Environmental Consequences of Proposed Unconventional Gas Well Drilling in the Delaware River Basin

Wayne County, Pennsylvania

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Wayne Land and Mineral Group, LLC (WLMG) seeks to construct and operate wells to extract natural gas within the Delaware River Basin in northwestern Wayne County, Pennsylvania. This is a speculative venture aiming, if successful in locating economic quantities similar to those found farther west, to extend the current production of natural gas about 9 miles eastward from existing "unconventional" (that is, deep, long horizontal bore, hydraulically fractured) wells in the Susquehanna River Basin of eastern Susquehanna County. To this end WLMG is challenging in federal court the authority of the Delaware River Basin Commission (DRBC), a federal-interstate entity broadly charged with protecting water resources for more than 15 million people, to exercise project review authority over natural gas drilling and production activities within the 13,539 square miles of outstanding watershed lands that it oversees. Since 2010 there has been an effective moratorium on unconventional gas production in the Delaware River Basin (**Figure 1**), given the current absence of DRBC regulations seeking to protect Basin resources and residents from adverse effects if unconventional shale gas were to be developed here. There is also a moratorium on such wells in effect throughout New York State, both within and outside the Delaware River Basin. Mineral rights reportedly have been leased by gas operators beneath about 200,000 acres of land in the upper Delaware River Basin.

The Marcellus Shale, a geological layer in the Appalachian Mountains, formed in the bed of ancient seas of Devonian age about 400 million years ago. Natural gas has long been known to exist, tightly bound within the layer of Marcellus Shale found more than 1 mile below the surface in Wayne County, but recent technological advances have rendered it relatively more accessible and profitable for extraction. Unconventional natural gas production from the Marcellus Shale has expanded rapidly during the 21st century in Pennsylvania, spreading from west to east outside the Delaware River Basin. More than two thirds of the nearly 16,000 wells drilled in Marcellus Shale 2008-2018 are in Pennsylvania (Jacquet et al. 2018).

Its initial vertical test well is proposed by WLMG to be drilled in an undeveloped, interior section of the Marcellus Shale geological formation that the plaintiff hopes will prove to be economically productive. Hundreds of productive Marcellus Shale gas wells have been drilled in Susquehanna County, but virtually none to date in western Wayne County or the adjacent lands of eastern Susquehanna County (**Figure 2**). Below the Marcellus, an older (Ordovician) and deeper formation known as the Utica Shale also contains natural gas and oil resources. It, too, has begun to be developed farther west in Pennsylvania and Ohio. The Utica Shale is more extensive than the Marcellus Shale in Wayne County and also prospectively could be developed there in the future. WLMG has indicated that it may sample the Utica Shale as well as the Marcellus Shale in its initial test well. A lateral from the vertical test well then would be extended horizontally to enable gas production, and additional wells would be installed on the well pad. Gas production would continue for decades if the reserves are sufficient. Noise, light, smells, air pollution, and traffic peak during shale gas well development, but continue for the life of well production. Unless abandoned wells are plugged successfully, leakage of gases and polluted waters from them can continue indefinitely.

Minimal environmental inventory, engineering design, and economic planning have been performed by WLMG, which controls only 182 acres of land and minerals in Wayne County. Thus it is difficult to address many specific details when addressing the foreseeable environmental consequences, if WLMG were allowed to proceed with its project. Economic value can be extracted from the proposed WLMG well pad only if a major industrial transformation is accomplished in Wayne County similar to that which has occurred recently in Bradford and Susquehanna Counties, not merely by installation of a single test well on WLMG's land. The infrastructure to support well development and to transport natural gas to market currently does not exist locally.

This report addresses reasonably foreseeable environmental consequences of proposed drilling, fracking, and transporting natural gas, were unconventional gas production to be allowed in the Delaware River Basin. Citations are provided to the ever-growing literature documenting the consequences of this industry, especially in Pennsylvania. All opinions contained in this report are expressed with a reasonable degree of professional certainty.

The Delaware River Basin is known for the quality of its surface waters and groundwaters, which supply millions of users in several States. The Marcellus Shale formation underlies much of that northern section of the Basin which has been designated as Special Protection waters (**Figure 1**). The production of shale gas using unconventional wells is a water-intensive process. In its major nationwide review of unconventional gas and oil production USEPA (2016) found scientific evidence that hydraulic fracturing activities can adversely impact drinking water resources. That report identified the conditions under which frequent and/or severe impacts from hydraulic fracturing activities can be expected:

- Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources;
- Spills during the handling of hydraulic fracturing fluids and chemicals, fuel, and produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;
- Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources;
- Injection of hydraulic fracturing fluids directly into groundwater resources;
- Spills and discharge of inadequately treated hydraulic fracturing wastewater to surface water; and
- Disposal or storage of hydraulic fracturing wastewater in unlined pits resulting in contamination of groundwater resources (Veil 2015).

The volumes of water needed for unconventional gas production are large compared to existing human demand in the Wayne County segment of the Upper Delaware River Basin. By 2018 the average Marcellus well required roughly 14 million gallons of water (Hughes 2019), about 80% of which remains long- term underground in the well and does not return to the surface water cycle. This withdrawal can aggregate to 500 to 1,200% of local existing water demands under full gas exploitation in the vicinity of the proposed WLMG project (Habicht et al. 2015). If taken from small streams during periods of low flow, the water withdrawn for fracking can pose a major loss to the aquatic ecosystem at the withdrawal site. WLMG representatives have suggested using pond or onsite well water for potable purposes during natural gas development. Drilling water and frackwater are expected to be trucked in, but plans remain uncertain.

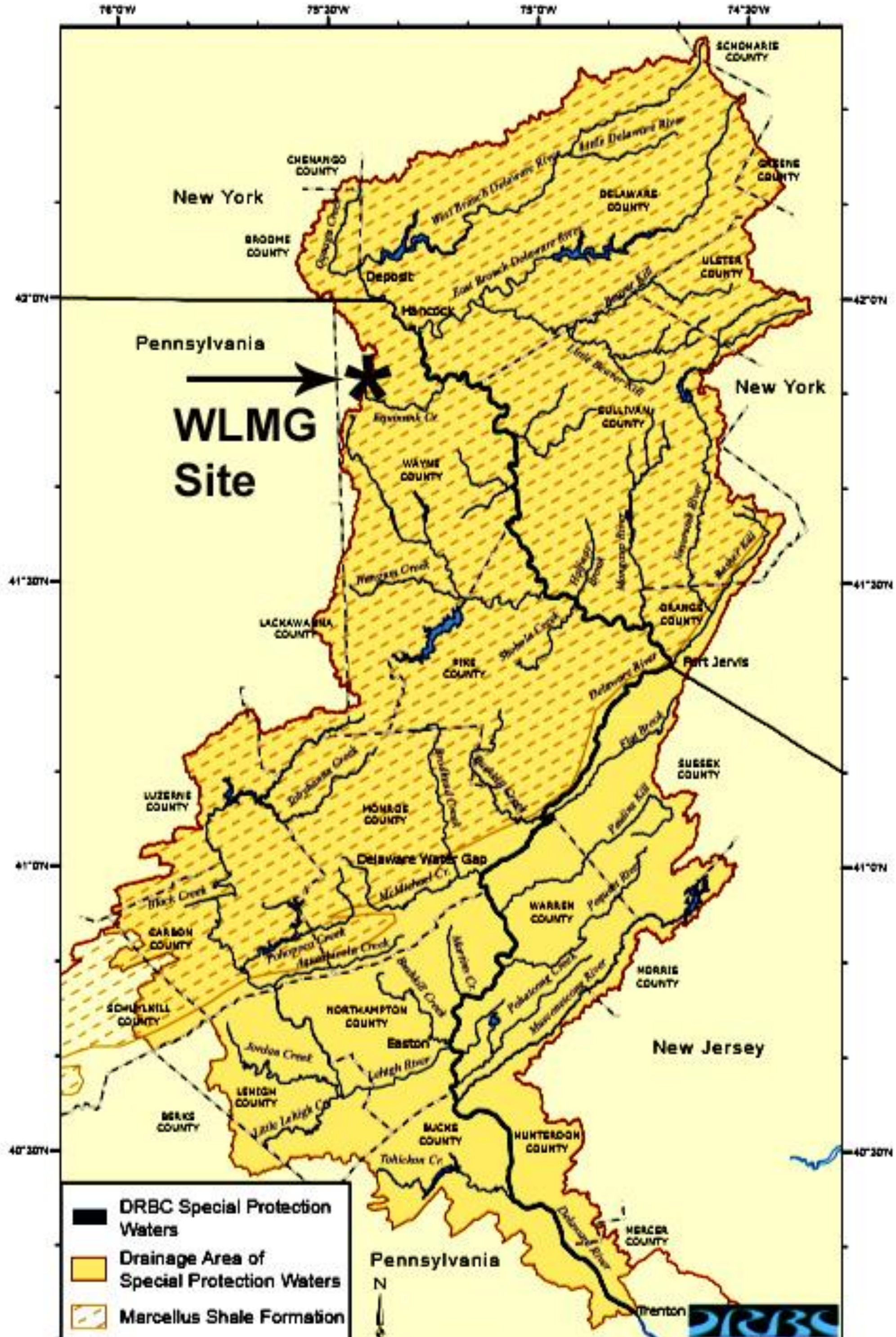


Figure 1. The Upper Delaware River Basin, Special Protection Watersheds, and extent of Marcellus Shale Formation. Proposed WLMG site is shown by the asterisk. Basemap is from the Delaware River Basin Commission.

Significant quantities of wastewater are generated by unconventional wells, despite the fact that most frackwater remains underground. The major constituents of water returned to the surface from unconventional natural gas wells raising environmental concerns are:

- salt content (measured as salinity, conductivity, or total dissolved solids [TDS]),
- oil and grease (a composite collection of hydrocarbons),
- inorganic and organic toxic compounds introduced as chemical additives to frackwater or that leached into the produced water from sources in the geological formation, and
- naturally occurring radioactive materials (NORM) that leach from the geological formation.

"Produced" waters from unconventional Marcellus Shale wells are much more saline than seawater, and their salt content increases over time during the life of a well (**Table 1**). During well development chemicals are added to the water and sand being forced into the well bore in order to combat scaling and maintain production efficiency, to inhibit corrosion, to coagulate fluids or break emulsions, and to dissolve mixtures. These chemicals affect the toxicity of produced waters, which can affect humans as well as fish and other aquatic biota (NYSDEC 2009). Chemicals of concern include benzene and its derivatives, methanol, xylene, naphthalene, kerosene, formaldehyde, ethylene glycol, butanol, and various acids. Concentrations of "wet" gases (hydrocarbons other than methane) and of crude oil are significantly lower in the Marcellus Shale gas wells of northeastern Pennsylvania than in the unconventional Marcellus wells of southwestern Pennsylvania.

Table 1. Salt concentrations increase over time in the produced water of Pennsylvania wells (Veil 2015).

Total Dissolved Solids Data (mg/L) over Time for Flowback Water from Selected Marcellus Shale Wells

Day 0	Day 1	Day 5	Day 14	Day 90
990	15,400	54,800	105,000	216,000
27,800	22,400	87,800	112,000	194,000
719	24,700	61,900	110,000	267,000
1,410	9,020	40,700	no data	155,000
7,080	19,200	150,000	206,000	345,000

Source of data: Hayes (2009)

Frac fluid water that does not initially return to the surface remains in contact with new rock surfaces created underground through the fracturing process and is able to dissolve additional constituents from the interstitial pores containing salts from ancient oceans (Balashov et al. 2015). The longer the water remains in contact with the fractures and pore spaces, the higher the dissolved constituent concentrations are likely to be, up to some practical saturation or equilibrium point. For the most concentrated example in **Table 1** (345,000 parts per million) more than one-third of the water sample consisted of TDS. This concentration approaches the limits of solubility.

Other constituents of flowback (the produced water discharged within 30 days of fracking in Pennsylvania) and waters subsequently discharged with the natural gas also show a trend of increasing concentration over time. This makes treatment of the later produced water more challenging than treatment of the early flowback water, although the early flowback consists of higher volumes. Operators seek to reuse produced water to the extent practicable, treating it to the extent necessary, because this is the least cost option for disposal of well fluids. Very little produced water from Marcellus Shale is treated sufficiently to allow its discharge to surface waters in Pennsylvania. There are few opportunities for underground injection of wellfield sludges in Pennsylvania or for depositing them in landfills. Most underground injection of Pennsylvania wellfield fluids that cannot be reused has occurred in Ohio, distant from Wayne County, and one of the consequences there has been increased earthquakes.

Methane is a much more potent greenhouse gas than carbon dioxide, and it is released to the atmosphere intentionally or inadvertently at every stage of gas production and distribution. Various chemicals become airborne as a result of unconventional gas development. They not only can travel through the air to damage human health but also are conveyed by rain onto ecosystems and into surface and ground waters.

Unconventional oil and gas production generated 90% of the Commonwealth's natural gas and 57% of its oil (crude plus condensate) in 2012 (Veil 2015). Over the period 2007-2012 Pennsylvania oil production increased 280%; gas production, 1300%; and produced water, 874%. Unconventional wells use much more water than conventional wells. On average, in 2012 each conventional Pennsylvania well generated 2.5 Mmcf of gas, 28 bbl of oil and condensate, and 80 bbl of water per year. Each Marcellus Shale well generated 331 Mmcf of gas, 300 bbl of oil and condensate, and 4,394 bbl of water (64% of that water was produced water). Each average Marcellus Shale well produced 11 times more oil, 132 times more gas, and 55 times more wastewater than each conventional well in 2012. Shale gas well return-water volumes are not required to be measured and reported in Pennsylvania.

The environmental consequences of drilling unconventional gas wells within the Delaware River Basin in Wayne County are discussed below, first at the local level in the vicinity of the proposed wellheads on the WLMG pad and then more generally for the upper Basin in Pennsylvania. Both segments of this discussion necessarily are constrained by (1) the absence of thorough environmental resource inventory for the lands that would be directly affected by WLMG well construction, operation, and support infrastructure including gathering pipelines, (2) an absence of detailed description concerning the vaguely proposed WLMG well construction, number of wells, operations, supporting pipelines, water supply, waste disposal, infrastructure including road improvements, and site decommissioning practices, and 3) a still fragmentary but growing literature analyzing the impacts of shale gas production. What is certain is that

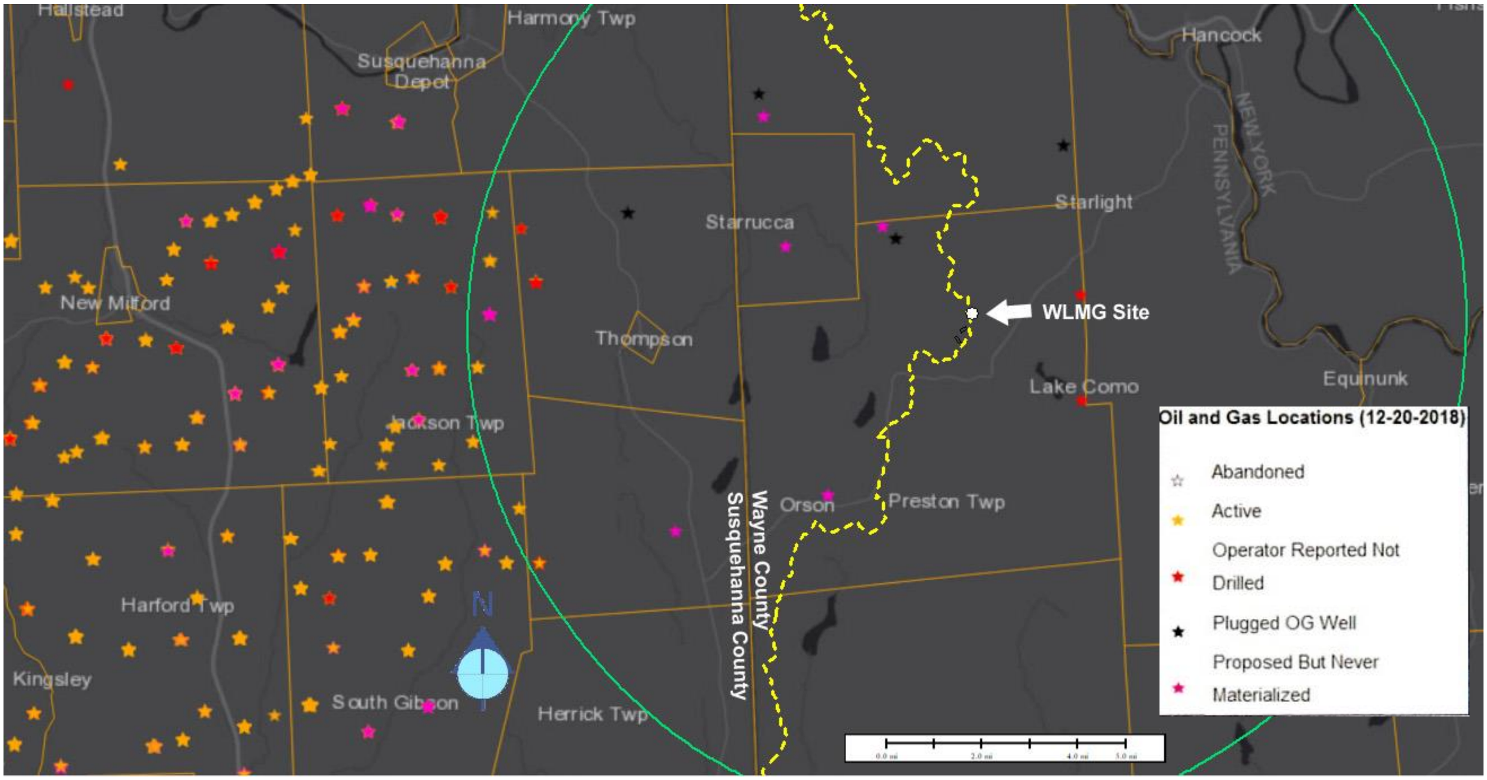


Figure 2. Existing oil and gas wells in eastern Susquehanna and northern Wayne Counties, Pennsylvania. Municipal boundaries are indicated. Green 10-mile radius circle is centered on proposed WLMG site. Yellow dashed line is boundary between Susquehanna (left, west) and Delaware (right, east) River Basins. Basemap from FracTracker.org.

gas production would convert the affected lands from rural forestry and farming uses to heavy industrial uses for many years. The proposed WLMG wells would be drilled about 9 miles east of existing oil and gas wells in Susquehanna County. The property is about 9 miles south and about 6 miles west of the Pennsylvania-New York boundary (**Figure 2**).

The geographical extent of mineral rights that WLMG controls apparently is 182 acres beneath a property of irregular shape with maximum dimensions of about 4,250 feet northeast-southwest and 2,250 feet northwest-southeast. WLMG has no detailed information on local geology and has made no estimate of the quantity or value of its natural gas reserves. Its representatives hope to gain access to additional property if their vertical test well encounters a promise of sufficient gas, prior to initiating horizontal drilling for production, given the uneconomically short lateral(s) that they could advance solely within their own land from their initial test bore or subsequent wellheads. Restricting short lateral bores within the limits of the 182-acre WLMG property clearly would not be economic under current market conditions for gas production from Marcellus Shale (**Figure 3**). No plan for the length or orientation of any borings from the proposed pad has been presented. Apparently as many as six wells might be installed on the proposed 5.7-acre pad, if access in future were gained to additional productive

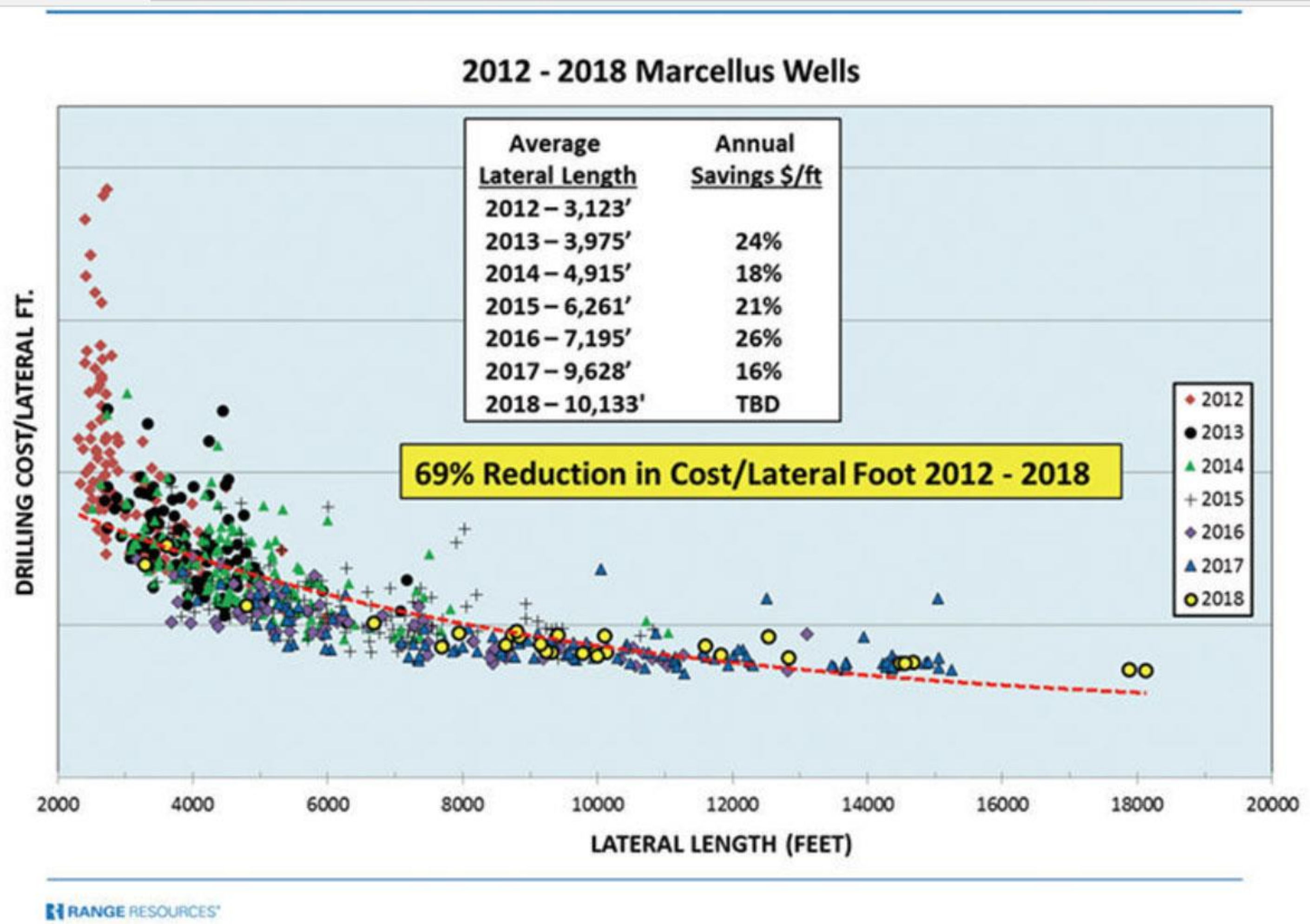


Figure 3. Cost reductions associated with increasing length of laterals at unconventional gas wells (Anonymous 2018). The economic trend toward wells with longer horizontal bores is clear.

shale beyond the current WLMG land. Some large well pads in Pennsylvania now support more than twenty individual wells, inasmuch as clustered wellheads and long laterals are efficient and entail less surface disturbance.

Current technology allows extension of laterals in Pennsylvania Marcellus wells 3.5 miles or more from the wellhead by well-capitalized operators (Fitzsimmons 2017, Carpenter 2019). Thus wells drilled on the WLMG site theoretically could extract gas from more than 38 square miles of surrounding lands, about 63% in the Delaware and 37% in the Susquehanna River Basins, if the applicant could acquire the mineral rights, constructed additional pads, and faced only technological constraints. Such well laterals potentially could extend into several municipalities in northern Wayne County (**Figure 4**). The initial proposal is for only one relatively short lateral extending 4 to 5 thousand feet from the wellhead of the initial vertical test bore. The orientation of lateral bores in Pennsylvania typically is adjusted to maximize the potential for gas capture, given the dip and strike of the local shale. These have not been ascertained at the WLMG site. Industry practice typically has located gas well pads 1 to 2 miles apart, aligned with natural fracture patterns.

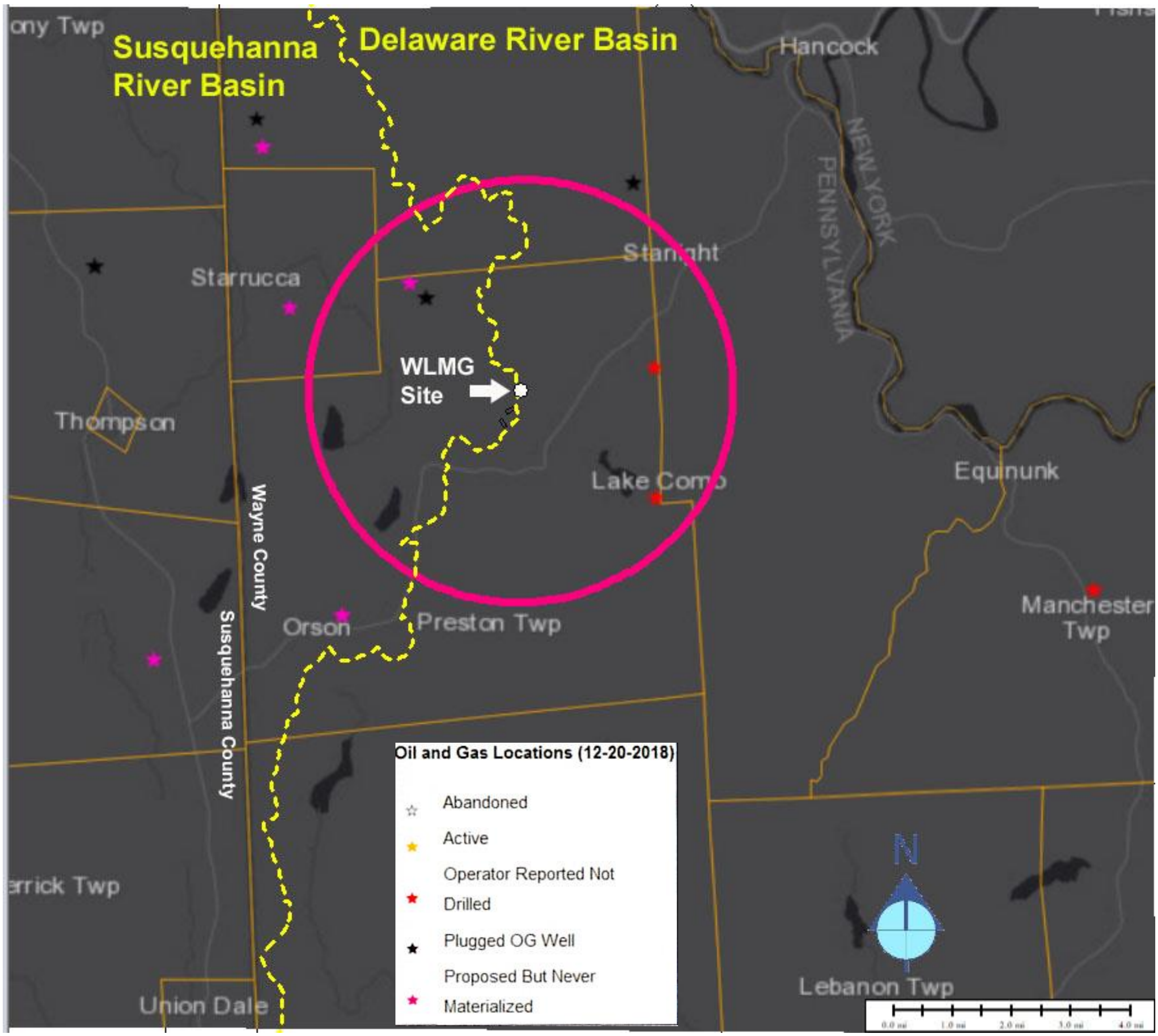


Figure 4. Theoretical gas withdrawal area surrounding proposed WLMG well pad. Pink circle is 3.5-mile radius (enclosing nearly 25,000 acres) to which practicable well laterals now can extend. Dashed yellow line separates Susquehanna (left, west) from Delaware (right, east) River Basin.

The general size of an unconventional gas "production unit" in Pennsylvania currently is about 640 acres. Several production units generally are needed for economic wellfield development, and gas production from about 5,000 acres reportedly is needed to warrant construction of a gathering pipeline. Natural gas can be compressed onsite and trucked to market, but the added cost at present usually is considered to render trucking an uneconomic alternative to gathering pipelines.

Localized Impacts

WLMG has proposed a rectangular, 5.7-acre well pad in the northeastern section of its property (black outlined rectangle, **Figure 5**). Pad dimensions have been identified as approximately 330 by 765 feet. This pad may or may not accommodate all of the wells that could be developed on the WLMG property. Additional land will be needed for access roadways (WLMG proposes the orange outline in **Figure 5**), for a gathering pipeline, and possibly for other ancillary facilities. Reportedly any pad would be rendered unlikely to leak spilled materials by installing a liner and a surrounding berm to confine precipitation and other liquids within it.

The subject property is no longer in use as a dairy farm, although one barn remains onsite. A mineral lease on the property by the Hess Corporation reportedly has expired. The WLMG land currently is used by a hunting club, and there is a hunting cabin onsite. WLMG reportedly sold some timber from forests on the property in 2016, shortly after acquiring ownership during a period of downturn in the natural gas industry. There are about five hayfields onsite (**Figure 6**), which WLMG maintains by mowing. There is one old quarry about 0.5 mile northeast underway nearby, so WLMG representatives think they could quarry rock onsite. There has been no recent survey of the property. The precise locations of its aquatic resources and any aquifer recharge areas have not been identified. One onstream pond and several patches of wetlands are known to exist onsite. Headwaters drain in several directions from the property, generally westward toward the Susquehanna River or eastward toward the Delaware River from the drainage divide.

The proposed WLMG pad location is covered mostly by core forest comprised primarily of deciduous trees. It occupies moderate to steep slopes (all within Wayne County soil survey slope classes B and C, with reported slopes in the relevant C class as steep as 25%). All five soil map units on the pad site also are classed by USDA-NRCS as Highly Erodible Land where erosion and sedimentation are especially likely to occur. LiDAR mapping shows a flow path northwest-southeast through the center of the proposed pad, although no US Geological Survey topographic maps or National Wetlands Inventory maps show aquatic features beneath these headwater forests. Onsite streams have not been delineated or inventoried for WLMG within the property, so potential direct impacts on those resources are not readily determined. There is one undelineated, 4-acre, onstream pond (a palustrine unconsolidated bottom wetland with fringing emergent herbaceous wetland margins) in the northwestern section of the property west of Beaver Hollow Road. Consultants to the plaintiff preliminarily have identified six wetland parcels totaling 4.5 acres onsite near the proposed well pad (**Figure 6**). The completeness and accuracy of the plaintiff's delineation of onsite wetlands and other waters have not been confirmed by any agency and have not been entered onto a professional land survey drawing. At least one forested wetland appears to continue northward beyond the limits of WLMG land.

Alternative locations for a proposed 5.7-acre well pad have received little attention. WLMG representatives reportedly first sought a pad location straddling the river basin boundary near the center of the property and oriented northeast-southwest. An alternative location was identified farther north, and that alternative reportedly was shifted eastward to the currently proposed pad site.

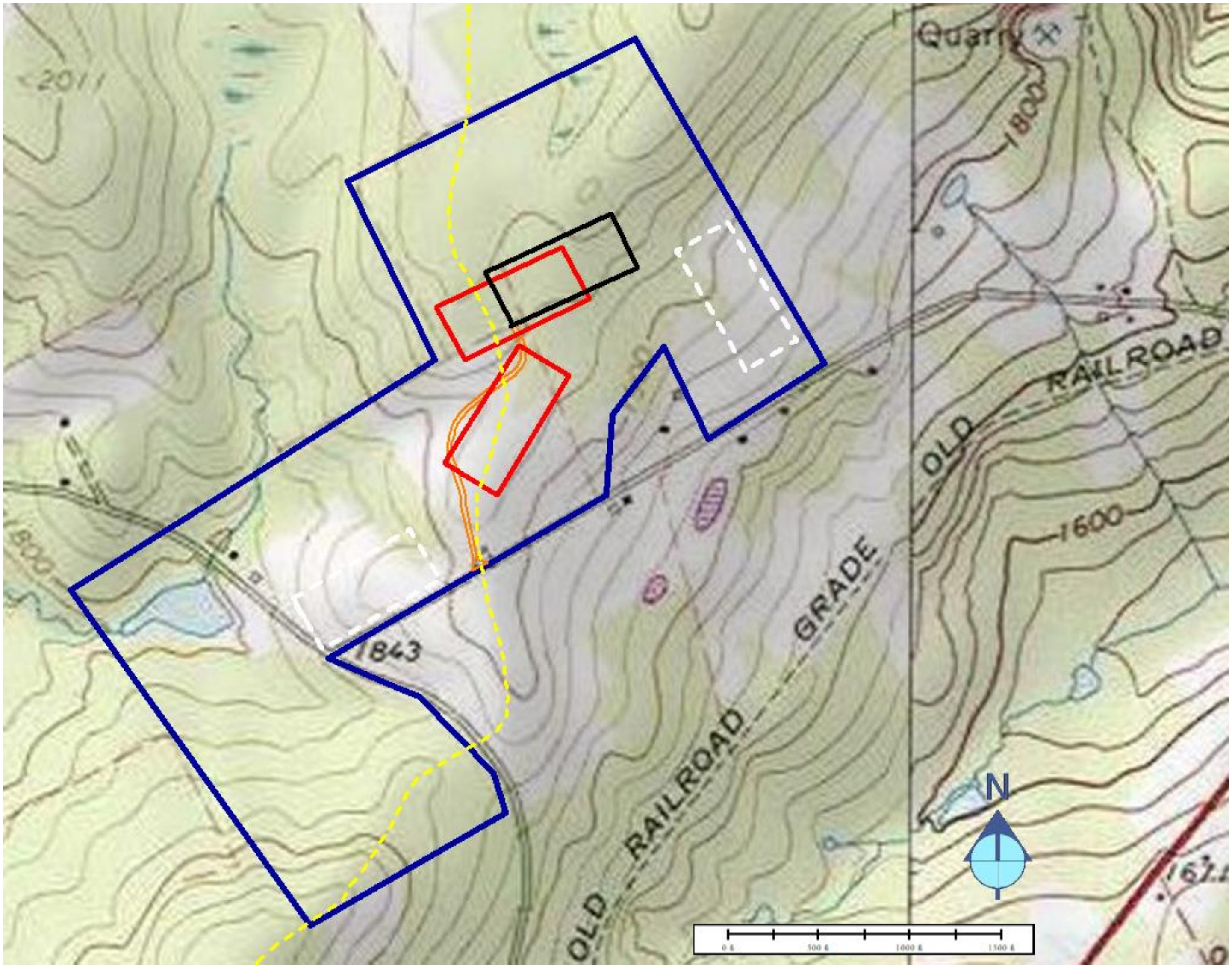


Figure 5. WLMG property (blue outline) on the 1992-95 Orson PA US Geological Survey 7.5-minute topographic quadrangle. The currently proposed wellpad is outlined in black; access road, in orange. Plaintiff's initially preferred location is outlined in red, as is its original alternate location. Other potential pad locations to minimize forest destruction are outlined in white (dashed). The ridge line between Delaware River Basin (right) and Susquehanna River Basin (left) is dashed in yellow. Rainbow Road forms the southeastern boundary of the property. Beaver Hollow Road crosses the western part of the site. Both those township roads intersect State Route 370, a small part of which is shown in the lower right corner of the map image (on the adjacent Lake Como PA quadrangle).

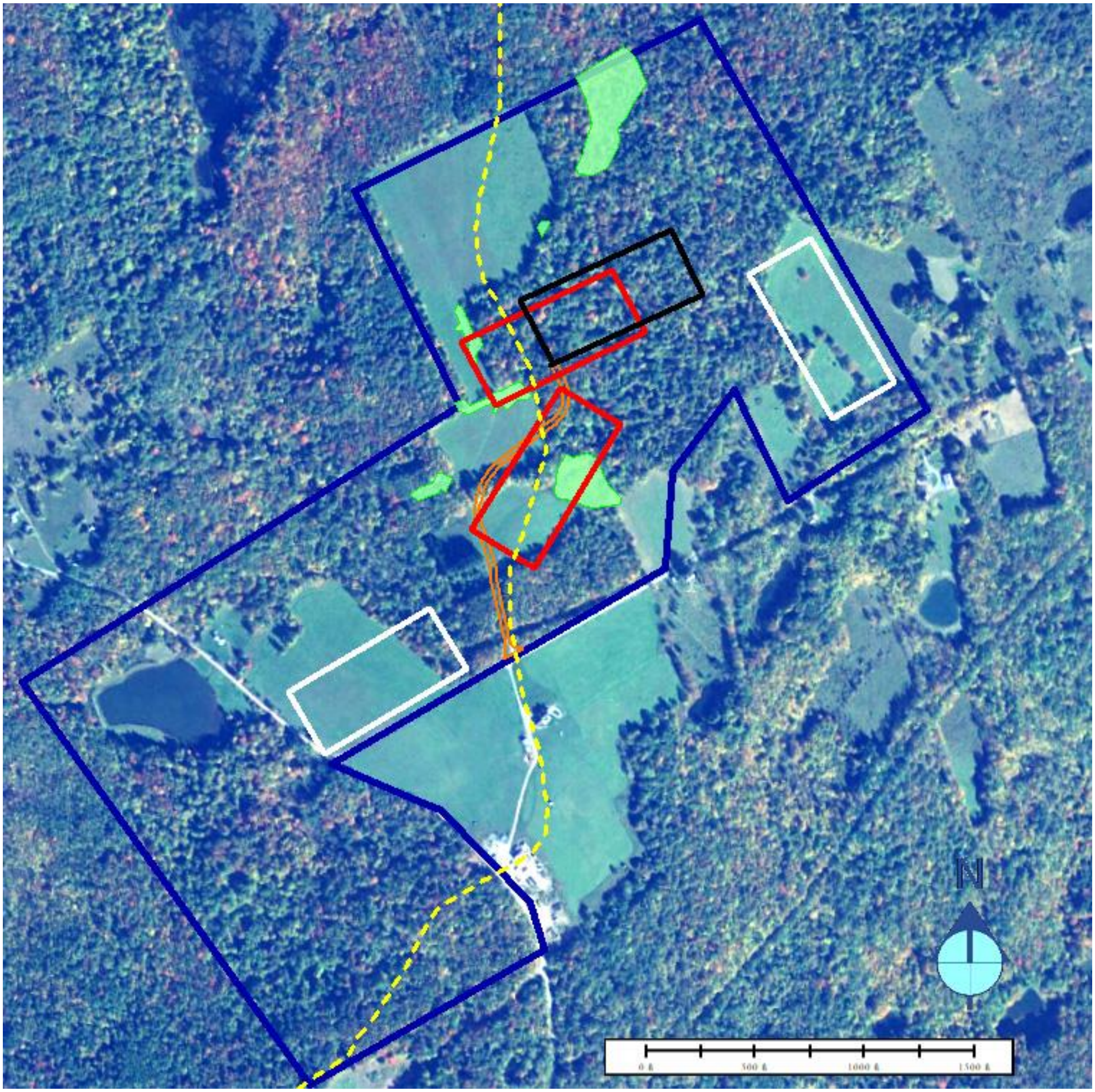


Figure 6. WLMG property (blue outline) on 10 September 2017 GoogleEarth aerial photograph. Proposed wellpad is outlined in black; access road, in orange. Plaintiff's initially preferred pad locations are outlined in red. Applicant's acknowledged wetlands are in yellow-green overprint. Other potential pad locations to minimize forest destruction are outlined in white. The ridge line between Delaware River Basin (right) and Susquehanna River Basin (left) is dashed in yellow.

Additional potential well pad locations in the Susquehanna Basin sections of the WLMG property exist within a few hundred or thousand feet of the proposed pad. For example, two alternatives can be identified chiefly in mowed hayfields close to Rainbow Road (white rectangles in **Figures 5** and **6**). One of these lies entirely within the Susquehanna River Basin. None of the alternative sites is flat, but slope is not a significant constraint for well pad locations in Pennsylvania, where land sculpting to form flat well pad sites on mountainous terrain is a common practice. It is obvious that there are several possible locations for a well pad on the WLMG land, if a comprehensive effort were made to avoid potential environmental impacts, based on a careful inventory of existing resources on and downslope from the WLMG site. Alternative potential well pads warrant careful evaluation in order to avoid or minimize potential impact to the Special Protection waters onsite and downslope in the Delaware River Basin.

WLMG indicated a preference for the well pad to be located in the southeastern part of the property near Rainbow Road, reportedly hoping to minimize distance and cost when connecting to a possible future pipeline under consideration by Linden Energy that might someday occupy an abandoned New York, Ontario, and Western Railroad right of way (**Figure 5**). There are no gas pipelines near the WLMG site at present. No route for any gathering pipeline to connect any encountered gas from WLMG to market has been identified by the plaintiff, and no pipeline right of way has been acquired or leased by WLMG.

Phased construction would include first building an onsite access road for heavy industrial truck traffic to the pad site. The 0.9-acre access road passes within 150 feet of three acknowledged onsite wetlands. Offsite township roads also may need improvements to support the truck traffic during the years of gas well development. The nearest State road is PA Route 370 about 1 mile east of the proposed WLMG well pad.

Where and how WLMG might stockpile and eventually dispose any rock cuttings, drilling mud, frackwater, return wastewater, or other materials and equipment off the proposed well pad during the years of well development have not been identified, so potential impacts of those facilities cannot be estimated. Such support facilities typically entail further land disturbance, soil compaction, and construction of impervious surfaces beyond a well pad and access road, especially if more than the initially estimated six wells here were to be constructed onsite. Sometimes such support facilities are shared among developers of nearby well pads in the Pennsylvania gas fields. The water needed for well development may be conveyed to the WLMG site by truck, and an existing source on the Delaware River mainstem at Hancock has been tentatively identified. Hancock is nearly 8 miles distant from the WLMG site as the crow flies, and the water must be raised more than 1,000 feet vertically in route to the proposed well pad. If 8,000-gallon tank trucks are used, 1,750 truckloads could be needed to import frackwater. To the extent support facilities may be removed or reduced in size following the completion of well development, some onsite land restoration may be possible, but none apparently has been proposed by WLMG. Closed canopy forest requires decades to regrow at minimum, if decompaction and topsoil are provided.

As a result of forest clearing and site regrading for the currently proposed well pad, soil erosion, stream sedimentation, and eutrophication are likely to increase downstream in the Special Protection Kinneyville Creek watershed of the Delaware River Basin. Current PADEP Best Management Practices in Pennsylvania do not protect sites and water bodies from erosion during the increasingly intense thunderstorms resulting from global warming, which are the periods when the greatest erosion and sedimentation occur. No protection is required by PADEP capable of handling large storms (those with a less than 2-year recurrence interval). Trout and other aquatic organisms have declined in the Marcellus gas fields of Pennsylvania, and have been destroyed completely by spills in some pristine streams (Grant et al. 2016).

All streams in the surrounding area of the Delaware River Basin are PADEP-designated High Quality Cold Water Fisheries (HQ-CWF) entitled to Special Protection. Streams in the adjacent Susquehanna River Basin west of the proposed pad are designated Cold Water Fisheries (CWF), not a Special Protection regulatory category. Existing use determinations have not been made in these streams, any of which may warrant protection of higher quality attained uses. A few scattered Class A wild trout streams have been recognized several miles to the southwest of the WLMG site and elsewhere in Wayne County that particularly warrant Special Protection by PADEP and are treated as having Exceptional Value attained use (these are Tier 3 Outstanding National Resource Waters in the terminology of the federal Clean Water Act). Such streams could most likely become impacted by spills from truck traffic carrying fracking chemicals and produced water or by gathering pipeline construction serving the WLMG site and other wells. In northwestern Pennsylvania fracking wastes have been linked to acidity and bacterial changes adversely affecting trout (Ulrich et al. 2018), and fracking also has been associated with mercury poisoning of fish (Grant et al. 2016).

Soils beneath forests readily accept precipitation, keep water temperature low via shading, and convey precipitation to groundwater for slow release to streams during periods of low flow. Hydrologic changes from gas well construction that reduce groundwater recharge and thereby reduce stream flow include effects such as forest clearing, soil compaction, and expansion of impervious surfaces during the construction of well pads, roads, storage basins, and pipelines (CHPNY and PSR 2019). These effects are most noticeable in small headwater streams high in the landscape. WLMG proposes to site its well pad at the top of the watershed at the uppermost limit of the Delaware River Basin. At the same time, consumptive use of fresh water from local sources is typical of unconventional gas well development, potentially causing damage to aquatic habitat during low flow periods if withdrawals are not accurately forecast and restrictive conditions observed. Perhaps the millions of gallons of drilling and fracking water needed by WLMG for gas well development can be successfully drawn from the Delaware River at Hancock. Some might be reused frackwater from wells in Susquehanna County. Soil compaction presumably could be partially addressed during site restoration, but its remediation is often overlooked and not required in Pennsylvania (Frazier 2018).

Proposed construction at the WLMG site will involve clearing and grading enough land to accommodate the heavy industrial uses, installing impervious surfaces to capture and contain precipitation and spills, followed by the importation and storage of equipment, steel pipe, water, sand (about 1 ton per lateral foot of bore), chemicals, diesel fuel, and other supplies to enable drilling an anticipated 7 to 8 thousand feet first downward into and then laterally several thousand feet more within the Marcellus Shale. The plaintiff anticipates drilling of the initial lateral bore 4 to 5 thousand feet outward from the test well, hoping in the future to obtain additional subsurface mineral rights extending some distance beyond the surface property. Then fracturing of additional wells with laterals is to occur within the shale layer to release the gas from natural fractures into the borings that extend outward from the wellheads. WLMG representatives hope the Marcellus Shale layer is 100 to more than 400 feet thick beneath their property and that it proves capable of yielding much natural gas.

The locations and methods of proposed disposal for wastewaters and solids generated by drilling, fracking, and gas recovery operations have not been specified. If water, sand, drill cuttings, and other materials were to be imported from and exported to existing gas well pads in the Susquehanna River Basin, it is more than 15 miles via local roads to the nearest State road in that direction (PA Route 171). Both "produced" flowback wastewater returned from unconventional gas wells and the solid materials generated by drilling contain various hazardous chemical and radioactive contaminants that need special care in handling, storage, treatment, and ultimate disposal because of their ability to pollute air, land, and water (Schmid & Co., Inc. 2013c).

In order to accomplish the plaintiff's purpose of producing and marketing the natural gas it hopes to extract from beneath its land and surrounding properties, construction of major gathering pipeline infrastructure will be necessary if the gas is to be competitively priced. WLMG has not indicated whether its operations will be paused at the stage of identifying extractable gas from its well(s). No gas can reach markets from shut-in wells until there is a pipeline connection. Construction of a pipeline on the abandoned railroad right of way southeast of the WLMG property is a speculative prospect that likely would benefit WLMG if it were to occur. But an offsite connecting pipeline would be needed even to reach that old railroad grade. There are no existing gathering pipelines in the surrounding parts of Wayne County. About 8 to 10 miles of new gathering lines are needed, extending either westward to connect with existing gathering lines that serve existing wells west of Thompson in Susquehanna County (**Figure 2**) or southward to reach an existing Tennessee major interstate gas transmission line that crosses Wayne County (**Figure 10**). Absent the arrival of an adjacent pipeline built by parties other than the plaintiff, installation of a gathering line merely to transport gas from WLMG wells to an existing market link would convert more than 100 acres of additional offsite forest and/or farmland to long-term industrial use.

According to WLMG, the cost of a gathering line probably would not be justified until gas production was assured from about 5,000 acres (nearly 8 square miles) of land (C. Coccodrilli 2019:236). Crossings of public roads, streams, and wetlands are likely, inasmuch as gathering lines are not confined to public road or utility rights of way in Pennsylvania. WLMG has not indicated that it has acquired any pipeline right of way. Thus it might need to postpone gathering line construction, possibly for years after initial test well development on its proposed or pad, until the cost can be spread among additional well pads in the vicinity.

WLMG has not disclosed sufficient information to assess the extent of forest, core forest, wetland, and stream crossing destruction that its natural gas development, if successful, would cause. The approximate limits of wetlands near the proposed pad have been preliminarily identified and avoided, but perennial and intermittent streamcourses onsite have not been surveyed. Temporarily disturbed forests will require many decades to regrow, and longer if their soils are not decompacted and then replanted with appropriate native species post-disturbance (Sitler 2013). Pennsylvania normally waives regulation of obstructions and encroachments into headwater streams with drainage areas smaller than 100 acres [25 Pa. Code §105.12(a)(2)], irrespective of their designated use, attained use, or ecological significance. Pipeline corridors typically are kept clear of trees permanently. Forested wetlands along pipelines are converted to herbaceous cover, even where wetland conditions are restored successfully. Offsite mitigation would be needed to replace the functions of forested wetlands in pipeline corridors, if impact mitigation were attempted.

The siting of gathering pipelines is virtually unregulated in Pennsylvania (Schmid & Co., Inc. 2013c). Unmarked, high-pressure gathering lines at various depths pose a sometimes-fatal hazard to equipment operators subsequent to well development (Phillips 2016). State permits are required where pipelines cross State roadways and where they cross streams in large watersheds. Permits also may be required where they cross recognized wetlands. Gathering pipelines for unconventional wells are being constructed in ever larger diameters at ever higher pressures similar to those of major transmission lines, but are not required to meet interstate construction standards. Pennsylvania regulators have been slow to recognize the dramatic increase in risk from that long posed by traditional gas well gathering lines of 6- to 8-inch diameter and low pressure. Gathering lines are seldom inspected by any agency representatives. Virtually no data have been collected on the risks they pose to people and the environment. Municipal authority to affect pipeline locations has been restricted in Pennsylvania, and few municipalities have tried to direct the location of gas development. Both well pads and pipelines often are sited in close proximity to homes in rural Pennsylvania, posing genuine risks to human health (**Figure 7**).

Gas gathering pipeline under construction near Warrensville, Lycoming County

A pipeline laying operation near a home in Greene County. (Michael Bryant / Staff Photographer)

Well pad fire in Avela PA, February 2011.

Figure 7. Shale gas gathering pipelines and a well pad fire in rural Pennsylvania (LWVPA 2012).

Generalized Impacts

If unconventional wells are constructed and operated successfully by WLMG at its proposed well pad, additional gas production from the Marcellus and Utica Shales is virtually certain to occur elsewhere in northern and central Wayne County within the partially known geologic deposits, which are considered potentially more productive than those in eastern Susquehanna County (**Figure 8**). The pace of well construction in Pennsylvania to date has been determined primarily by demand as reflected in the market price of natural gas. Experience over the past decade in nearby Bradford and Susquehanna Counties and elsewhere in Pennsylvania Marcellus gas fields provides guidance as to likely impacts. State drilling permits for individual counties in northeastern Pennsylvania have been issued at rates of several hundred per year (Schmid & Co., Inc. 2013c). The pace of actual well development activity has varied with market conditions.

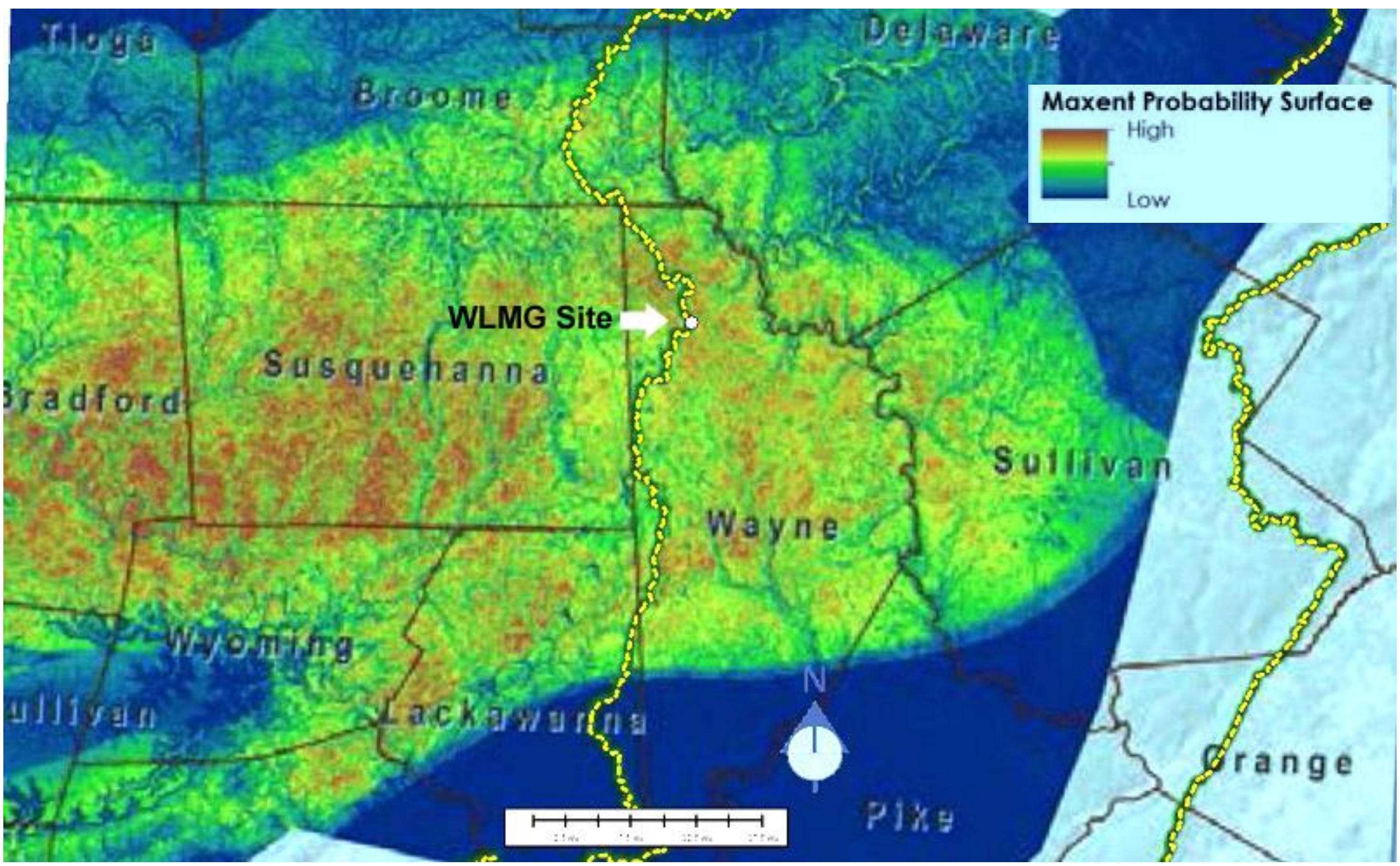


Figure 8. Marcellus Shale resource probability in northeastern Pennsylvania (Habicht et al. 2015). Limits of Delaware River Basin are highlighted by dashed yellow line. Counties are labeled.

The impacts of gas field development can be summarized as land use change, forest fragmentation, water and waste management issues, truck traffic, water quality reduction, air quality decline, and human health and safety consequences. During the 2010-2016 period about 4 percent of core forest in Lycoming County was lost as a result of gas development, primarily from construction of roads and pipelines (Langlois et al. 2017). Core forests are critical habitat for many species of wildlife, including migratory birds whose populations are declining. Land use changes, truck traffic, noise levels, and potential water pollution typically peak during well development. Gas production declines rapidly in Marcellus Shale wells, and refracturing may be needed after a few years. Methane and other contaminants may leak from wells and pipe joints during an extended period of resource production over years or decades, and the compressors moving gas long distances along gathering pipelines and transmission pipelines will emit significant noise, leak methane, and discharge exhaust from their large engines for many years. Pipeline maintenance blowdowns are another major source of methane and other air pollutants (SPEHP 2015). Compressor stations leak gases even when not in operation (Subramanian et al. 2015). Incomplete combustion and sunlight conversion of methane released at compressor stations has led to production of formaldehyde, a known human carcinogen, and other toxics such as benzene and hexane also are measurable around compressors (Macey et al. 2014; Neuhauser et al. 2014). Increasingly the adverse consequences for human health are being identified among populations living close to oil and gas operations, as further discussed below.

Sludges filtered from well wastewaters are typically disposed in landfills, where they can generate polluting leachates unless the landfills were designed specifically for toxic chemicals (Troutman 2019). There are no facilities for treating oil and gas waste near the proposed WLMG pad (**Figure 9**). USEPA has not sought to regulate numerous oil and gas chemical additives, relying instead on voluntary adoption of management practices by the industry to lessen consequences for human health (USEPA 2019; Horwitt 2016, 2018). Wastes from Pennsylvania wells are not closely tracked (Hill et al. 2019, Tasker et al. 2018). Meanwhile the industry, in cooperation with PADEP, is eager for USEPA to continue allowing discharge of well wastewaters to Publicly Owned Treatment Works and for PADEP to expand use of wellfield brines for roadway dust suppression and ice melting (CDAC 2019).

Disposal of conventional oil and gas well brines long was allowed in Pennsylvania for deicing and for dust control on unpaved roads after minimal testing of the brines. These wastewaters contain various salts, radioactivity, and organic contaminant concentrations, often many times higher than drinking water standards. Bioassays also indicated that these wastewaters contain organic micropollutants that affected signaling pathways consistent with xenobiotic metabolism and caused toxicity to aquatic organisms. The potential toxicity of these wastewaters is a concern as lab experiments demonstrated that nearly all of the metals from these wastewaters leach from roads after rain events, likely reaching ground and surface water (Tasker et al. 2018). In Pennsylvania from 2008 to 2014, spreading conventional O&G wastewater on roads released over 4 times more radium to the environment than O&G wastewater treatment facilities and 200 times more radium than spill events.

Through computerized modeling based on physical constraints and recent experience in other Pennsylvania counties, Habicht et al. (2015) estimated that there could be more than 2,400 Marcellus wells developed on several hundred well pads in the Delaware River Basin section of Wayne County, if current moratoria were lifted (**Figure 10**). Their modeling was based on the resource probability shown in **Figure 8**. The

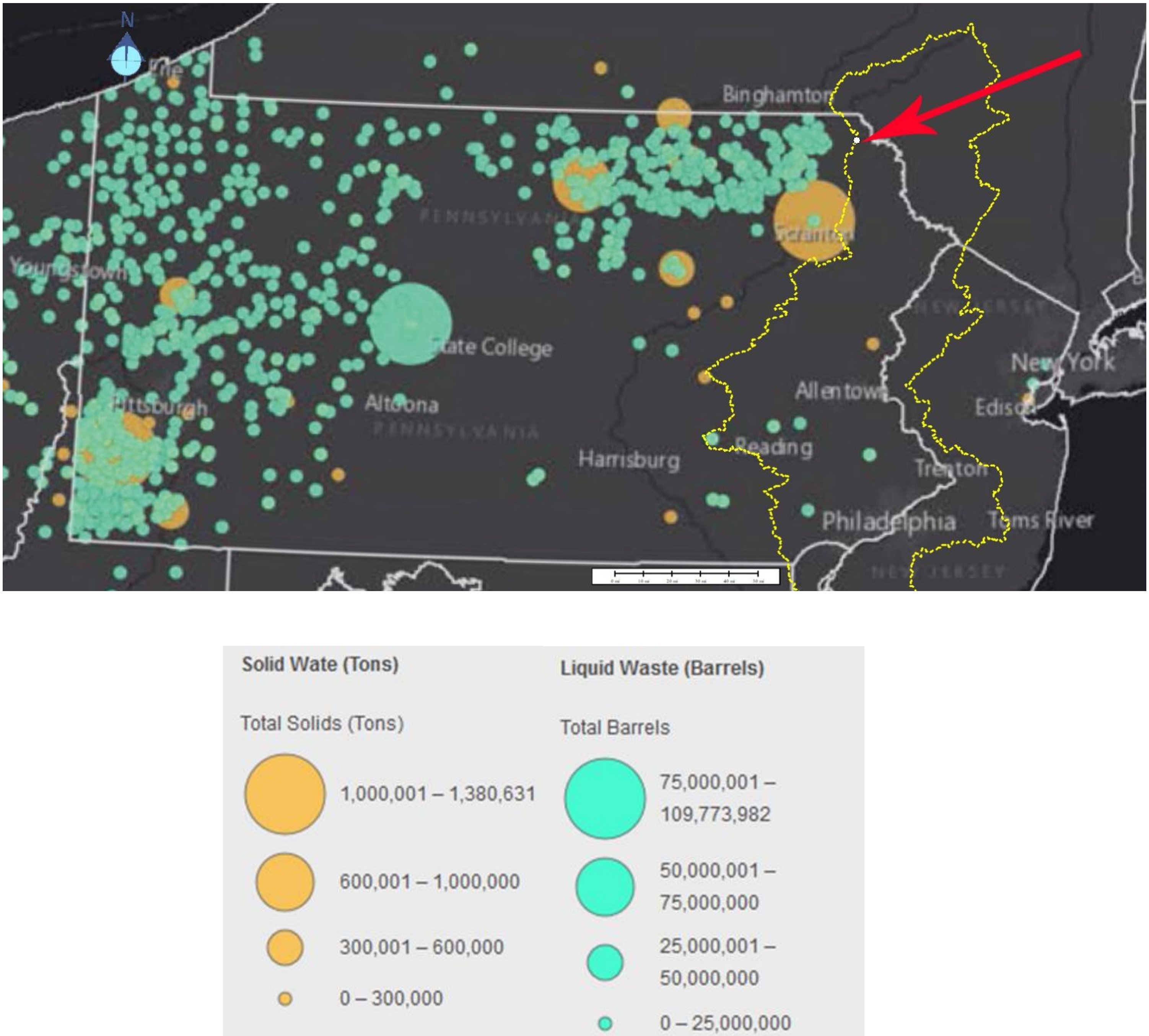


Figure 9. There are no gas waste disposal facilities in Wayne County, so much truck haulage will be needed for the proposed WLMG well(s). WLMG site is the white dot at the end of the red arrow. Delaware River Basin is outlined in yellow. Base graphic from FrackTracker.

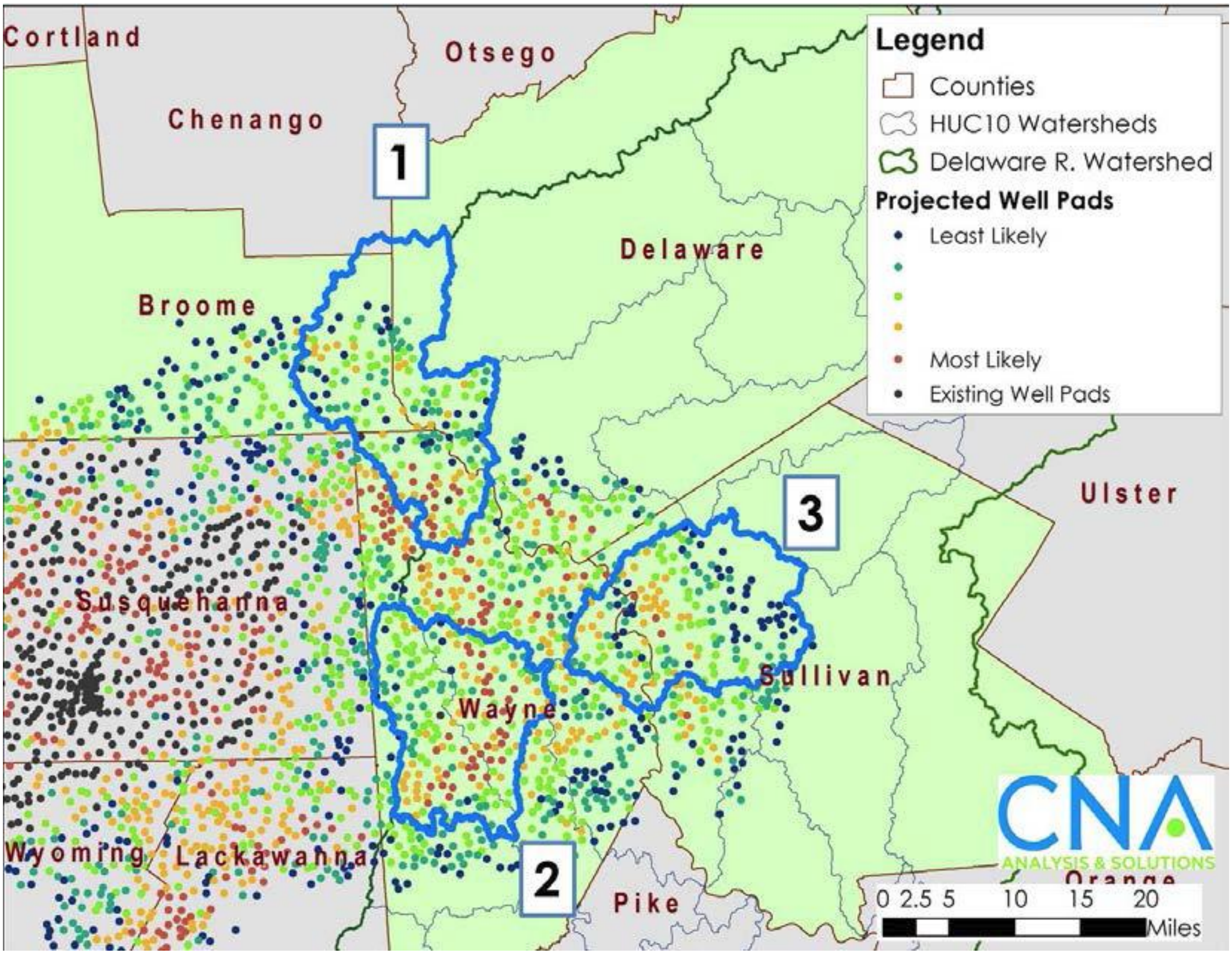


Figure 10. Potential locations for new well pads (projected at 4 wells per pad) in the Upper Delaware River Basin. Three study areas outlined in blue were chosen for analysis from the counties shown in green by Habicht et al. (2015).

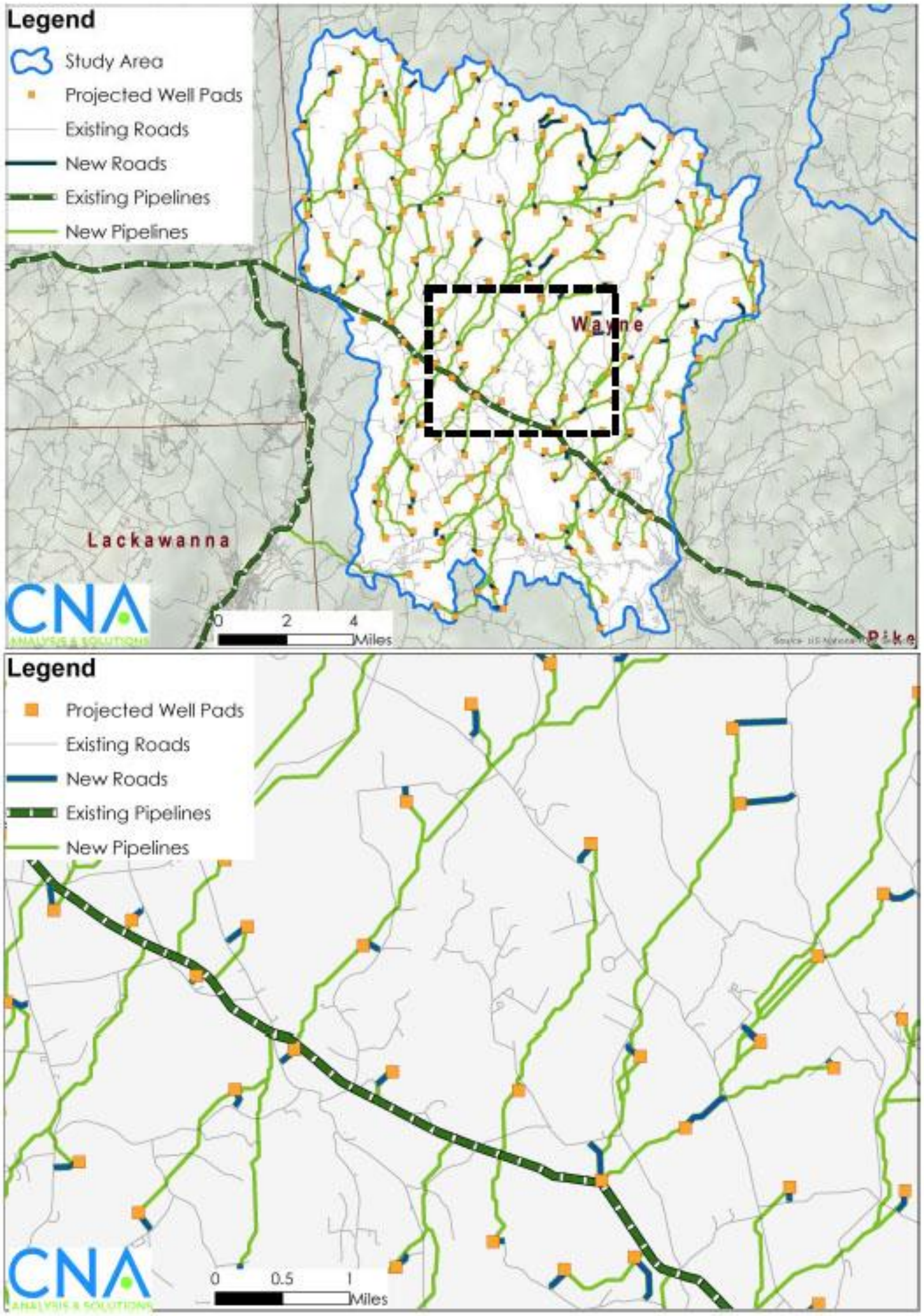
proposed WLMG pad lies south of Study Area 1 and north of Study Area 2 on the watershed boundary (**Figure 10**). Study Area 2 is shown in greater detail in **Figure 11**. Habicht et al. (2015) used reasonable assumptions concerning well pad spacing, the available but incomplete wetland and stream information, and probable setbacks from known streams, reservoirs, and buildings. At an average rate of about 20 acres per well pad (74% for gathering line construction, 21% for well pads, and 5% for roads) and 4 wells per pad, the total landscape conversion to industrial uses was estimated at 2 to 3 percent of the total land area (now all consisting of forests and farmlands). In addition to protecting public water supplies, forests in the upper Delaware River Basin today sequester carbon, recharge aquifers, filter clean air, provide habitat for wildlife, maintain fisheries, and encourage eco-tourism. About 1 to 2 percent of total forest land would be lost, and an additional 5 to 10% of the existing interior forest land would be converted to edge forest.[1]

Invasive plants typically spread rapidly onto lands disturbed by gas operations in Pennsylvania (Mulhollem 2018). Habicht et al. (2015) concluded that the amount of land converted to industry by gas development in its Study Area 2 (a roughly 12- by 15-mile area of 162 square miles located just south of the proposed WLMG well pad in central Wayne County) would be comparable to constructing 58 King of Prussia shopping malls there. (King of Prussia Mall is a suburban Montgomery County, Pennsylvania, landmark and one of the largest retail shopping destinations in the United States.) New roads, well pads, and pipelines probably would resemble the landscape shown in **Figure 11**.

Certain aquatic ecosystems, including headwater areas such as where the proposed WLMG well pad is proposed to be located, are highly sensitive to changes in flow regime, which can induce a decrease in species richness, increase in predators, increase in generalist and highly mobile species, and decrease in cold-water specialist organisms (Kaplan et al. 2008, Sweeney and Jackson 2010). There is a 4-acre pond in the Susquehanna River Basin section of the property that WLMG may use for potable water supplies during gas development.

Natural gas wastewaters, including shale brine that flows back to the surface during fracking and long-term gas production, carry highly concentrated salts, dissolved solids, metals, and radioactive materials in addition to the chemicals used to expedite the drilling and fracturing of rock. These wastewaters must be carefully captured, stored, and either treated before release to the environment, injected into permanent disposal wells, or dried and placed in industrial waste landfills. Spills of fuel, chemicals, and wastewater from trucks and pipes occur, and may result in enforcement if fish kills or other consequences are noted (**Figure 12**). For example, fish, salamanders, crayfish, and aquatic macroinvertebrates were killed along three quarters of a mile of tributary stream in Cross Creek Park, Washington County, Pennsylvania, by spilled frackwater in 2009 (Pittsburgh Post-Gazette 2009). Leaks and spills of fracking chemicals and

[1] Edge forest is land with trees at least 15 feet tall sited less than 300 feet (~100 m) from non-forested areas such as roads or fields. Edge forest supports many species of relatively common and invasive wildlife, both plants and animals with broad habitat tolerance. In contrast, interior core forest more than 300 feet from edges supports many rare and vulnerable species that have specialized requirements seldom met in disturbed areas.



Source: National Park Service (background)

Figure 11. Projected landscape pattern for a section of central Wayne County, based on recent Marcellus Shale gas development in Bradford and Susquehanna Counties (Habicht et al. 2015). The proposed WLMG well pad is about 2 miles north of the northwest section of this No. 2 Study Area (upper graphic) and 2 miles south of No. 1 Study Area (**Figure 10**).

This small frackwater pipeline joint failure caused loss of more than 10,000 gallons of fluid resulting in a fish kill in High Quality Brush Run watershed, Washington County, 2009. Damage to fish, salamanders, frogs, and oligochaetes here was recorded by PADEP.

Figure 12. Actual surface water pollution from shale gas development.

wastes also can affect human health (Crosby et al. 2018), as well as livestock and wildlife (Phillips 2011). Improper discharges of gas wastewater to Pennsylvania streams have generated numerous violations, and any resulting fines represent a minor cost of doing business for the gas industry (Niedbala 2018; Maykuth 2013; Levy 2011). PADEP (2019b) has reported 345 incidents of damage to private well water supplies from oil and gas activities.

The production of natural gas is associated with potential groundwater contamination from casing leaks and by spills, with the introduction of methane and other contaminants into domestic well water and stream water, and with impacts on the health of exposed humans and livestock, all of which can vary locally in response to environmental conditions and construction practices (Woda et al. 2018; Bourzek 2018). Drilling fluids are virtually unregulated in Pennsylvania, but have ample opportunity to contaminate groundwater prior to installation of casing pipes and concrete (Troutman 2019). The kinds and quantities of chemicals added to fracking fluids are not fully disclosed, but are subject to spills and leakage to surface waters and groundwaters (Horwitt 2018, Troutman 2019). Methane can disperse into groundwater, migrate into buildings, and disperse into the atmosphere (Burgos et al. 2017). Stream contaminant inputs are accompanied by loss of forest stream cover in Pennsylvania gas fields, resulting in a decline of aquatic habit quality (Sweeney and Jackson 2010).

WLMG has not identified the location of potential receptors in the vicinity of its well(s) or how it proposes to minimize adverse impacts on neighbors from noise, light, exhaust pollution, airborne particulates, or traffic during well drilling and development. Such impacts on nearby residents as well as on wildlife can be severe. Human mortality in the United States increases with airborne levels of fine particulates ($PM_{2.5}$) and ozone with no evidence for zero-effect thresholds (Di et al. 2017). Airborne wastes are transmitted by precipitation to surface waters. A statistical analysis of the scientific literature on health impacts of fracking available from 2009 to 2015 demonstrated that:

- 69 percent of original research studies on water quality found potential for, or actual evidence of, fracking-associated water contamination,
- 87 percent of original research studies on air quality found significant air pollutant emissions, and
- 84 percent of original research studies on human health risks found signs of harm or indication of potential harm (Hays and Shonkoff 2016).

The followup study showed 90.3 percent of all original research studies published from 2016-2018 on the health impacts of petroleum fracking documented a positive association with harm or potential harm (Ferrar, Jackson, and Malone 2019). Methane leaks from fracked wells increase over time (Yudhowijoyo et al. 2018). Radium levels in drill cuttings from shale are found at significantly high concentrations, but are exempt from federal regulation. The half-life of radium 226 is 1,620 years; of radium 228, about 6 years. Radium concentrations remain at toxic levels even after frack wastewater has passed through industrial waste treatment plants (Swiedler et al. 2019; Lauer et al. 2018). In Pennsylvania elevated concentrations of radium 226 and 228 (at about 200 times background), strontium, and barium, all characteristic of Marcellus Shale gas well return waters, were detected more than 11 miles downstream from a centralized return-water waste treatment plant (Burgos et al. 2017), where the relatively small volumes discharged relative to stream flow were deposited in Conemaugh River Lake, Indiana County. Other contaminants of drinking water associated with chemicals released from produced waters include sulfates, acetone, toluene, and bromide. When bromide reacts with the chlorine commonly used to treat public water supplies, bromates and other brominated compounds (including trihalomethanes, some of which are carcinogenic) can form disinfection byproducts that enter urban drinking waters, from which they are not readily removed, leading to human disease (Huang et al. 2018; Liberatore et al. 2017).

Maximum allowable concentrations of several contaminants in wastewaters are based primarily on known effects on human health for those chemicals that have been studied. Yet the impacts of many industrial chemicals used by the unconventional gas industry have not been studied alone, much less in combination, despite exponential growth in the recent literature on health impacts (CHPNY and PSR 2019; Horwitt 2016, 2018). Stream organisms can be more sensitive than humans when constantly exposed to relatively low concentrations of waterborne chemicals. Contaminants from treated gas production wastewaters discharged to Pennsylvania streams can raise natural background concentrations of certain elements---notably barium and strontium---more than 500-fold during periods of low flow with resulting ecotoxicity (Hammer et al. 2012). Iodide, radium, and ammonium seldom are measured during sampling of brines and flowback waters. Total dissolved solids limits on industrial discharges in Pennsylvania also are ten times higher than typical background concentrations in Upper Delaware River Basin streams, so even the discharges currently allowable by State regulators are likely to entail a decline in water quality. Cement casings in long well bores offer another potential pathway for release of contaminated frackwaters and methane into both underground aquifers and surface waters.[2] Stream pollution in gas production watersheds has been found to be highly variable (Akob et al. 2015), but the links between fracking activity and stream pollution are becoming documented (Heilweil et al. 2015, Darrah et al. 2014).

Land cover changes resulting from unconventional gas production have both short-term and long-term effects on hydrology reflected both in water quality and water quantity. Water quality is affected by greatly increased erosion and sedimentation during pipeline, well, and road development, especially where forest is removed. Total suspended solids concentrations increase. Long-term erosion and sedimentation rates increase significantly from deforested land, especially during the winter months. Carbon sequestration also is lost when forest cover is removed, and the loss of carbon storage from gas field development is more widespread and prolonged than from timber harvest (Young et al. 2018). Best Management Practices for erosion control often fail in steeply sloping terrain in Pennsylvania. Erosion and sediment controls are not easily enforced, inspections by State regulatory staff are few, and violations frequently occur in Pennsylvania gas fields and along pipelines under construction (Delaware Riverkeeper Network 2016a, Zenes 2013). Surface runoff rates increase, along with a decrease in surface infiltration and aquifer recharge. Water temperature increases, to the detriment of trout and other aquatic organisms (Delaware Riverkeeper Network 2016b). The average rate of annual reduction in groundwater recharge per square mile ranged from 0.35 to 2 million gallons in a modeling analysis of northeast Pennsylvania Marcellus Shale gas fields in the Susquehanna River Basin (Habicht et al. 2015). They estimated the consequent potential reduction in groundwater recharge from their Study Area 2 in Wayne County as 140 to 330 million gallons annually, if typical Marcellus Shale gas production were undertaken there. These effects are most likely to be significant locally in the highest elevations of headwaters in the Basin, such as the vicinity of the proposed WLMG well pad, where base flow is of greatest consequence to streams draining small watersheds.

Public health aspects of shale gas extraction in Pennsylvania have begun to receive serious attention only since the unconventional shale gas industry was authorized, and public health concerns still receive minimal, if any, consideration during the review of applications for State permits (Bonnet 2018). The human population of Wayne County is not concentrated near the WLMG well pad in rural Preston Township, but there are half a dozen offsite residences nearby, as close as 750 feet to the proposed pad. The locations and current quality of surrounding domestic water supply wells have not been identified, nor have routes for the primary plumes of polluted air that will leave the pad. WLMG has not evaluated the capability of existing public roads to serve its significant gas drilling and fracking vehicular traffic during the months or years of its well development activities. Because no drilling or fracking water is to be acquired or wastes disposed locally, the maximum generation of heavy industrial truck traffic can be expected from gas development at the WLMG site. In any case, several thousand truck trips would be needed to haul drill rigs, steel pipe, drilling water, frackwater, and wastewater in and out. As mentioned

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[2] Immediate cement and casing failures affect about 2% of all unconventional wells. Over time the rate of such failures increases dramatically. In the Marcellus Shale gas fields of northeastern Pennsylvania, the rate of failure is 8.5 times higher than in the rest of the State (Ingraffea et al. 2014; Davies et al. 2014).

above, the quantities of water needed for developing unconventional wells is vastly greater than for conventional shallow oil and gas wells in Pennsylvania (Burgos et al. 2017).

The proportion of congenital heart defects encountered in human infants is dramatically greater for women who live in close proximity to gas wells during early pregnancy, as compared with comparable control populations (McKenzie et al. 2019). These are the most common kinds of birth defects in the United States, and are particularly common near unconventional petroleum well development in rural areas. Such defects are the leading cause of infant mortality in the United States, are associated with failure to thrive and developmental problems, and can lead to brain injury. Computerized databases such as PSE (2019) are beginning to aid in accessing the literature on human health and environmental impacts of shale gas production activities.

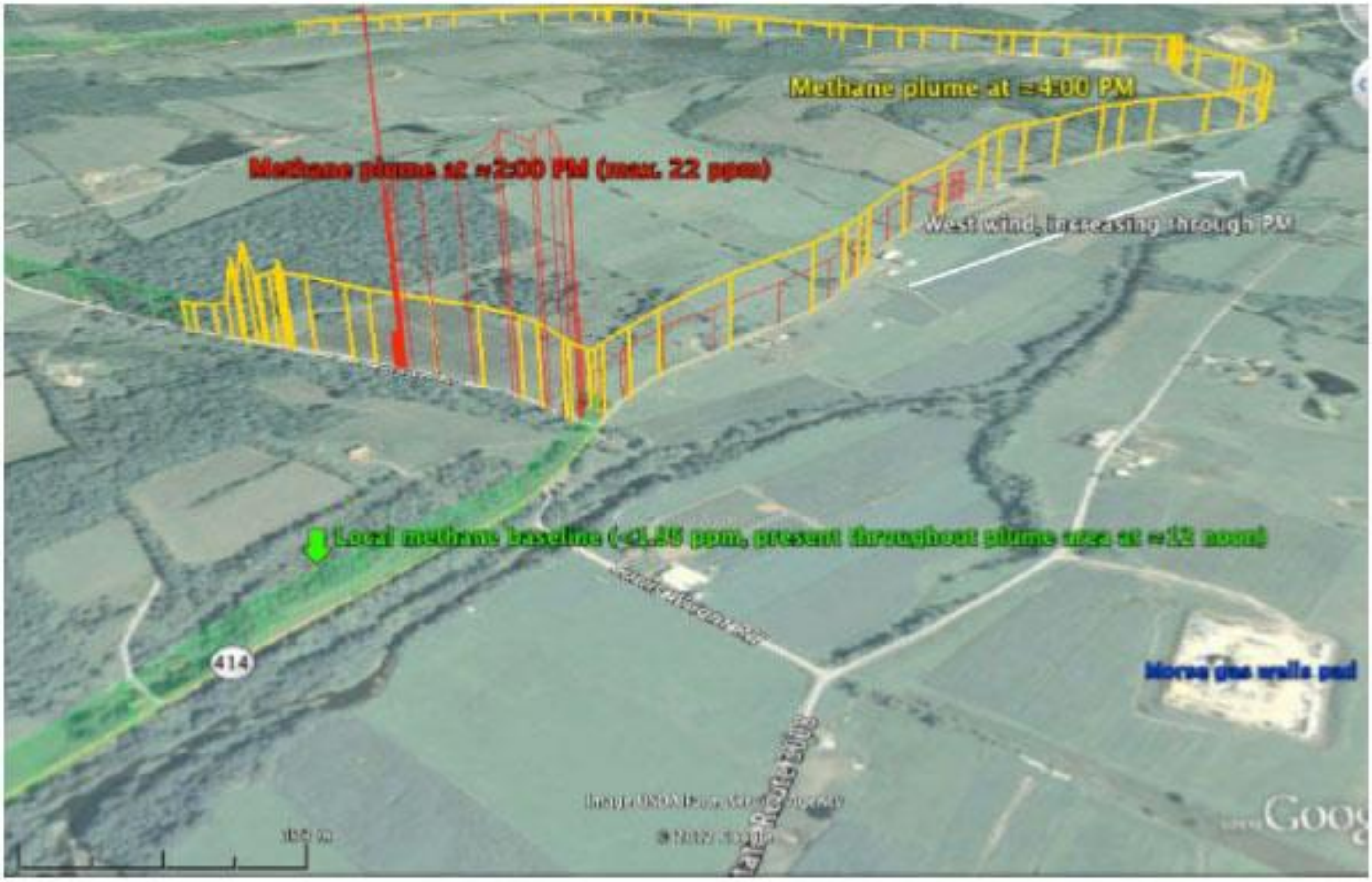
Air quality impacts from unconventional natural gas production vary across the spectrum of gas field activities. Atmospheric concentrations of oxides of nitrogen (NOx), volatile organic compounds (VOCs), and primary fine particulate matter (≤2.5 µm aerodynamic diameter; $PM_{2.5}$) from wellfield activities such as drilling, hydraulic fracturing, compressor stations, and completion venting have been increasing significantly (Anirban, Adams, and Robinson 2016). At present rural Wayne County in general has high quality air. Diesel-powered engine exhausts increase near gas well pads during pad construction, drilling, and fracking and from the transport of equipment, water, chemicals, proppant, and wastes by truck. Ozone and other pollutants in the unconventional well fields attain levels typical of urban environments.

Open ponds for condensate and fracking wastes produce noxious odors as well as contaminant emissions, even when their fluids do not leak. Frackwater storage pits, of course, too often do leak (Hopey 2014). Such facilities may be permitted elsewhere, even if the proposed use of enclosed tanks at the WLMG well pad is reinforced by permit conditions. Long-term emissions of nitrogen oxides will result from the gas compressor exhausts that are necessary to get gas to market, with the estimated 12 needed for Wayne County expected to increase nitrogen oxides in the County by amounts ranging from 66% to nearly 200% of current countywide emissions, should the DRBC moratorium be lifted (Habicht et al. 2015). The emissions equivalent, for each of those compressors, would be that of adding 53,000 vehicles to Wayne County roads for a year. Volatile organic compounds, sulfur compounds, and particulate matter in Wayne County air also would increase measurably.

Unburned methane leaking from wells, valves, and pipes contributes to global warming, because it is a much more potent greenhouse gas than carbon dioxide. The typical average leakage of 6% of total methane from gas production and transport is well above the 3.2% maximum necessary if the burning of natural gas were to provide less greenhouse impact than coal burning for equivalent energy production. Recent measurements of methane leakage in gas fields and at all steps of gas distribution have shown previous estimates of leakage to be far understated (Alvarez et al. 2018; Barkley et al. 2018; Omara et al. 2016; Caulton et al. 2014). Elevated indoor methane levels have been recorded at homes in Marcellus gas production areas of southwestern Pennsylvania (Alawattegama et al. 2015). Indoor radon concentrations also have been on the increase in Pennsylvania areas of Marcellus gas development (Hurdle and Phillips 2015).

Noise levels alongside roads and well pads peak during well development and refracturing activities, but pumping station noise and air pollution along gathering lines continue for years (Shepherd et al. 2010, Hays et al. 2017). Noise levels from gas operations have posed health problems in Pennsylvania (Richburg and Slagley 2018). Long laterals require large engines on well pads to provide the high pressure (to 7,500 pounds per square inch) needed to move well fluids through miles of pipe and to force proppant sand into blasted and natural fractures in the shale. Noise levels also are significant on rural roads carrying heavy industrial gasfield truck traffic.

Health risks would increase as a consequence of unconventional natural gas production of Marcellus and Utica Shales in Wayne County, where some 40% of residents (about 30,000 people) live within 1 mile of likely well pads. Hospitalization rates in Pennsylvania rise with increases in gas wells (Denham et al. 2019). Infant health is significantly impaired where Pennsylvania mothers have spent pregnancy close to gas wells (McKenzie et al. 2019; Hill 2018; Currie et al. 2017; Casey et al. 2016). Rates of depression rise with the intensity of gas development (Casey et al. 2018), as do cases of childhood asthma (Willis et al. 2018). Similarly, hospitalization rates of adults and of senior citizens for asthma, pneumonia, and other respiratory diseases are higher in Pennsylvania counties with fracking operations (Peng et al. 2018; Weinberger et al. 2017; Tustin et al. 2017; Song and Kusnetz 2016). Bladder and thyroid cancers also are increasingly common in the fracking counties (Finkel 2016). Well water, stream, and air contamination by methane, fine particulate matter (Evans et al. 2015), and other gas production-generated pollutants such as ozone (Swarthout et al. 2015) are being experienced by residents of Pennsylvania Marcellus Shale gas fields (**Figure 13**). Gas well contamination can render domestic wells unusable for many months (Gibbons 2014). Most Wayne County residents rely on groundwater wells for potable supplies. Recent studies have shown higher rates of hospital admissions for cardiology and neurology patients in Pennsylvania counties with shale gas production (Jemielita et al. 2015).



Methane concentrations from gas exiting natural faults and fractures in Leroy Township, Bradford County, on 25 July 2012. Green bars show concentrations at background level. Yellow and red bars show elevated concentrations at two times of day (2 pm and 4 pm). This plume encompassed about 1.6 square miles and originated from a gas discharge area occupying at least 30 acres. The red spikes showing maximum concentrations are relatively distant from the presumed originating source at Morse wells 3H and 5H in the lower right corner of the view, 0.4 mile away near the intersection of Curtis Wright Road and Southside Road (State Route 3008), where a casing leak had been reported on 19 May 2012 (Ackley & Payne 2012b). Towanda Creek parallels Route 414 in the center of the oblique photograph.

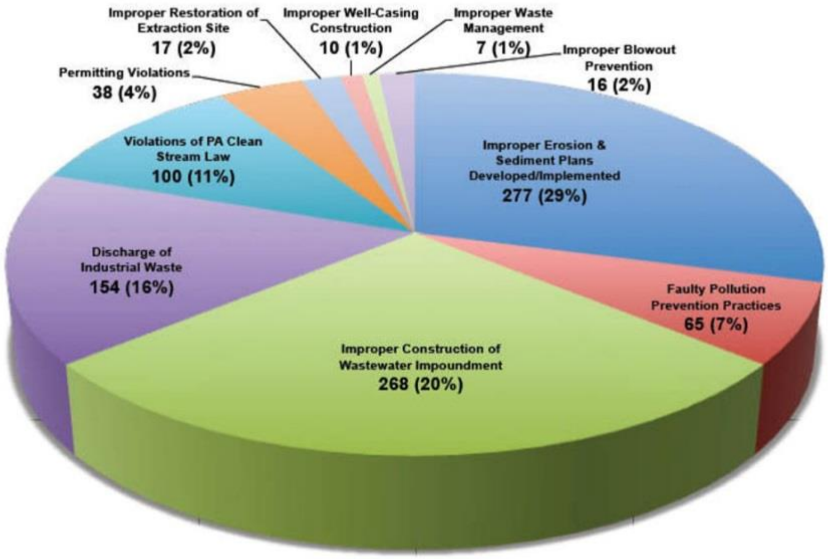
Figure 13. Methane from shale gas production in rural Pennsylvania.

Regulatory Concerns

The DRBC was established in part to protect the quality and quantity of water supplies and to allocate them among the many millions of human users of water in the Delaware River Basin. New York State has determined that, for the foreseeable future, unconventional gas production from Marcellus Shale and similar deposits is too damaging to human health and to the environment to be allowed. In contrast, Pennsylvania has authorized extensive Marcellus gas production outside the Delaware River Basin. Consequently, to date the adverse impacts of this industry have not been experienced within the Delaware River Basin in Pennsylvania.

In Pennsylvania the rhetorical attention given to environmental protection through laws, ordinances, regulations, and permit programs is belied by ineffective implementation. The Pennsylvania Department of Environmental Protection (PADEP) has difficulty protecting both natural resources and the health of people affected by unconventional gas development. PADEP has experienced halving of its budget over the past decade, despite ever growing workloads. It has failed to secure complete, internally consistent permit applications for approval of proposed construction that comply with its published regulations designed to protect water, wetlands, soils, and other ecosystem characteristics, especially for large projects such as coal mines (Schmid & Co., Inc. 2000, 2013a, b, 2015), pipelines (Schmid & Co., Inc. 2014, 2016a, b, 2017a, b), and powerlines (Helbing & Szybist 2014). PADEP gas well approvals have been issued quickly after cursory review (Associated Press 2011/2019). State regulation of encroachments and obstructions into streams and floodways in watersheds smaller than 100 acres is waived [25 Pa. Code §105.12(a)(2)], despite the necessity of maintaining the quality of headwaters if our rivers are to have any chance of protection or restoration (Kaplan et al. 2008).

Superficial, incomplete, and inaccurate inventories of existing features on lands directly impacted by regulated activities render it impossible to avoid or minimize adverse impacts (Schmid 2019). PADEP staff seldom make field determinations of existing use in larger streams where encroachments are proposed, despite the requirement in 25 Pa. Code §93.4c(a)(1). Unrecognized impacts on misidentified resources do not generate permit requirements to attempt compensatory mitigation. Chemicals used in well drilling and fracking are not required to be disclosed, and the identities of some are known only to manufacturers, not even to drillers or gas producers (Horwitt 2018, 2016). Health effects are presumed to be minimal without data, and safety threshold concentrations for many chemicals are simply unknown. Monitoring of compliance with limits on waste discharges is not assured, and public investigation of monitoring records is difficult (Schmid & Co., Inc. 2010; Legere 2013). Agency inspections that reveal violations are not always followed up by enforcement actions to correct unnecessary environmental damage, and penalties for violations are negligible (Woodwell 2016; **Figures 14** and **15**). Self-reporting of violations has not been effective in the gas fields (Hamill 2014). Recordkeeping for fracked-well wastewaters in Pennsylvania is incomplete, and more than one third of such wastes were unaccounted for during the period 1991-2017 (Hill et al. 2019). Air quality monitoring of gas field wastes is seldom performed and methods are not well developed (Brown et al. 2014). Drill cuttings are not defined as solid waste in Pennsylvania, are not analyzed for pollutants, and frequently are disposed onsite in pits (Steinzor and Balzel 2015).



952 "serious" violations of PADEP regulations at shale gas wells by 43 drillers over a 30-month period, 2008-2010.

Figure 14. Violations in PA shale gas wells, 2008-2010.

Total Violations for 2011	1,192
Notice of Violation Issued *(35% of total violations)*	421
Consent Order & Agreements Issued *(0.05% of total violations)*	7
Consent Assessment of Civil Penalties Issued *(6% of total violations)*	80
Violations Receiving No Enforcement Action *(63% of total violations)*	753
Violations Receiving No Fines *(93% of total violations)*	1,105
Total Fines Collected	$2,452,988

Source: PA Department of Environmental Protection website as of May 1, 2012

Figure 15. Violations at Marcellus Shale gas wells summarized from PADEP by Clean Water Action (2012).

Suggested Routine Inspections
At least once during siting a well
At least once during drilling a well
At least once during casing a well
At least once during cementing a well
At least once during completing a well
At least once during altering a well
At least once during stimulating a well.
At least once during, or within 3 months after, the time period in which the owner or operator is required to restore the site, after drilling the well
At least once prior to a well being granted inactive status.
At least once during well plugging
At least once during, or within 3 months after, the period in which the owner or operator is required to restore the site, after the well is plugged or abandoned.
At least once before the bond or other financial security is released.
At least once a year to determine whether compliance with the statutes administered by DEP has been achieved.

Special Inspections
At least once prior to the issuance of a permit, if a waiver or exception is requested by the permit applicant.
At least once in verifying or resolving objections or determining the Department's response to objections, when objections are raised to a permit application.
At least once prior to the authorization to use an alternate method for plugging, casing or equipping the well
At least once during the periods that an alternative method for plugging, casing or equipping the well is being used or installed.
At least once when a well is being reconditioned or repaired or when casing is being replaced.
At least once a year, if there is onsite brine disposal or residual waste disposal subject to the statutes referenced in § 78.902 (relating to policy).
At least twice a year if the well is located in a gas storage reservoir or in a gas storage reservoir protective area.
If there is a violation, at least once to determine whether the violation has been corrected, or whether there is a continuing violation.
At least once, in response to a complaint.

Figure 16. Expected Pennsylvania inspections as set forth in existing regulations (25 Pennsylvania Code §78.901-906. "Inspection Policy Regarding Oil and Gas Wells").

For a comprehensive analysis of enforcement of oil and gas regulations in several States including Pennsylvania, Sumi (2012) tabulated the onsite inspections that any careful reader of PADEP regulations might expect to be performed routinely at gas wells in the Commonwealth (**Figure 16)**. In reality, PADEP inspectors do not perform frequent inspections of shale gas wells. In 2011, there were 8,216 active Marcellus wells to be inspected by 88 inspectors (more than 93 for each inspector), not counting the nearly 70,000 active, conventional, non-Marcellus wells for which the same 88 inspectors were also responsible (those also rarely are inspected). Since 2011 the number of PADEP gas well inspectors has increased slightly, but there are now more than 12,000 active unconventional and 101,000 conventional Marcellus gas wells active in Pennsylvania (PADEP 2019a). The careful analysis for Earthworks Action by Sumi (2012) concluded that Pennsylvania has not adequately enforced laws and regulations that pertain to the oil and gas industry. Virtually no similar requirements apply to gas gathering pipelines, which are virtually never inspected.

If DRBC were to allow this industry within the Pennsylvania section of the Basin, its regulations to reduce in-Basin damage at minimum would need to fill the tremendous regulatory gaps that currently allow widespread damage to waters, other natural resources, and human health in other parts of Pennsylvania (Schmid & Co., Inc. 2018). Unconventional shale gas production in the Basin – particularly without meaningful protective regulations in place and the financial resources and qualified staff necessary for DRBC to perform its own detailed permit review and field inspection -- will lead to inevitable environmental destruction. Among other harms, such unregulated industrial activity will result in lasting harm to the Basin's extraordinary water resources.

Authorship

This report was prepared by James A. Schmid with the assistance of Stephen P. Kunz. Dr. Schmid is a biogeographer and plant ecologist with 50 years of experience in environmental consulting. Both he and Mr. Kunz are certified Senior Ecologists (Ecological Society of America), Professional Wetland Scientists (Society of Wetland Scientists), and Wetland Delineators (US Army Corps of Engineers). Both Dr. Schmid and Mr. Kunz have prepared environmental impact statements and assessments for numerous federal, State, and local agencies.

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