition of over 90 percent of the products in the database is unknown.

Of the known constituents identified in the dSGEIS and by TEDX, many are recognized as hazardous to water quality and human health. The dSGEIS identified chronic or acute health effects such as cancer or impacts to the reproductive, respiratory, gastrointestinal, liver, kidney, or nervous systems for one or more chemicals in nine of eleven chemical structural categories. The analysis did not characterize health effects for each individual chemical, citing “very limited” compound-specific toxicity data for many fracturing chemicals. Of the products identified in the TEDX database, significant percentages contain one or more chemicals that are associated with negative health effects: cancer (33% of products contain one or more chemicals associated with cancer), endocrine disruption (41%), reproductive problems (34%), immune suppression (58%), genetic mutation (43%), and other adverse health impacts.

The use of fracturing fluid additives containing known or suspected carcinogens, endocrine disrupting compounds (EDCs), or other contaminants that may cause human health impacts from long-term or chronic exposure at very low doses is of particular concern to the water supply. As mentioned above in Section 1.3, the regulations concerning drinking water quality are continually evolving. It is reasonably foreseeable that future regulations will include lower thresholds and encompass emerging contaminants of concern, including EDCs. Accordingly, the introduction of hundreds of tons per day of fracturing chemicals into the watershed over a period of several decades, the possibility of subsequent gradual penetration of low levels of contaminants into the environment and the water supply via multiple transport pathways, and the difficulty of removing many of these contaminants from groundwater and surface supplies, pose public health risks that should be carefully considered and avoided.

4.5 Surface Spills

Accidental spills, leaks, and releases associated with natural gas well drilling and fracturing activities have resulted in hundreds of documented groundwater and surface water contamination incidents across the country. Surface spills can be a relatively common occurrence at well sites because the drilling and fracturing process involves transfer of large volumes of fluids between trucks, tanks, wells, pits, etc., often at high flow rates and pressures, substantially increasing the likelihood of a spill due to human error, equipment failure, or accident.

Surface spills in the NYC watershed may be categorized as resulting in either acute or chronic impacts based on proximity to streams and reservoirs. Acute spills are considered here to include accidental or intentional chemical releases that occur adjacent to or in a stream or reservoir. Chronic spills are considered to occur at the well site or beyond the immediate vicinity of a stream or reservoir.

Acute Spills

There are a number of acute surface spill scenarios of concern in the NYC watershed, such as a truckload of raw fracking chemicals or a tanker of flowback/produced water releasing its contents into a NYC reservoir or tributary stream. In addition to substantially compromising operations and public confidence in the water supply, acute spills could also result in MCL violations. Given the enormous volume of chemicals and wastewater that could be transported into and generated within the NYC watershed over a multi-decade development period, acute spill scenarios are realistic and should be expected. This is particularly true in light of the proximity of roads adjacent to NYC reservoirs and the heavy volume of truck traffic required to haul wastewater and chemicals.

To examine the sensitivity of the NYC water supply to acute spills of fracturing chemicals, an analysis of the mass of fracturing chemicals required to violate an MCL at Kensico Reservoir was conducted (Appendix C). The analysis is based on fracturing chemical data and assumptions presented in dSGEIS supporting documents.[31] Both the dSGEIS analysis and the following analysis are structured as simple dilution calculations that assume the chemical mass enters a reservoir directly and is completely and instantaneously mixed with its contents.

Consistent with dSGEIS assumptions, reservoirs were assumed to be one-third full. Such low storage levels would only be expected to occur under severe drought conditions. However, the one-third full assumption is equivalent to the more realistic situation in which the reservoirs are relatively full and the contaminant mass mixes with only one-third of the reservoir's volume as a result of short-circuiting. Complete mixing in reservoirs with volumes as large as NYC's is not a reasonable assumption under most circumstances. Short-circuiting due to stratification, density currents, and prevailing flow patterns is considered more typical.

Two spill scenarios were considered, the key difference between them being the volume into which the chemical mass is diluted:

- Scenario 1 dilutes the contaminant mass with the contents of Kensico Reservoir. This represents a situation in which a load of fracturing chemicals spills into Rondout and the chemicals short-circuit into the intake chamber and are conveyed downstream to Kensico Reservoir.
- Scenario 2 dilutes the contaminant mass with the contents of Kensico and Rondout Reservoirs. This represents a situation in which a load of fracturing chemicals spills into Rondout or near its mouth and mixes completely with the contents of Rondout and Kensico. This is also representative of the impact of spill into Cannonsville, Pepacton, or Neversink Reservoirs that occurs near their respective intake structures.

Under these simple dilution assumptions, the mass of chemical required to violate an MCL is simply the product of the reservoir volume and the MCL, which is 0.05 mg/l for all chemicals considered here. To gauge the number of wells or hydrofracturing operations associated with the mass of chemical required to violate an MCL, data from the dSGEIS analysis was used to

[31] dSGEIS, Alpha Technical Report, *Survey of Regulations in Gas-Producing States, NYS Water Resources, Geology, New York City Watershed, Multi-Well Operations, and Seismicity*, Section 4.8 and Tables 4.3 – 4.5.

develop an estimate of the mass of each chemical required to fracture one well.[32] This data is presented in Table 4-4, along with an estimate of the mass of chemicals required to violate an MCL in Kensico, expressed in terms of fracture job equivalents, for both Scenarios 1 and 2.

Table 4-4: Fracturing Chemical Spill Scenarios for Kensico Reservoir

Chemical *0.05 mg/l MCL for all chemicals*	Estimated mass required to fracture one well (kg)	Fracture job equivalents required to exceed MCL	
		Scenario 1 (dilution with volume of Kensico)	Scenario 2 (dilution with volume of Kensico + Rondout)
2,2,-Dibromo-3-Nitrilopropionamide (1)	3019	0.6	1.7
Methanol (1)	1565	1.2	3.2
Ethylene Glycol (1)	1110	1.7	4.6
C12-15 Alcohol, Ethoxylated (2)	1110	1.7	4.6
Ethoxylated Castor Oil (2)	555	3.5	9.1
Isopropanol (Isopropyl Alcohol) (2)	555	3.5	9.1
Ethoxylated C11 Alcohol (1)	555	3.5	9.1
Alcohols C9-11, Ethoxylated (1)	391	4.9	12.9
(1) dSGEIS Frack Mix 1 (2) dSGEIS Frack Mix 2			

For Scenario 1, the mass of chemicals associated with just one to five hydraulic fracturing operations could be sufficient to violate an MCL at Kensico Reservoir. For Scenario 2, the mass of chemicals associated with two to thirteen hydraulic fracturing operations could be sufficient to violate an MCL at Kensico Reservoir.[33]

This analysis should not be taken to indicate that these or comparable spill scenarios would constitute an imminent threat to public health. In the event of a major spill operators would respond immediately upon learning of the event and take appropriate operational measures to protect the water supply, including water quality sampling, adjusting intake levels, reducing flow rates or taking reservoirs off-line, etc.

This analysis does suggest that large scale development of natural gas wells in the watershed, and associated substantial increases in chemical and waste hauling, can be fairly characterized as increasing the risk of water quality impairment relative to current conditions. It also highlights the importance of stream and reservoir buffers in mitigating such risks.

Though this analysis has focused on MCLs, it is important to note that water quality contamination is important in and of itself, even if it does not trigger an MCL violation. NYCDEP's mission is not to supply water that merely meets regulatory limits but "to reliably

[32] Due to confidentiality requirements the dSGEIS analysis does not present data on the mass composition of additives or the mass of additives or constituent chemicals required to fracture a well. The scenarios presented in the dSGEIS analysis do provide sufficient information to back-calculate the mass of chemicals required to fracture a well.

[33] Undiluted hydrofracking chemicals are trucked to well sites and then mixed with large volumes of water. Multiple wells may be fractured on a well pad sequentially or at nearby wellpads and therefore significant quantities of undiluted chemicals could be involved in a surface spill.

deliver a sufficient quantity of *high quality drinking water* and to ensure the *long term sustainability* of the delivery of this most valuable resource."[34]

Chronic Spills

In addition to acute spills, it is reasonable to expect that development of natural gas resources in the watershed will be accompanied by an increased frequency of chemical, wastewater and fuel spills at or near well pads. This is a natural outcome of a complex and intensive industrial activity occurring dozens or hundreds of times per year across the watershed. Site spills can be reduced through implementation of best management practices (BMPs) for pollution prevention, waste minimization, chemical handling and storage, etc. Even with appropriate BMPs and regulations, however, mechanical failures, human errors, and accidents are inevitable. Impacts will be minor when on-site personnel respond quickly and limit the impacts of the incident. But significant contamination can occur when spills go undetected, plans are not followed, equipment is not maintained, and/or BMPs are not implemented.[35]

Even if most site spills are mitigated with minimal impact, the chronic occurrence of multiple spills per year over a period of several decades can be expected to compromise public confidence in the quality of NYC's unfiltered water supply.

4.6 Subsurface Migration

Subsurface migration of fracturing fluids or formation water and pressures could present risks to potable water supplies if such fluids were to intercept a shallow fresh water aquifer or NYC infrastructure. Potential migration pathways include migration of fracturing and formation fluids along the well bore as well as migration across and out of the penetrated and hydraulically fractured strata. This section identifies risks associated with these migration pathways. Containment of fluids within the well-bore is provided for by well construction techniques that include multiple casings and cemented annular spaces extending below fresh water aquifers. The competency of the overlying strata and control of the fracturing process to limit induced fractures to the target formation are relied upon to provide a hydraulic barrier for containment of fracturing and formation fluids within the gas-bearing formation.

The review of regional geology and tunnel construction data presented in Section 2 indicates that vertical migration of deep groundwater, methane and/or fracking chemicals is a foreseeable occurrence, given the existence of naturally occurring and laterally extensive vertical brittle geological structures, and the documentation of faults and seeps during tunnel construction. This section also considers whether activities and subsurface alterations that can be anticipated to accompany natural gas exploration and development would present a risk to subsurface water supply infrastructure or operation.

The presence of numerous brittle structures in the regional bedrock is well documented. Presently identified brittle structures that have been mapped in the Catskill/Delaware watershed can extend up to seven miles laterally and up to 6,000 feet in depth.[36,37] The vertical and lateral persistence of these features in conjunction with the potential for failed casings or other

[34] NYCDEP-BWS Mission Statement.
[35] Case studies are provided in the Rapid Impact Assessment, NYCDEP, 2009.
[36] Hill et al, 2008.
[37] Engelder and Lash, 2008.

unforeseen occurrences could result in significant surface and subsurface contamination of fresh water aquifers, as illustrated by incidents in other well fields, most notably documented in Garfield County, Colorado (migration of toxic formation material through subsurface fractures) and Dimock, Pennsylvania (migration of natural gas to the surface via improperly cased wells). Similar mechanisms could permit migration of material into the fresh water aquifers that comprise the NYC West-of-Hudson watersheds and present potential risks to water quality and tunnel lining integrity.

Existing Migration Pathways

Brittle geological features such as faults, fractures and crushed zones were encountered during water supply tunnel construction. Groundwater inflows were also encountered at numerous locations during tunnel construction, and in several cases, these align with mapped faults, fractures or linear features. More importantly saline, methane, and hydrogen sulfide seeps were encountered as well. These seeps are considered to be indicative of a hydraulic connection to naturally-occurring pressurized groundwater/fluids from much deeper strata. Existing connections to deeper strata can transmit pressurized fluids (e.g., saline and/or radioactive formation water and residual hydrofracturing chemicals) upward to the vicinity of the fresh water aquifer and tunnels (and to the surface).

Casing and/or grouting problems, improper plugging or abandonment of wells, extensive subsurface fractures and the region-wide development requiring the operation of thousands of wells may enhance existing hydraulic connections and/or create new connections. Wells that are not properly plugged and abandoned could become a conduit for the introduction of contaminated fluids into the fresh water aquifer. It is estimated that location and condition records are lacking for over 50 percent of the previously constructed oil and gas wells in New York State. State-wide this amounts to approximately 40,000 existing wells that could serve as migration pathways for injected fluids but for which regulators do not have sufficient information to take protective actions. Given the prior history of oil and gas development, most of these are presumably in the western part of the state. However, some gas wells were drilled in the watershed region, indicating prior interest in developing the resource and the possibility of undocumented or improperly abandoned wells.

Effects on Underlying Strata and Migration Pathways

The force of thousands of feet of overlying rock produce high lithostatic pressures in deep low permeability gas reservoir rock units such as the Marcellus formation. Given the low primary porosity of these units they are often considered to act as a hydraulic barrier that can prevent the migration of fluids from lower formations to overlying strata. Hydrofracturing for natural gas development diminishes the isolating properties of the targeted shale, compromising the integrity of this subsurface barrier between surface aquifers and naturally occurring, low quality formation water, as well as other fluids introduced into the shale.

New fractures generated during well development and stimulation that propagate vertically beyond the target formation can create or enhance hydraulic pathways between previously isolated formations. Technical supporting documents provided with the dSGEIS indicate that:

> *"Hydraulically induced fractures often grow asymmetrically and change directions due to variations in material properties. In formations with existing natural fractures, such as*

the Barnett and Marcellus shales, hydraulic fracturing can create complex fracture zones as fracturing pressure reopens existing fractures and as induced fractures and existing fractures intersect. Actual fracture patterns are generally more complex than the current conceptual models predict." (dSGEIS ICF Task 1 Report, p5)

This, and several other similar statements in technical documentation provided in support of the dSGEIS, suggest that extension of induced hydraulic fractures above the target formation, although not an intended result, can be anticipated to occur in some cases when hydrofracturing a large number of wells. Furthermore, subsurface features are expected to be stressed or altered in the future as a result of naturally occurring geologic changes and/or disturbances associated with widespread hydraulic fracturing. The dSGEIS indicates that fracturing may be accompanied by "as much as" a one percent increase in volume of the hydrofractured rock. It is reasonable to anticipate that this would alter rock stresses over an indeterminate distance which could facilitate fluid migration along existing brittle geological structures. The long-term impacts from thoroughly and extensively fracturing and expanding a rock unit that underlies a widespread area to the greatest extent that is economically feasible and then depressurizing the formation through the removal of compressed gas is difficult to quantify; especially in terms of how the overall activity will impact brittle structures in the overlying strata. Potential impacts that can be anticipated include movement of fluids at faults and fractures, alteration of subsurface flow pathways, vertical migration of fluid and depressurization of confined material as illustrated in Figure 4-1.

Injection Well Operations

Underground injection is an alternative sometimes used for disposal of waste water produced by natural gas production. Class II underground injection wells are employed in other gas plays, and as of November 2008, there were reportedly over 60 permits for Class II UIC wells for flowback water disposal in New York.[38] While there is uncertainty as to the geological feasibility of underground injection in the watershed region, the potential operation of injection wells could create additional risk to the NYC West-of-Hudson watershed and related water supply infrastructure, as injection well operation presents many of the same risks for subsurface migration of fluids and has been associated with seismic events elsewhere.

Pressure Gradients

Lithostatic pressures acting on the Marcellus formation and its limited transmissivity account for the observed high confining pressures of the fluids occurring within the formation.[39] These confining pressures can result in hydraulic grades well above the elevation of any of NYC's reservoirs, or the pressure in water supply tunnels, even without considering the pressure increases imposed during hydrofracturing. Vertical migration of fluids (e.g., brine, methane, hydrogen sulfide) from deeper strata and infiltration into water supply tunnels is hydraulically possible, even with tunnels in operation.

[38] ALL Consulting, LLC (Arthur, J.D, Bohm, B., Coughlin, B.J., Layne, M.). *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs.* Presented at the International Petroleum & Biofuels Environmental Conference, Albuquerque, NM, November 11-13, 2008.

[39] Hill, David G.; Lombardi, Tracy E. and Martin, John P. 2008. *Fractured Shale Gas Potential in New York.* New York State Energy Research and Development Authority, Albany, New York.

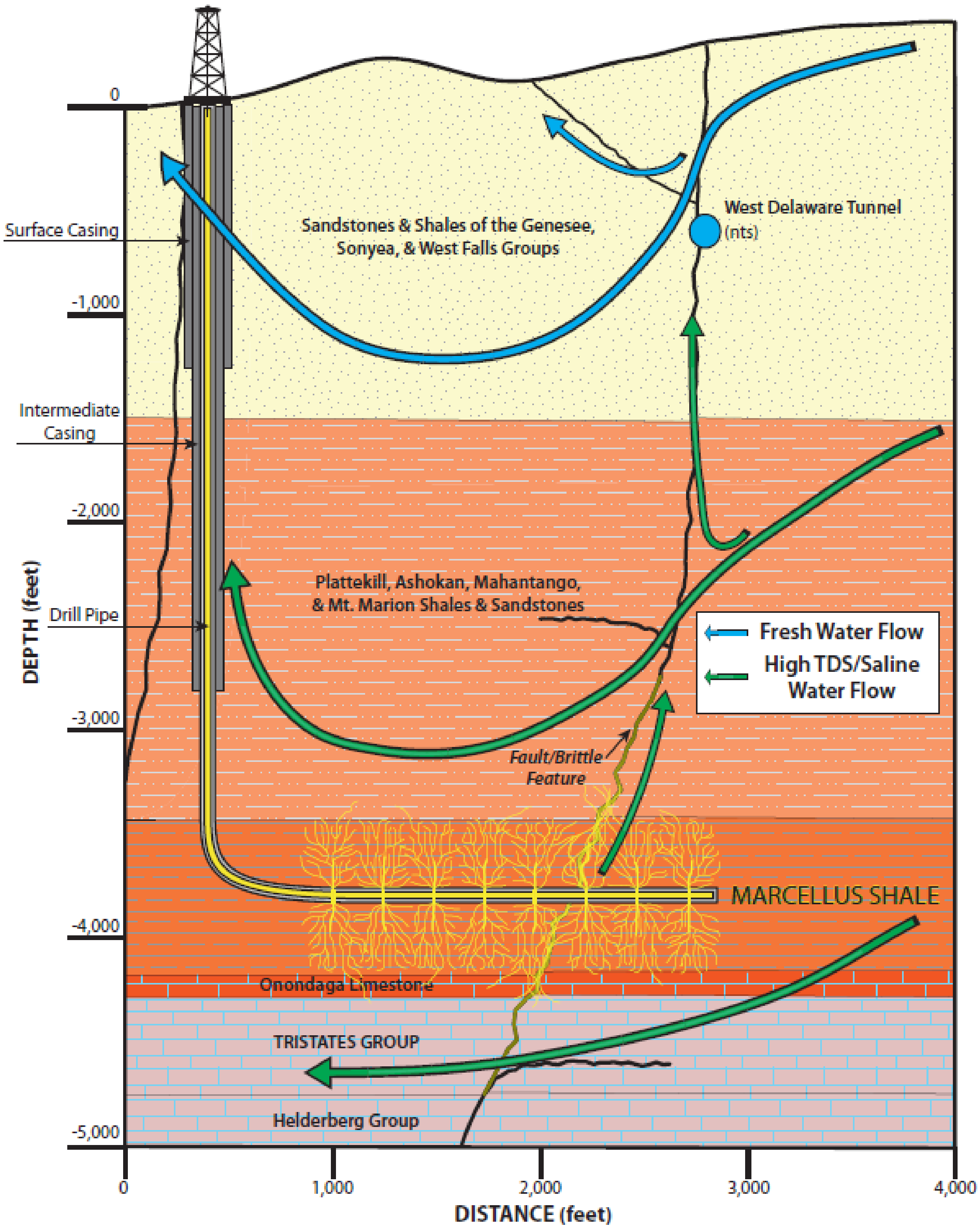

Figure 4-1: Examples of potential flow regime disruption mechanisms

NYC Tunnel and Aqueduct Impacts

NYC operates over 100 miles of deep-rock water supply tunnels in the West-of-Hudson region. Although these tunnels are generally located in overlying strata, in some locations they are in direct contact with the Marcellus formation. Primary impact considerations for this infrastructure are described below.

Tunnel Lining Structural Considerations

The unreinforced linings of NYC tunnels were designed to keep water in, not to withstand external pressures beyond those anticipated in their design. The incremental increase in fluid pressure that could theoretically be transmitted from the Marcellus could exceed the compressive strength of tunnel liners. Structural analysis of concrete tunnel liners exposed to asymmetric external pressure loads indicates that there is potential for detrimental effects on the liners upon the imposition of uneven external pressures as low as 25 psi. These detrimental effects could include liner cracks, which would facilitate infiltration of pressurized fluids. Pressure transmission to the vicinity of tunnels could occur during fracturing, or it could occur after fracturing, when newly expanded fractures expose tunnel linings to naturally occurring formation pressures. During hydrofracturing operations, tunnel liners could be exposed to still higher pressures.

Infiltration to Water Supply Tunnels

Sections of deep-rock tunnels could be subject to inflow of fluids from deeper strata through cracks in tunnel lining. This could occur most readily during the rare occasions when a tunnel is out of service, dewatered, and internal pressures are reduced, or in a tunnel which operates at atmospheric pressure, as does much of the Shandaken Tunnel that leads from Schoharie Reservoir to Esopus Creek. As indicated by the consideration of the degree of confining pressures occurring in the Marcellus, it is also hydraulically possible for pressurized fluids from deeper formations to infiltrate an operating tunnel. Additional liner cracks can be anticipated to develop as the tunnels age, due to normal geologic activity (e.g., seismic activity), and to changes in subsurface conditions associated with widespread hydrofracturing, gas reservoir depletion/withdrawal and injection well operation.

An analysis of the chemical concentrations in flowback water documented in the dSGEIS and their potential influence on water quality in flow conveyed by NYC's water supply tunnels is summarized in Table 4-5. The analysis has been performed for tunnels operating at 500 mgd, using both the maximum and median concentrations reported in the dSGEIS for flowback water.[40] It shows that there are several constituents of flowback water which could cause tunnel discharges to exceed prevailing water quality limits upon infiltration into water supply tunnels at relatively modest rates. Most of these exceedances are associated with infiltration rates of several hundred gallons per minute, rates which were documented during tunnel construction. However, documented concentrations of barium, a toxic heavy metal, would cause water quality exceedances upon infiltration to tunnels at rates as low as 10 to 20 gallons per minute. Also of note are the analyses for elevated concentrations of chlorides and total dissolved solids (TDS). These constituents are associated with the target formation and are most characteristic of

[40] With the exception of the Rondout-West Branch section of the Delaware Aqueduct, which has a hydraulic capacity of 890 mgd, the capacities of the remaining West-of-Hudson tunnels range from 500 to 700 mgd, although they are typically operated at flow rates several hundred mgd below capacity.

produced water rather than flowback. As such, the available mass of these constituents would not be limited to that introduced directly by hydrofracturing.

Table 4-5: Infiltration Rate to Tunnels that Would Cause Tunnel Discharge to Exceed NYSDEC Part 703 Water Quality Limit

Parameter	NYSDEC Part 703 Water Quality Limit (mg/l)	Flowback Concentration Estimates[1] (mg/l)		Infiltration Rate that Would Cause Tunnel Discharge to Exceed Part 703 Limits[2] (gpm)	
		Median	Maximum	At Median Flowback Concentration	At Maximum Flowback Concentration
Chlorides	250	56,900	228,000	1,520 gpm	380 gpm
TDS	500	93,200	337,000	1,860 gpm	510 gpm
Barium[3]	1	662	15,700	520 gpm	20 gpm
Benzene	0.001	0.48	1.95	720 gpm	180 gpm

Notes:
1. Flowback concentrations per dSGEIS Table 5-9.
2. Assumes aqueduct flow of 500 mgd. Infiltration rates calculated for water quality standard violations would be proportionately lower at lower aqueduct flows.
3. Supporting documents included with the dSGEIS list barium concentrations as high as 19,200 mg/l.

Given that the lengths of the West-of-Hudson tunnels range from 5 to 45 miles, and groundwater infiltration was encountered at rates of 100 gpm or more at some locations during construction, the calculated infiltration rates are not implausible especially if existing fractures are widened or additional fractures are created. Allowing for the long-term influence of extensive hydrofracturing and possible injection well operation, the possibility of infiltration from an overpressurized source at rates calculated above is a realistic risk to water quality conveyed by NYC's water supply tunnels. If maximum contaminant levels become more stringent, as is likely, then even lower infiltration rates could violate regulatory limits.

In summary, there is sufficient pressure under natural and gas-well enhanced conditions to drive fluids or gas upward from deep formations into tunnels or above grade, via geological faults or fractures, and there is potential for both structural damage to tunnel liners and violations of regulatory limits.

Water Supply Operations

The enhanced migration of fluids from deep formations could also include the migration of gases such as methane and hydrogen sulfide. Migration could occur through pre-existing brittle structures and may be further influenced by laterally extensive zones of elevated hydraulic conductivity associated with tunnel routes and vertically drilled shafts. Tunnel and shaft routing configurations may also permit the accumulation of methane and/or hydrogen sulfide in pockets of the infrastructure that require access from time to time for inspection and/or maintenance purposes. In such instances, the accumulation of either of these gases could represent an increased health and safety risk. The most serious potential consequence would be a methane gas explosion, which could threaten personnel and seriously damage critical infrastructure.

Related Precedent

The migration of fracking chemicals and/or poor quality formation water into overlying groundwater, watershed streams, reservoirs, and directly into tunnels is a reasonably foreseeable risk. The failures postulated above are not theoretical: they have occurred, at least with respect to impacts on streams and groundwater. A well-documented case occurred in Garfield County, Colorado in 2004 where natural gas was observed bubbling into the stream bed of West Divide Creek.[41] In addition to natural gas, water sample analyses indicated ground water concentrations of benzene exceeded 200 micrograms per liter and surface water concentrations of benzene exceeded 90 micrograms per liter – 90 times the NYSDEC Part 703 water quality limit for discharge of benzene to surface waters. Operator errors, in conjunction with the existence of a network of faults and fractures, led to significant quantities of formation fluids migrating vertically nearly 4,000 feet and horizontally over 2,000 feet, surfacing as a seep in West Divide Creek. It should be noted that the vertical separation between the Marcellus Shale and the West Delaware Tunnel ranges between 3000 and 5500 feet, well within the vertical distance seen in this incident in Garfield County, Colorado. Clearly there is a very real potential for methane migration from the Marcellus shale to the City water supply tunnels.

Although remedial casings installed in the well reportedly reduced seepage, the resulting benzene plume has required remediation since 2004. Subsequent hydrogeologic studies have found that ambient groundwater concentrations of methane and other contaminants increased regionally as gas drilling activity progressed, and attributed the increase to inadequate casing or grouting in gas wells and naturally occurring fractures.[42]

Groundwater contamination from drilling in the Marcellus shale formation was reported in early 2009 in Dimock, PA, where methane migrated thousands of feet from the production formation, contaminating the fresh-water aquifer and resulting in at least one explosion at the surface.[43,44] Migrating methane gas has reportedly affected over a dozen water supply wells within a nine square mile area. The explosion was due to methane collecting in a water well vault. Pennsylvania Department of Environmental Protection has since required additional ventilation, installed gas detectors and taken water wells with high methane levels offline at impacted homes to reduce explosion hazards. At this time the root cause remains under investigation and a definitive subsurface pathway is not known. This case is of particular concern since the terrain and geology in Pennsylvania is very similar to that of the NYC watershed: Dimock is only 35 miles from Deposit, NY and the Cannonsville Reservoir Dam.

In addition to these cases, there have been numerous reports of smaller, localized contamination incidents that have resulted in well water being contaminated with brine, unidentified chemicals, toluene, sulfates, and hydrocarbons.[45] In most cases the exact cause or pathway of the contamination has not been pinpointed due to the difficulty in mapping complex subsurface features. The accumulating record of contamination events that are reportedly associated with, or

[41] Colorado Oil and Gas Conservation Commission (COGCC). 2004. *Order no. 1V-276.* (http://cogcc.state.co.us/orders/orders/1v/276.html accessed 3/13/09).
[42] G. Thyne. *Review of Phase II Hydrogeologic Study.* Prepared for Garfield County. (CO) December 12, 2008.
[43] Wilber, T., *DEP zeros in on gas tainting water.* Binghamton Press and Sun Bulletin. January 30, 2009.
[44] Wilber, T., *PA officials reviewing Cabot drilling plan.* Binghamton Press and Sun Bulletin. October 13, 2009.
[45] See Rapid Impact Assessment Report for a discussion of various case studies of contamination.

in close proximity to hydrofracturing and natural gas well operations, suggests water quality impairments and impacts can be reasonably anticipated.

4.7 Wastewater Treatment and Disposal

Fracturing fluids that are returned to the surface as flowback and produced water from the formation tend to have very high TDS and chlorides, and may be contaminated with hydrocarbons, radionuclides, heavy metals, and fracturing chemicals, thus requiring specialized treatment and disposal. Approaches to treatment and disposal of drilling wastewater that have been employed elsewhere include:

- Underground injection wells;
- Industrial wastewater treatment followed by reuse or surface disposal; and
- Industrial pretreatment, followed by conventional treatment and surface disposal.

Underground injection is a common and frequently preferred method for disposal of drilling and fracturing waste. The feasibility of underground injection at the capacity that will be needed to accommodate waste from extensive development of the Marcellus formation as a natural gas resource has not been established. If underground injection proves feasible, the number of injection wells in New York could increase substantially. Injection well failures resulting in surface and groundwater contamination have been reported elsewhere.[46] Injection well operation has also been associated with induced seismicity which could increase subsurface migration of fluids from hydrofractured strata and other deep formations.

Treatment and disposal of wastewater is complicated by the high concentrations of numerous constituents of the waste stream and the presence of constituents that are not amenable to conventional treatment, such as naturally-occurring radionuclides and high concentrations of heavy metals. Experience in Pennsylvania to date is relevant to the issues that will face New York, and a concise summary of the waste disposal situation in Pennsylvania is provided in the abstract for a paper presented at the September 2009 Eastern Regional Meeting of the Society of Petroleum Engineers:

> *"In the Commonwealth of Pennsylvania, new regulatory limits have been proposed further limiting discharges. The Pennsylvania Department of Environmental Protection announced on April 15, 2009 that all industrial discharges will be limited to 500 mg/l TDS on January 1, 2011. There are currently no facilities in the state that can treat flowback fluids to this level. The options for an economic solution are few for operators in dealing with these saline flowback fluids. Evaporation/crystallization (EC), the only established technology for treatment of the produced waters that can achieve the newly proposed TDS limit, produces a very highly concentrated brine solution or large volumes of crystalline salt cake that still must be disposed. A 1 million gal/day crystallization plant will generate approximately 400 tons/day of salt waste. Unless some beneficial use for these residues can be found, they will require disposal in a secure solid waste facility. A typical municipal landfill cannot accept large volumes of crystalline salts and suitable facilities can do so only at a premium. Further, an EC plant is very energy intensive and*

[46] Hudak, P.F., Wachal, D.J. *Effects of Brine Injection Wells, Dry Holes and Plugged Oil/Gas Wells on Chloride, Bromide, and Barium Concentrations in the Gulf Coast Aquifer, Southeast Texas, USA.* Environment International. Vol. 26. Issues 7-8. June 2001. Pages 497-503. Copyright 2001. Elsevier Science, Ltd.

thus has the potential for increased air quality impact and greenhouse gas emissions in addition to its cost of operation. The Marcellus shale gas industry may be left with no economically viable disposal options."[47]

The 400 ton per day figure cited above corresponds to a solids concentration of approximately 100,000 mg/l, which is comparable to the median value reported for flowback samples in the dSGEIS (93,200 mg/l), and well below the maximum reported value of 337,000 mg/l.[48] As such, the solids load generation rate of 400 tons per million gallons could be higher.

Recycling of flowback can help to reduce the volume of wastewater generated, but the high concentration of scale-forming constituents limits the amount that can be recycled. Treatment and further dilution with fresh water is typically needed for re-use of flowback water, and significant quantities of residuals remain to be disposed. As noted above, currently available industrial treatment options are very limited. Treatment of Marcellus gas well wastes is the subject of several current research initiatives, but these are at very early stages. In general the availability of adequate treatment and disposal facilities for natural gas wastewater is severely limited.

Table 4-2 estimates the annual average wastewater generation rate for the full build-out scenario of 6000 wells in the watershed at 2.6 to 3.5 mgd, without allowance for additional load that could be generated by refracturing operations. To meet a 500 mg/l effluent limit for a 3.5 mgd, 100,000 mg/l TDS waste stream by dilution only would require 700 mgd of fresh water. The solids load associated with this waste stream would be *1,100 to 1,500 dry tons <u>per day</u>*. For comparison, the NYCDEP wastewater treatment plants serving NYC treat approximately 1.2 billion gallons of sewage per day and produce about 400 tons per day of dry sludge solids.

Judging by the flow rates calculated to dilute this waste stream, it is evident that dilution is unlikely to provide a feasible solution, once the gas resource is developed to a significant degree. The viability of injection wells in this region for waste disposal is unproven. Lastly, the only established technology for treatment would produce large volumes of solids which will need to be transported and disposed of, and which will likely include elevated levels of radioactivity which would further limit solids disposal options.

The quantities cited above are for an assumed 6,000 well full build-out scenario, and necessarily rely on a number of estimates with respect to flowback and produced water rates. However, these estimates are for potential gas well development within the NYC West-of-Hudson watershed alone, and do not take into account gas industry waste streams that would be generated in any other areas in New York State or Pennsylvania. If allowance is made for refracturing, these waste estimates could be about 2.5 times higher.

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[47] Blauch, M.E. (Superior Well Services, Inc.); Myers, R.R., Moore, T. R.; Lipinski, B.A. Exco - North Coast Energy, Inc.; Houston, N.A. (Superior Well Services, Inc.). *Marcellus Shale Post-Frac Flowback Waters - Where is All the Salt Coming from and What are the Implications?* SPE Eastern Regional Meeting, 23-25 September 2009, Charleston, West Virginia, USA. Copyright 2009. Society of Petroleum Engineers Paper Number 125740-MS. Abstract referenced at http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-125740-MS&soc=SPE December 2009.

[48] NYSDEC. 2009. *Draft supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program (SGEIS)*. New York State Department of Environmental Conservation Division of Mineral Resources, Albany, NY.

Clearly, the development of natural gas resources will present a significant waste disposal challenge for which there is no clear or viable solution evident at this date. Failure to adequately account for regional wastewater disposal needs has resulted in at least one recent incident of surface water quality violations. In October 2008 excessive gas well brine disposal at publicly-owned treatment works (POTWs) in the Monongahela Basin contributed to high TDS in the river and its tributaries.[49] The elevated TDS concentrations caused taste and odor problems in drinking water, high levels of brominated disinfection by-product precursors at water treatment plants, and violations of particulate limits in power plant emissions. Waste disposal is a direct concern for NYCDEP, as the absence of economically viable disposal options will incentivize irresponsible and illegal waste handling and disposal practices.

[49] *Pennsylvania DEP Investigates Elevated TDS in Monongahela River*. Water and Wastes Digest. October 27, 2008

Section 5: Summary

This section summarizes the impacts of natural gas development using horizontal drilling/high-volume hydraulic fracturing on the NYC water supply watershed and infrastructure.

Rate and Density of Well Development in the NYC Watershed

Reasonably foreseeable natural gas well development scenarios for the NYC watershed based on experience in comparable formations suggest that under favorable economic and regulatory conditions annual well completion rates would increase from initial rates as low as 5 to 20 wells per year to an average of 100 to 300 wells per year, potentially peaking at 500 wells per year. Consistent with NYSDEC spacing unit requirements and development in other formations, it is estimated that on the order of 3,000 to 6,000 wells could ultimately be drilled and fractured in the NYC watershed. This does not include re-fracturing of the same wells, nor does it include drilling and fracturing of wells to tap natural gas in the Utica, Oriskany, or Trenton/Black River formations underlying the NYC watershed. Development of these formations would require additional well construction but not necessarily new ancillary infrastructure.

Meaningful assessment of risks and impacts must be guided by the scale of natural gas development. Any individual hydraulic fracturing operation poses a relatively small risk to the water supply. But at the rates and densities of development as currently practiced elsewhere in the Marcellus and comparable formations, the likelihood of negative impacts and the subsequent risk to the water supply is substantially higher. When the issue is considered from the standpoint of not one well but of hundreds or thousands of wells, the cumulative risks become significant. Prevention of polluting activities is certain to protect water quality and infrastructure from these cumulative risks. To illustrate minimum mitigation measures that would be required to reduce risks for any one individual impact, Appendix D sets forth certain mitigation strategies.

The following are considered foreseeable risks, and merit detailed consideration:

Land Disturbance, Site Activity, and Truck Traffic (Industrialization)

- High levels of site disturbance, truck traffic and intensive industrial activity, on a relatively constant basis, over a period of decades, and attendant impacts on overall watershed health.
- Trucking activity will be accompanied by provision of equipment and material supply systems (warehouses, garages, support services), gas gathering and pipeline systems, compressor stations, and waste disposal systems.
- Without some limits on the rate or density of development in the watershed, it is reasonable to expect that a significant and relatively rapid industrialization of the NYC watershed could occur.

Tunnel Integrity and Subsurface Migration

- Widespread hydraulic fracking will permanently and irreversibly compromise a significant geological formation that presently constitutes part of the subsurface system that isolates near-surface, fresh water flow regimes from non-potable, highly saline waters of deeper formations.
- The subsurface impact of repeated and extensive fracturing on intervening strata will increase the likelihood of the migration of hazardous chemicals and/or poor quality formation water and infiltration into overlying groundwater, watershed streams, reservoirs, and tunnels.

- The inadvertent extension of fractures beyond the target strata, and long-term changes in subsurface stresses will likely increase the number and capacity of migration pathways through the geologic strata underlying the watershed, and increase the likelihood of subsurface contamination of the water supply system.
- Infiltration of formation or fracking fluids could cause tunnel discharges to exceed NYSDEC discharge standards even at low infiltration rates.
- Transmittal of pressurized fluids from presently isolated deep formations could expose the external surfaces of the unreinforced concrete tunnel liners to excessive pressures and compromise liner integrity.

Water Withdrawals

- Despite representing a small portion of overall watershed yield, withdrawals for hydrofracturing could significantly impact commitments for water supply and habitat protection, particularly during periods of drought. The severity of impacts will depend on the amount and timing of withdrawals. Withdrawals while reservoirs are spilling would have little impact. Withdrawals during dry periods could increase the duration of drought watch, warning, or emergency conditions.
- Delaware Basin withdrawals downstream of the NYC West-of-Hudson reservoirs could impact system operations by requiring increased releases to meet in-stream flow requirements. Similarly, withdrawals from the Upper Esopus Creek could require increased releases from Schoharie Reservoir to meet minimum downstream flow requirements.
- Excessive water withdrawals may also impact aquatic habitat and biota.

Chemical Usage

- Introduction of hundreds of tons per day of fracturing chemicals into the watershed over a period of several decades will likely be accompanied by the gradual dispersion of low levels of toxic chemicals into the environment and potentially the water supply via multiple transport pathways.

Surface Spills

- A chronic and persistent occurrence of small scale surface spills and contamination incidents will inevitably accompany the thousands upon thousands of fluid transfer activities necessary for widespread hydrofracturing and gas well operation, and can be expected to reduce public and regulatory agency confidence in the quality and safety of the water supply.
- Occasional acute spills that could cause operational impacts, potential MCL violations and further undermine confidence in the ability to maintain current high water quality standards.

Wastewater Treatment and Disposal

- The flowback and produced waters resulting from hydrofracturing and gas well operations will produce an industrial-strength waste stream characterized by exceptionally high concentrations of a wide range of substances with the potential for adverse health and water quality effects which can be expected to exceed existing treatment and assimilative capacities within a few years.
- There is high level of uncertainty as to whether effective waste treatment processes and sufficient capacity will be available in the future. Sufficient dilution capacity is unlikely to be available. Residuals productions associated with the only presently available treatment

technology could produce a waste stream that amounts to three to four times the dry sludge total disposed of by NYC's fourteen wastewater treatment plants.

- Solids disposal options will be further limited by elevated levels of radioactivity.
- Waste management and transport will likely contribute to a long-term, low level increase in truck traffic and transport of hazardous chemicals.
- Siting of injection wells and or treatment facilities will add an additional category of industrial activity to the region.
- Widespread use of injection wells, if geologically feasible, would provide additional contaminant transport pathways and could possibly increase low-level seismic activity, increasing opportunity for subsurface contaminant transport.

Filtration Avoidance Determination

- Given the importance of watershed protection for unfiltered water supply systems, major changes in land use and/or increased levels of industrial activity in the watershed could jeopardize the Filtration Avoidance Determination granted to the Catskill and Delaware water systems and decrease public confidence in the high quality of the NYC water supply.
- In the event that filtration is ultimately required, NYC expects that the current $10 billion filtration plant design would not be adequate to remove the chemicals that could be introduced into the watershed. Advanced oxidation, granular activated carbon adsorption, and/or membrane filtration processes could be required. All of these advanced processes are significantly more expensive than the current design, and it is quite possible that the available treatment site would not even accommodate the additional treatment technology. Net impacts on overall treatment facility requirements processes would be expected to increase costs by at least 50 percent and possibly more than 100 percent relative to the current design.

Taken together, these potential impacts - some very likely, some less so, many simply unknown –suggest that large-scale horizontal drilling/high-volume hydraulic fracturing in the NYC watershed will substantially increase the overall risk to the NYC water supply compared to current conditions.

This assessment has focused on activities and impacts that would most directly affect NYC's water supply system. Other effects, which for the purposes of this effort have been considered to be secondary, would not necessarily be minor or insignificant. Induced growth, and the economic changes that it would bring, can adversely impact water quality. It often results in additional demand on roads and other local infrastructure, including schools, local water supply and municipal wastewater treatment systems, hospitals and emergency services. Adverse air quality impacts and impacts on flora, wildlife and soil chemistry can also be expected given the level of industrial activity that would accompany hydraulic fracturing and horizontal drilling operations, particularly if implemented at rates and densities employed elsewhere.

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COMMENTS ON THE SCOPE OF THE EPA'S PROPOSED STUDY OF HYDRAULIC FRACTURING
By Paul A. Rubin

Hydraulic fracturing of shale formations and related surface activities has the potential to permanently and irreparably harm ground and surface water resources in New York State. Extensive existing fracture and fault networks throughout the Appalachian Basin may provide upward pathways for contaminant and gas migration through geologic zones believed to be physically isolated, based on incomplete data. As a result, there are significant health and environmental risks associated with advancing horizontal gas drilling in Otsego County, New York and elsewhere in the Appalachian Basin.

Herein, HydroQuest provides a comparison between Otsego County ground and surface water resources and those in New York City's West of Hudson River watershed, demonstrating that they are virtually indistinguishable and require similar water quality protection. I offer this conclusion based on my training as a geologist, hydrogeologist, and hydrologist with more than twenty-eight years of professional environmental experience which includes work conducted for the New York State Attorney General's Office (Environmental Protection Bureau), Oak Ridge National Laboratory (Environmental Sciences Division), the New York City Department of Environmental Protection, and as an independent environmental consultant as President of HydroQuest. Within the broad field of hydrology, I have specialized expertise in both ground and surface water hydrology.

The notion has been recently advanced that some Appalachian basin watersheds (i.e., New York City West of Hudson River and Syracuse) are more vulnerable to contaminant excursions and therefore, should be afforded greater protection through a more stringent permitting process. The decision to exclude New York City and Syracuse from the "generic" review process must stem from the respectively larger populations supplied by these water resources. It appears to be strictly a political decision, without defensible scientific, geological or hydrologic basis.

The potential environmental threats to Otsego County ground and surface water resources from hydraulic fracturing-related contaminant excursions are not significantly different than those present in New York City's West of Hudson River or Syracuse watersheds. **The following set of six colored GIS map figures provide the scientific rational in support of considering Otsego County and New York City watershed areas equally.** These figures may also be viewed at: http://hydroquest.com/OtsegoConfidential/.

Figure 1: **The bedrock geology of the Otsego County and New York City West of Hudson River watershed areas is essentially the same.** As depicted in Figure 1, many of the upper bedrock units present in Otsego County are the same as those present in New York City's West of Hudson watersheds. Geologically, these units are comprised of a series of sedimentary shales, siltstones, sandstones, and some conglomerates layered from the Honesdale Formation downward through and below the Marcellus Formation. These rock units were deposited under the same hydrologic conditions through the widespread area now recognized by geologists as the Catskill Delta. Before the sediments of these rock units were lithified into bedrock, they were shed northwesterly from the ancestral Acadian Mountains.

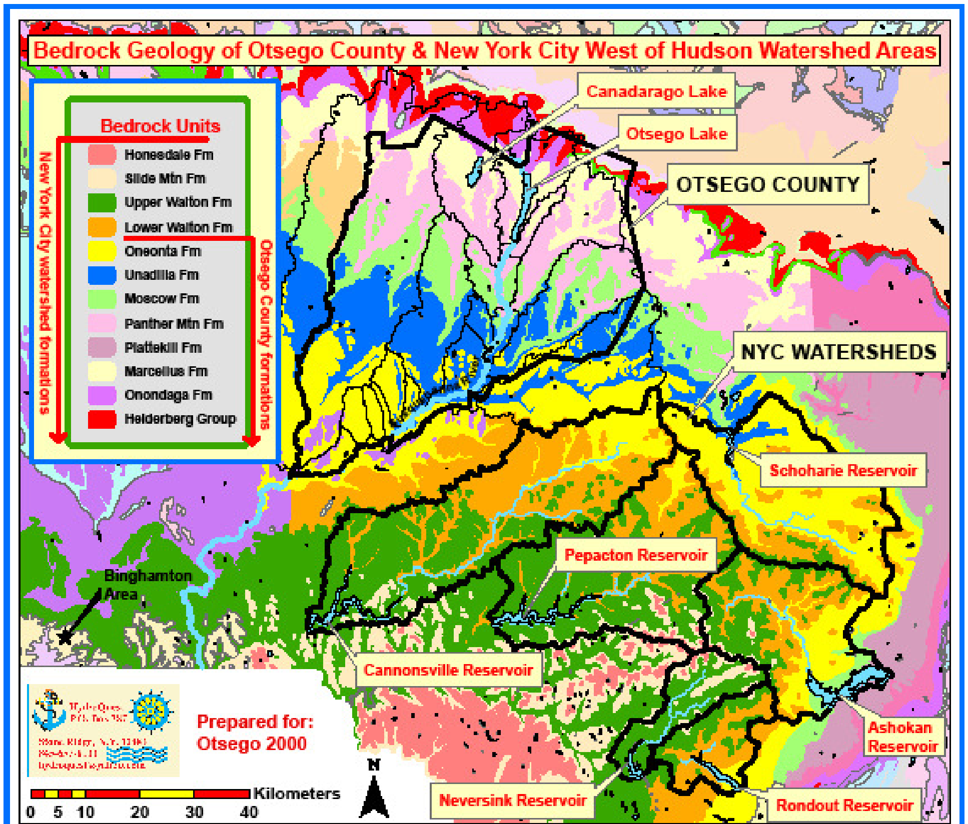

Figure 1: Bedrock geology of the Otsego County and New York City west of Hudson River watershed areas. The bedrock geology is essentially the same in both areas. However, some of the uppermost NYC watershed area formations have survived glaciation and erosion. [Geology synthesized from three NYS Museum databases.]

Figure 1.

As reflected in Figure 1, it is apparent that erosion has, in places, removed some of the uppermost bedrock units through glaciation and erosion. In places, both Otsego County and New York City watershed areas have the same bedrock units exposed at the ground surface (e.g., Oneonta Formation). Significantly, geologically and hydrologically, ground and surface water flow in both the Otsego County and New York City watershed areas behaves similarly – all potentially being vulnerable to gas field related contaminants from below and above. Indeed, because some of the Otsego County bedrock formations are stratigraphically closer to the Marcellus Shale than those in New York City watersheds, the risk of contamination is even greater there. Geologically, there is no reason why Otsego County watersheds should not be afforded the same degree of protection as NYC watershed.

Carbonates of the Onondaga Formation and Helderberg group outcrop in the northern portion of Otsego County. These carbonate formations, while stratigraphically lower than the Marcellus shale, overlie other shale beds that may be gas rich (e.g., the Utica shale of the Trenton Group). This is indicated by gas leases over these formations (see Figure 5). These carbonate formations are recognized among karst hydrologists as being karstic or cave/conduit bearing in nature. An important aspect of karst is its effect on water supply and contaminant transport. Water in solution conduits can travel up to several kilometers per day, and contaminants can move at the same rate. This poses serious problems when monitoring for water quality. Contaminants enter the ground easily through sinkholes and sinking streams, and filtering is virtually non-existent. Even small solution conduits can transmit groundwater and contaminants hundreds of times faster than the typical unenlarged fracture network. Hydrofracking related contaminants that may enter karstic solution conduits, from below or above, would quickly degrade groundwater and surface water quality. As a result of the DEC's failure to address this significant environmental concern, it must be studied by the EPA.

Figure 2: **The Draft SGEIS fails to reference all known fault and fracture information**. The DSGEIS relies on outdated and limited fault and fracture set locations throughout New York State. Figure 2 is the chart prepared by consultants for inclusion in the DGSEIS. Many more were known at the time of the issuance of the DSGEIS as reflected in Figures 3 and 4, discussed below. As a result of the DEC's failure to analyze more recent fault mapping, the risk of ground and surface water contamination through seismic activity stemming from natural causes or from lubrication and pressurization along dormant faults through fracturing has not been adequately addressed and must be studied by the EPA.

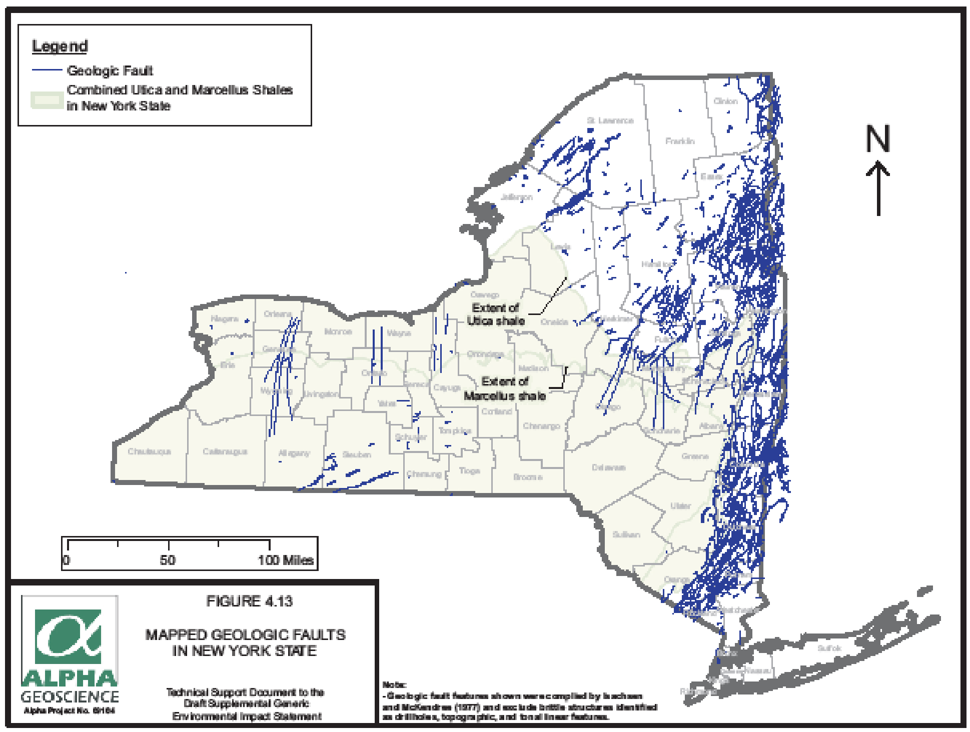

Figure 2: Draft SGEIS 9/30/2009, Page 4-26, Figure 4.13. Text from DSGEIS Page 6-154: "The possibility of fluids injected during hydraulic fracturing the Marcellus or Utica shales reaching a nearby fault and triggering a seismic event are remote for several reasons. The locations of major faults in New York have been mapped (Figure 4.13) and few major or seismically active faults exist within the fairways for the Marcellus and Utica shales." Compare this DSGEIS figure with Figures 3 and 4.

Figure 2.

Figures 3 and 4: **Numerous confirmed faults and lineaments known in Otsego County and New York State were not discussed in the DEGEIS. These and other faults may provide pathways for contaminated fracture fluids, deep-seated saline water, radioactivity, and gas migration to migrate to aquifers, reservoirs, lakes, rivers, streams, wells, and even homes.** Jacobi and Smith (2002) document the epicenters of three seismic events in eastern Otsego County. These seismic events indicate that earth movement occurs from great depth along faults upward to aquifers and potentially to exposure at the ground surface. The great lateral extent of these faults, and their visually observable connectivity with other faults, confirms that the process of hydraulic fracturing, which may interconnect naturally occurring faults and fractures, has a great and very real potential of causing contaminants to migrate to aquifers and surface water from localized zones across and beyond county and watershed boundaries.

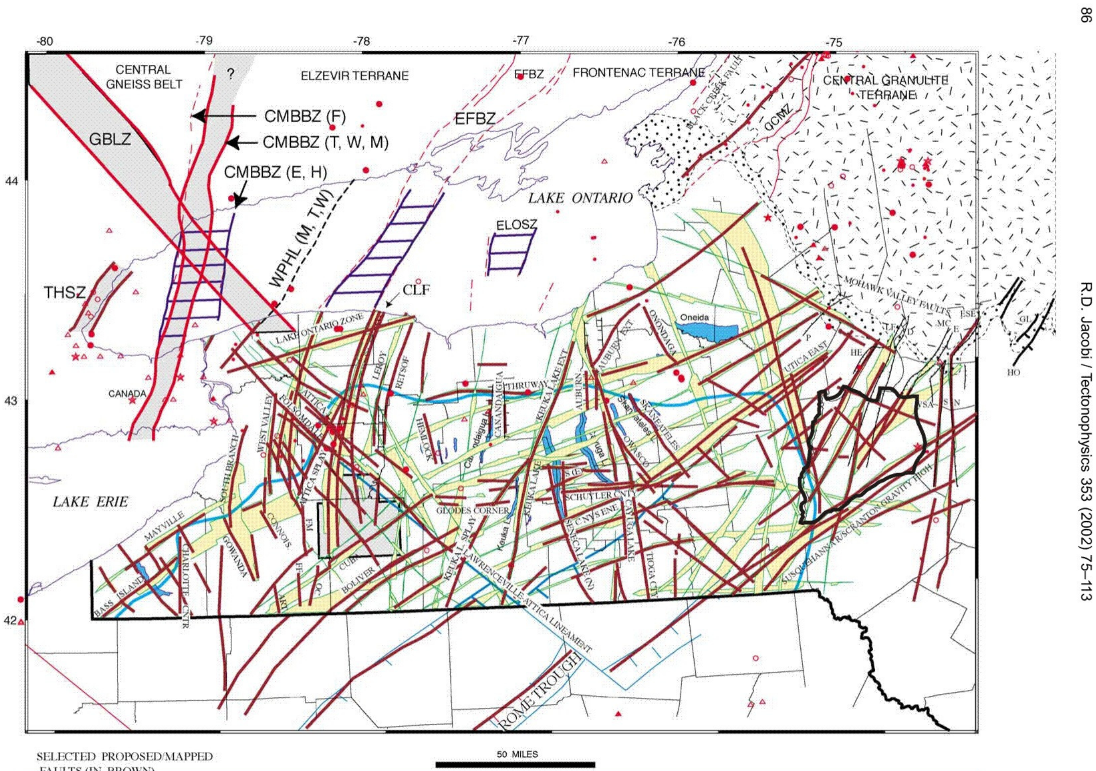

Figure 3: Numerous confirmed faults portrayed by Jacobi (2002, Fig. 5). Otsego County is outlined in black. In Otsego County, northwest-trending magnetic anomalies, E97 lineaments, and topographic map lineaments are all coincident with northwest-striking Fracture Intensification Domains (FIDs) and faulted monoclines (Jacobi and Smith, 2000). Jacobi documents the epicenters of three seismic events in easternmost Otsego County as being located on the NE-trending E97 lineament and gravity gradient that mark the Susquehanna River/Scranton Gravity High faults.

Figure 3.

Fracking contaminants, once mobilized vertically along fault planes and fractures, especially under pressurized conditions, can reach freshwater aquifers. Even if all fracking fluids were comprised of non-toxic chemicals, the risk of interconnecting deep saline-bearing formations (i.e., connate water) and/or radioactive fluids with freshwater aquifers is not warranted. Any commingling of deep-seated waters, with or without hazardous fracking fluids is unacceptable. Documented gas excursions near existing gas fields demonstrate that vertical pathways are open. If gas can migrate to the surface it is highly likely that hydrocarbon and contaminant-rich Light Non-Aqueous Phase Liquids (LNAPLs) will also reach aquifers and surface water resources. These contaminants may then also migrate to down gradient wells, principal aquifers, and waterways.

Importantly, these Figures provide a very <u>conservative</u> approximation of the actual number of fractures and faults present throughout Otsego County and New York State. In establishing a relationship between seismicity and faults, Jacobi (2002) examined Fracture Intensification Domains (FIDs), E97 lineaments (Fig. 3), topographic lineaments, gradients in gravity and magnetic data, seismic reflections profiles, and well logs. Jacobi states:

> *"In interbedded shales and thin sandstones in NYS, fractures within the FID that parallel the FID characteristically have a fracture frequency greater than 2/m, and commonly the frequency is an order of magnitude greater than in the region surrounding the FID."*

Jacobi (2002) portrays an earthquake of magnitude 4.5-4.9 as having occurred in Otsego County (Fig. 3). Jacobi makes a case for repeated reactivation along faults in the Appalachian Basin. Furthermore, and importantly, Jacobi addresses his and Fountain's identification of FIDs based on soil gas anomalies over open fractures:

"Certain sets of FIDs are marked by soil gas anomalies commonly less than 50 m wide (Jacobi and Fountain, 1993, 1996; Fountain and Jacobi, 2000). In NYS, the background methane gas content in soil is on the order of 4 ppm, but over open fractures in NYS, the soil gas content increases to 40-1000+ ppm."

The fact that Jacobi and Fountain have successfully identified and measured methane seepage from fractures that most likely extend downward to gas producing shales shows that open vertical pathways already exist, confirming the risk of increasing gas excursions as a result of hydraulic fracturing. Clearly, Jacobi and Fountain's work suggests that expanding fractures that now naturally release methane from gas-rich shales will provide even greater gas and contaminant migration pathways when interconnected and widened via hydraulic fracturing. Failure to recognize this and to allow expansive interconnection of existing faults and fractures is a recipe for environmental disaster throughout Otsego County and the Appalachian basin.

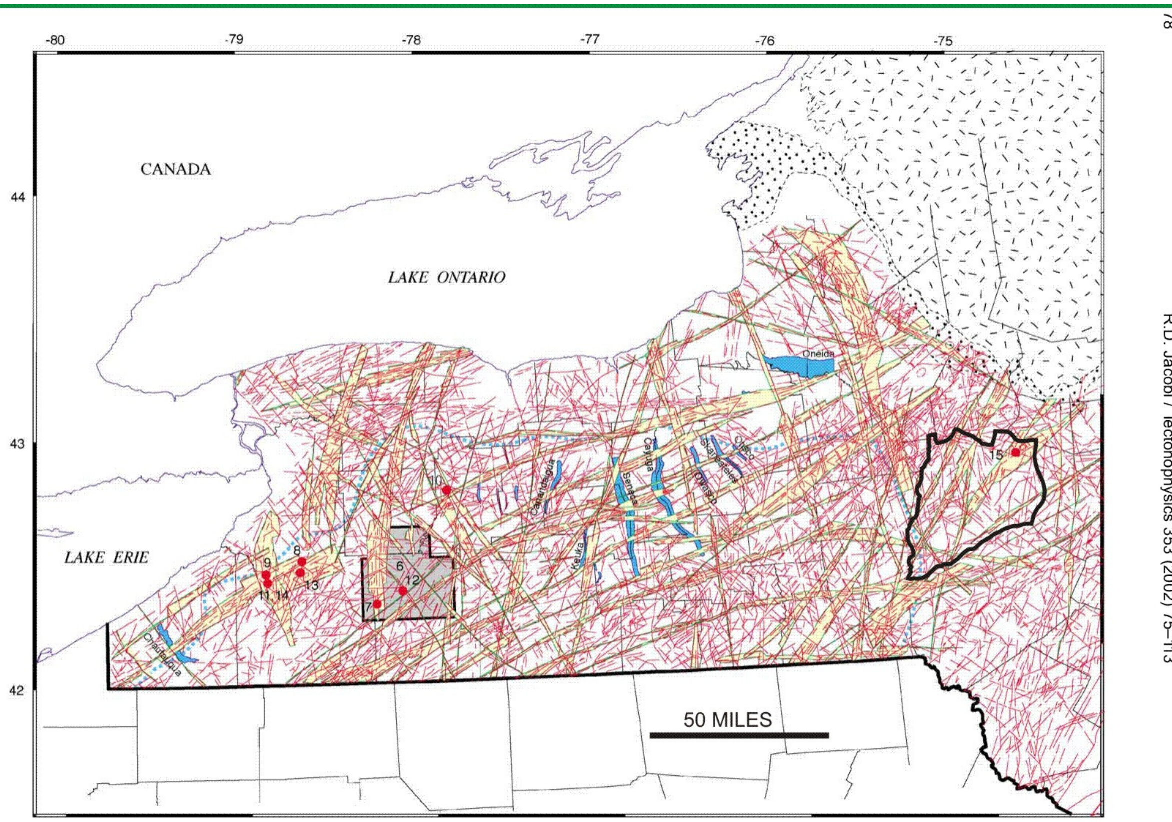

Figure 4: 1997 Landsat lineaments (red lines) as portrayed in Robert D. Jacobi's Figure 2 (2002). Lineaments and faults are widespread throughout the Appalachian Basin in New York State. These fractures and basement faults were examined via analysis of Landsat images, DEM data, aerial photography, side-looking aperature radar, hyperspectral imaging, soil gas anomalies, and field groundtruthing. Jacobi demonstrates that many of these features are seismically active. This contrasts with findings of few fractures and little seismicity presented in the DSGEIS. These and other closely spaced fractures may provide pathways for upward methane and radioactive gas migration after hydrofracturing. Similarly, high angle faults may provide upward pathways for pressurized, contaminant-laden, hydrofracturing fluids to reach freshwater aquifers. Otsego County is outlined in black.

Figure 4.

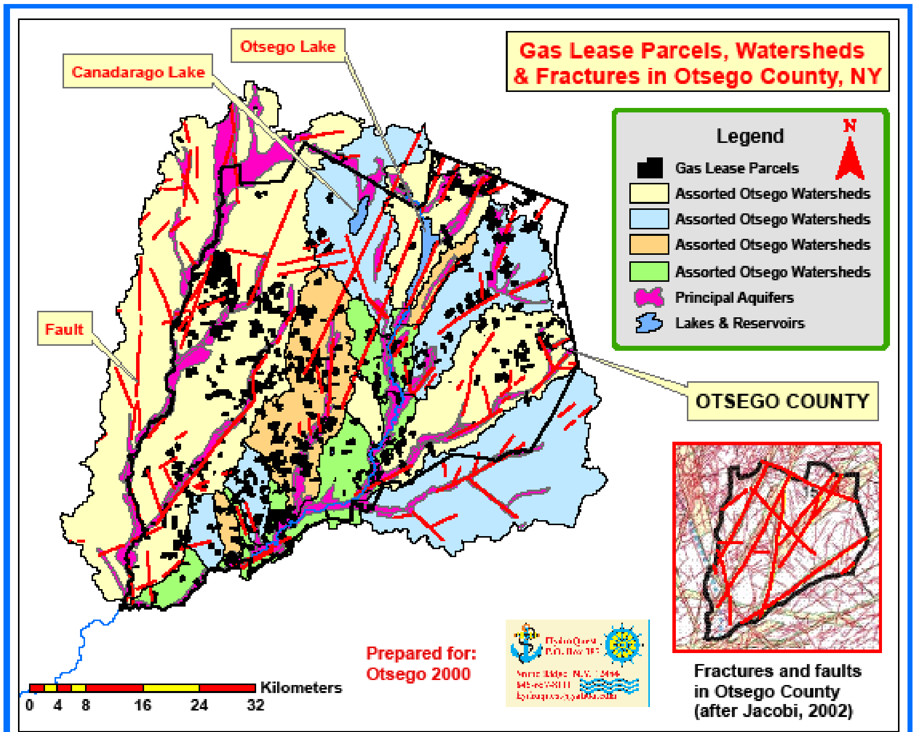

Figure 5: Otsego County is experiencing a significant increase in gas leases throughout the county. Some 953 leases of eleven companies are depicted here, current as of Sept. 2009 (data courtesy of OCCA). This number may now have doubled. Leased lands are in all watersheds, both over and upgradient of principal aquifers. Depictions of fractures and faults from NYS Museum and Jacobi (2002) conservatively show potentially extensive vertical contaminant migration pathways that are likely to degrade bedrock aquifers of individual homeowners, principal aquifers located in valley bottoms, and down gradient surface water sources including Otsego Lake and the Susquehanna River. Upward gas migration is likely to cause both an explosive and health risk.

Figure 5.

Figure 5: **Gas leases in Otsego County are increasing throughout all watersheds, thereby potentially jeopardizing the water quality of principal aquifers, wells, reservoirs, and surface waterways.** Otsego County is experiencing a significant increase in gas leases throughout the county. Some 953 leases of eleven companies are depicted here, current as September 2009. This number may now have doubled. Leased lands are found in all watersheds, both over and up gradient of principal aquifers. Depictions of fractures and faults from the New York State Museum and Jacobi (2002) conservatively show extensive vertical contaminant migration pathways that are likely to degrade bedrock aquifers of individual homeowners, principal aquifers located in valley bottoms, and down gradient ground and surface water sources including Otsego Lake and the Susquehanna River.

A 2008 OCCA map of gas leases shows many overlying principal aquifers and others within a 1-mile buffer of major surface water supplies (i.e., Otsego Lake, Wilber Lake). The risk to aquifers, rivers, streams, lakes, reservoirs, and the Susquehanna River should not be tolerated. Because the density, location, aperture width, and length of all fractures (often present and not visible beneath a soil mantle) are not known, <u>it would not be prudent to risk placement of gas wells and their respective chemical storage or impoundment sites anywhere within watersheds that contain reservoirs used for public water supplies</u> (e.g., Lake Otsego, Wilbur Lake, New York City reservoirs). The contaminant risk, risk to public water quality perception, and potential remedial costs are not warranted by the potential economic and energy gain.

This conclusion is supported by a growing catalog of hydro-fracking related accidents in other gas-field plays (see e.g., Hazen and Sawyer, 2009). Accidental spills of fracking fluids and flow-back water has the potential of contaminating ground and surface water. Similarly, lateral and upward migration of hydro-fracturing chemicals pose a real risk to County aquifers, especially to moderate and high yield unconfined aquifers situated in stream valleys that receive their base flow recharge from up-gradient groundwater aquifers. Approximately 60% of Otsego County listed community and non-community water supplies rely on groundwater.

Aquifer contamination may retard residential growth in the county and may degrade principal and primary aquifers. Similarly, many high yielding unconfined aquifers may flow into and recharge the Clinton Street - Ballpark Valley Aquifer System that is a sole source of drinking water for approx. 127,555 residents of Vestal, Johnson City, Endicott, Nichols, Waverly, and Owego. Beyond this, the City of Binghamton and other downstream communities' primary water source is the Susquehanna River - a water supply system analogous to that of NYC's, except without impounded reservoirs.

Figure 6: **Watersheds throughout Otsego County and the New York City west of Hudson River basins are physically located atop similar bedrock types which recharge geologically similar underlying aquifers.** Ground and surface water flow throughout most of Otsego County provides the drinking water source for private and community wells, high-yielding principal aquifers, lakes, and reservoirs. In and beyond Otsego County, this water coalesces to form the Susquehanna River and recharge a sole source aquifer – the source water for the City of Binghamton and other down stream communities. Geologically and hydrologically, with the exception of more above ground impoundments, water resources of Otsego County are equally vulnerable to surface and subsurface chemical excursions documented as being associated with hydro-fractured gas wells and flow-back water impoundments elsewhere.

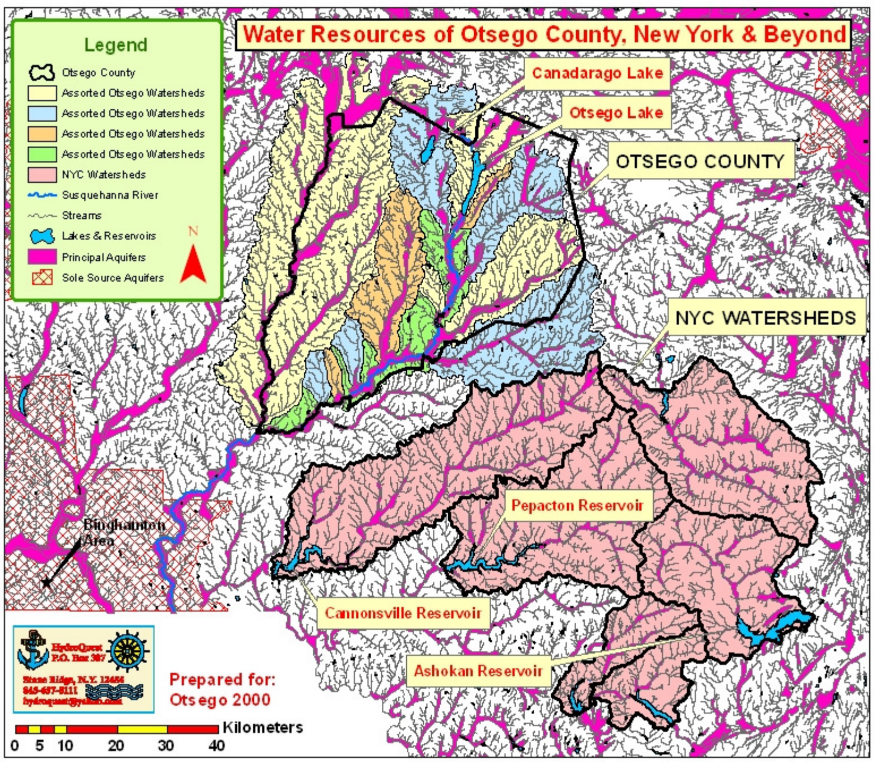

Figure 6: Surface water and groundwater flow throughout most of Otsego County provide the headwater source for private and community wells, high-yielding principal aquifers, lakes, and reservoirs. In and beyond Otsego County, this water coalesces to form the Susquehanna River and recharge a sole source aquifer - the source water for the City of Binghamton and other down stream communities. Geologically and hydrologically, with the exception of more above ground impoundments, water resources of Otsego County are equally as vulnerable to surface and subsurface chemical excursions documented as being associated with hydrofractured gas wells and flowback water impoundments elsewhere. All Otsego County watersheds highlighted are sub-basins of the larger Susquehanna River watershed.

Figure 6.

Conclusion

The characterization of vertical fractures, faults, and methane soil gas in Otsego County and elsewhere in the Appalachian Basin in the DSGEIS is inadequate and, as such, does not sufficiently address pre-existing contaminant (i.e., gas and fluid) pathways that extend from the Marcellus shale to aquifers and the ground surface. Drilling, hydro-fracturing and enhancement of gas-bearing fractures may significantly increase gas excursions to formerly isolated geologic formations. Review of reports and news articles indicate that significant environmental contamination has occurred in geologically similar settings, including explosive hazards and groundwater and surface water contamination.

Documentation by Jacobi of Fracture Intensification Domains based on methane soil gas anomalies over open fractures reveals evidence that naturally occurring fractures and faults provide upward gaseous migration pathways, even in the absence of deep hydro-fracturing in the Marcellus shale. If fracture and fault networks are integrated and enlarged via hydro-fracturing processes, it is likely that methane and radioactive gas excursions will increase.

The reality of oil and gas development in New York State and elsewhere is that for a variety of reasons hydrocarbons have contaminated ground and surface waters. Reasons for this include poor containment of fracturing fluids, spills of flow-back water, intentional illegal disposal, mixing of different formation waters (e.g., brine and fresh water), inadequately grouted casing, spills, and various forms of operator error. Gas production in Otsego County and elsewhere in the Appalachian Basin would almost certainly result in contaminant excursions, even under the best planned conditions. The presence of confirmed fractures and faults that extend from gas-rich geologic beds to the ground surface, some of which extend laterally for miles and are closely linked with others formed under similar structural conditions, pose potential contaminant pathways to surface waterways, reservoirs, and freshwater aquifers.

Because the density, location, aperture width, and length of all fractures (often present and not visible beneath a soil mantle) are not known, it would not be prudent to risk placement of numerous gas wells within watersheds that contain lakes and reservoirs used for public water supplies (e.g., Lake Otsego, Wilbur Lake, New York City reservoirs). From a water quality standpoint three facts stand out: 1) there is a point at which the actual total number of toxic contaminants introduced into a groundwater flow system no longer matters because the water is unlikely to ever be potable again no matter how much money is spent attempting to remediate it, 2) eventually, even deep groundwater flow systems discharge to surface water, albeit it may take many years to occur (i.e., analogous to a slowly ticking time bomb), and 3) it makes little sense to jeopardize the quality of surface and groundwater by intentionally introducing vast quantities of toxic contaminants into the environment, especially where gas-conducting fractures and faults are known to extend from gas-bearing formations to the ground surface.

It is important to recognize that once our natural resources have been compromised as a result of an operator error, a major contaminant excursion, or an unforeseen breaching of geologic beds, that it is often impossible to remediate and restore them to their pre-existing conditions. Failed confining beds and contaminated natural resources often represent an irrevocable commitment of our lands. Our decision to risk New York State resources and properties must weigh all the health and environmental risks against exploitation of short-lived gas reserves and financial gain.

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