Marcellus Shale Impacts on Water Quality in Lycoming County

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Report produced for

Trout Unlimited & Lycoming County

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Introduction

With the advent of hydraulic fracturing, Marcellus Shale has become a prominent source of natural gas in the United States. This report will focus more on the geographic extent of Lycoming County and the environmental impacts in the county, particularly those relating to water quality and trout habitats. After presenting some background information on both Lycoming County and Marcellus Shale, the discussion shifts to issues concerning land use and water quality. The next section focuses on trout and how it is impacted by Marcellus Shale. Existing Marcellus Shale regulations in Pennsylvania industry recommended practices are examined. Finally, the report presents recommendations that will aid in minimizing the potential impacts on trout and water quality in Lycoming County.

Executive Summary

This report provides an in-depth analysis of Marcellus Shale activity in Lycoming County, and how that activity impacts water quality, both for human and trout populations. This report will provide our clients a basic introduction to Lycoming County, background information on Marcellus Shale and Hydraulic Fracturing, land use changes for drilling activity, an overview of water contamination and wastewater disposal in the drilling process, an overview of trout and the effects of drilling activity on trout population, existing regulations for drilling activity, recommended practices for drilling activity, a conclusion of our findings, and our own recommendations for Lycoming County and Trout Unlimited.

First, we provide an introduction to Lycoming County as a whole. Lycoming County's uniqueness stems from the fact the county has a great amount drilling activity, six major trout streams, and a relatively large population. Throughout this report, we will expand on how closely those three aspects impact one another and water quality, and possible ways to maintain the relationship between drilling activity, trout population, human population, and water quality. The information contained in this report will help our clients, Lycoming County and Trout Unlimited, make a decision on how to manage Marcellus Shale drilling activity in Lycoming County.

Secondly, the report contains background information on Marcellus Shale and Hydraulic Fracturing as whole. Hydraulic Fracturing is incredibly relevant to the issue of water quality because of the possible negative effects of unconventional drilling activity on water quality. This section contains information about Marcellus Shale itself, the process of Hydraulic Fracturing, an explanation of the chemical composition of Hydraulic Fracturing fluids, the economic considerations for Hydraulic Fracturing, and the environmental considerations for Hydraulic Fracturing. This section will be a foundation for our clients' knowledge of drilling activity in Lycoming County.

Thirdly, we discuss the land use changes with drilling activity in Lycoming County. The drilling of the Marcellus Shale has changed land usage in Lycoming County. We consider how drilling activity will directly impact the landscape and the possibility of forest fragmentation. Although drilling activity has changed land usage in Lycoming County, the amount of activity has not severely changed Lycoming County land as a whole. Forest fragmentation, however, could possibly have a negative impact on Lycoming County. Forest fragmentation can change the functionality of an ecosystem, which could have potential ramifications for the trout of Lycoming County.

Fourthly, the report discusses the usage and possible contamination of freshwater in the drilling process, along with the disposal of the resulting wastewater. This section discusses both surface water and groundwater contamination. The main issue with groundwater contamination is the contamination of shallow aquifers. Shallow aquifers provide water for household and agricultural activities. The usage of freshwater is also a pertinent issue. One well will use 2-8 million gallons of water per drilling process. The over usage of freshwater can have potential negative implications for both the human and trout populations of Lycoming County. Another issue this report discusses is the disposal of wastewater. This report discusses two possible ways of disposing wastewater: a.) the wastewater is transported to a wastewater treatment facility or b.) the wastewater is reinjected back into the subsurface at shallower depth. In the state of Pennsylvania, wastewater treatment is required by law, and wastewater treatment facilities are currently the most feasible way of treating wastewater. The reinjection of wastewater back into the Marcellus is not as feasible because of the high water table in the Appalachian region.

Next, we discuss trout and the possible effects of drilling activity on trout population and how the three species, Brook ,Brown and Rainbow Trout, are at risk. The Brook trout are the only native naturally producing species and they are the most susceptible to changes in the water quality. There are 4 classifications of streams including Class A, Wilderness, Natural Reproduction and Stocked trout streams. The trout face hydrological changes such as pinched off streams, groundwater (coldwater) reduction as well as increased brine or TDS levels which raise the temperature of the water causing death at temps above 73°F. Some of these chemicals also cause death pre spawn era as well as reductions in growth further reducing the amount of fish and spawning availability. If not treated and disposed of properly the wastewater can cause several issue in groundwater from direct injection or concentrated pollution issues if treated at an improper plant.

The report also discusses current regulations and recommended practices of drilling activity with regards to water supply. These regulations are concerned with the requirement of a drilling permit, the distance between a drilling site and a water source, and the permissible amount of TDS in the water. Within the regulations, the report discusses who is accountable for each regulation. Recommended practices are also discussed in this report. There are recommended practices for site planning of drilling activity, pre-drill water supply surveys, and water pipelines. With regards to site planning, the land must be regulated, before and after drilling activity occurs. Pre-drill water supply surveys show the quality of the water before drilling activities begin. These can be useful in case there are any further arguments about water quality in that drill site. Water pipelines should only be built if necessary.

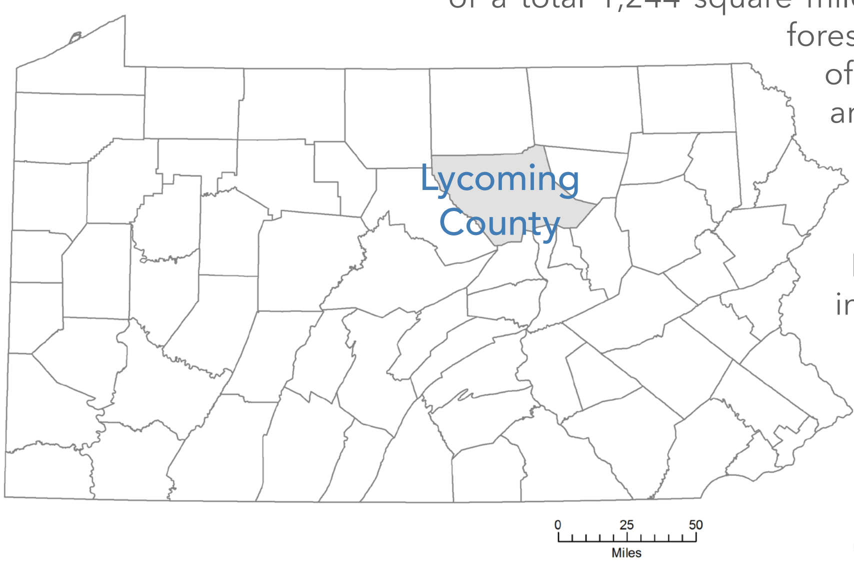
We have several recommendations concerning the issue of water quality in Lycoming County. These recommendations concern contaminants, possible spills/accidents, land use, trout streams, and drill site locations. Our recommendation for dealing with contaminants is wastewater should only be treated at fully equipped facilities. Our recommendation for possible spills is to increase the monitoring of drilling activities to mitigate the spillage of waste water. The usage of land in drilling activity in Lycoming County is not a cause for concern, so this is not a pressing issue in the overall debate of water quality. Our recommendation concerning trout streams is to conduct water quality tests every month. Our recommendation for drill site locations is to require a drill site to be 300 feet away from a water supply.

Introduction to Lycoming County

When considering impacts of Marcellus Shale gas extraction on water quality in Pennsylvania, a reasonable first place to look is Lycoming County. Here, we see a booming gas industry and high quality fisheries co-occuring in the same watersheds, forests, and communities. Taking a closer look at Lycoming County can provide insights both relevant and valuable to local companies and policy makers as well as land managers and trout enthusiasts across the region.

Geography

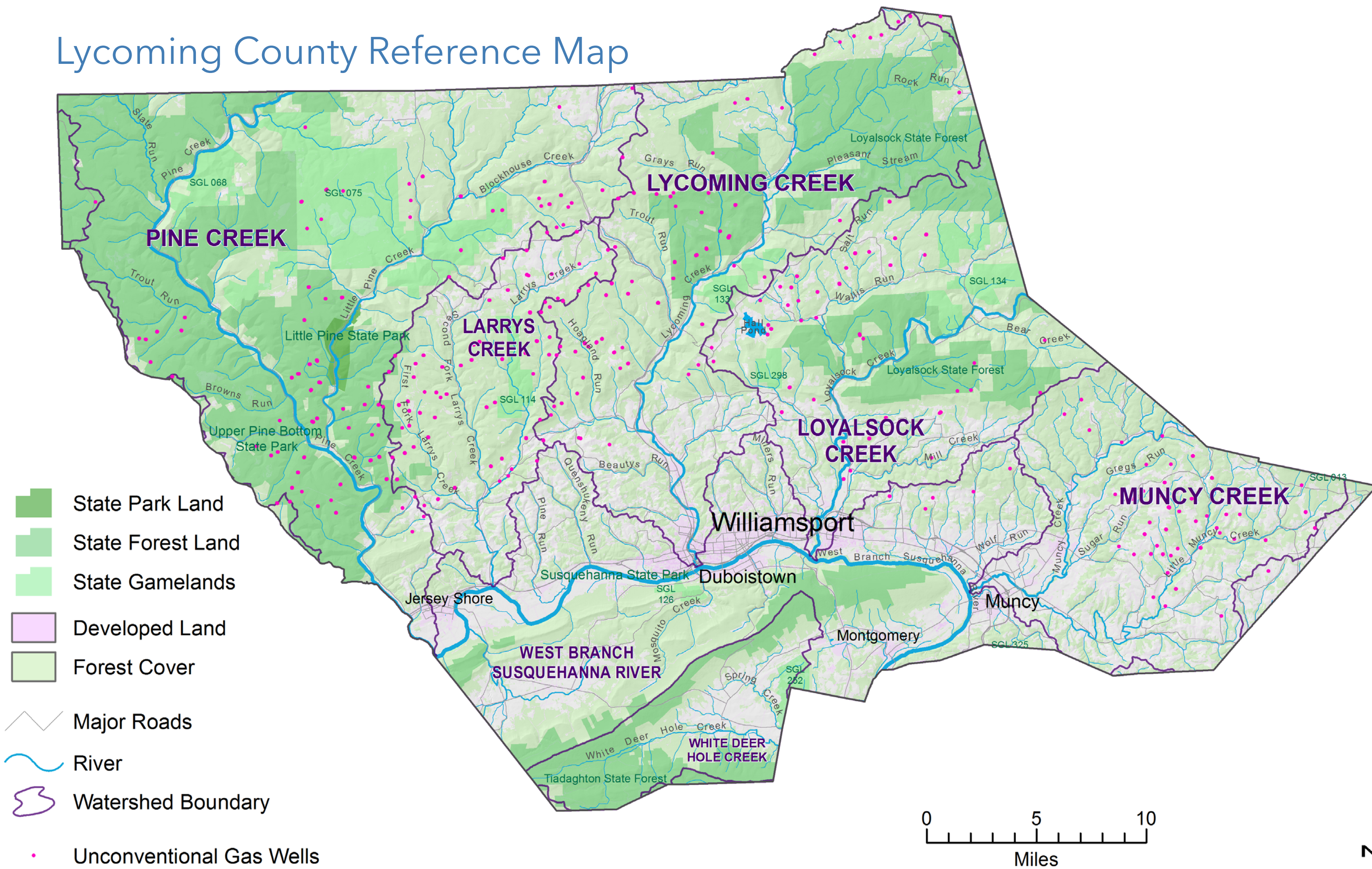
Lycoming county is located in north-central Pennsylvania. The county has a total population of 116,111 people and the largest city is Williamsport. Approximately 920 square miles of a total 1,244 square miles in the county are forested, much of it part of the Tiadaghton and Loyalsock State Forests. The county is part of the Chesapeake Bay Watershed and includes a long stretch of the West Branch Susquehanna River. A total of 1,066 stream miles are found in the county with some of the largest watersheds being Pine Creek, Larry's Creek, Lycoming Creek, Loyalsock Creek, Muncy Creek, and White Deer Hole Creek, all of which drain into the West Branch Susquehanna River. Of these streams, 72% have naturally reproducing populations of trout. The county's northern half is defined by the Allegheny Plateau and the southern half is part of Pennsylvania's Ridge and Valley Province. Refer to the reference map for more information about the county's geography.



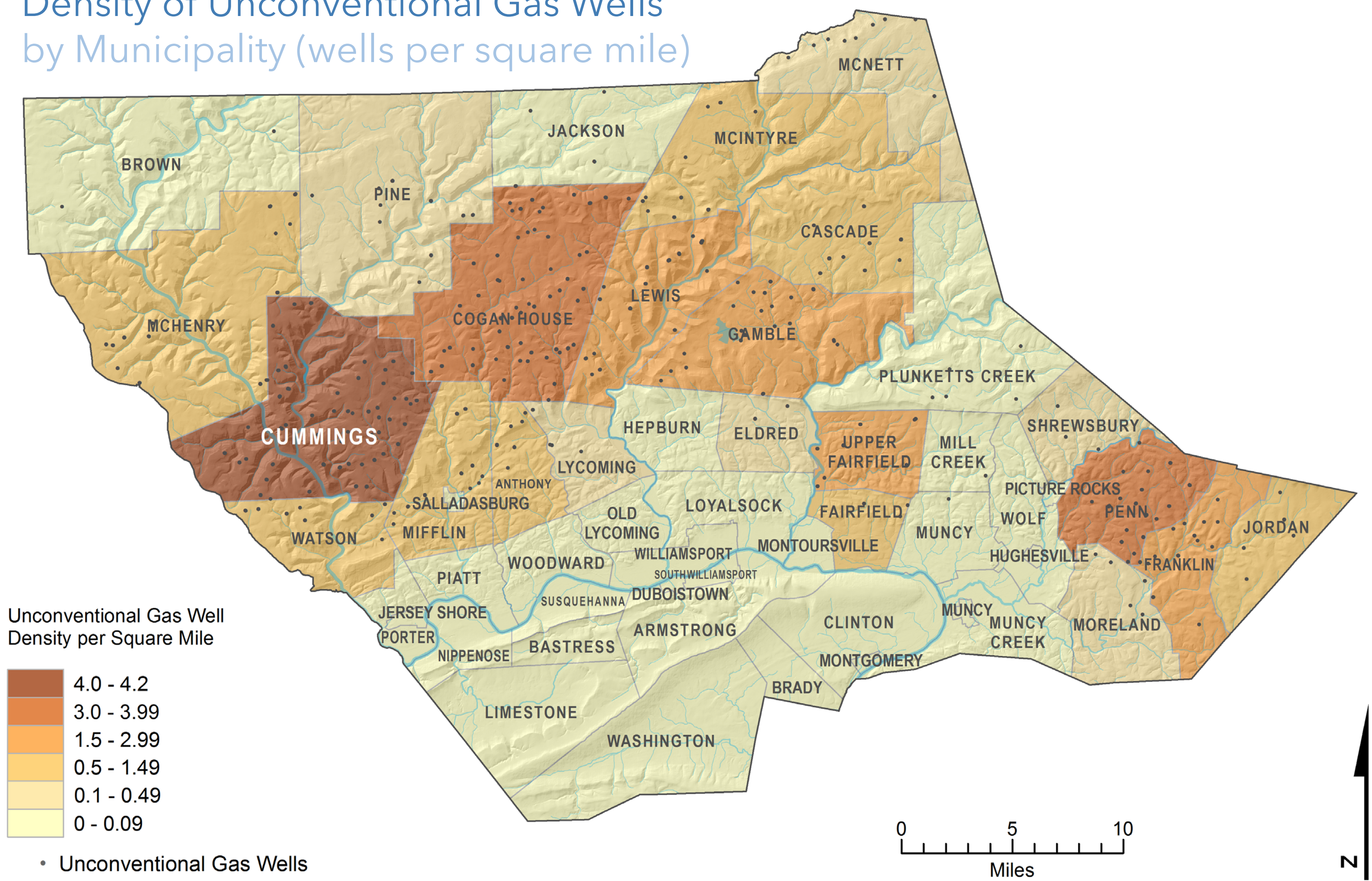
Marcellus Shale Gas Extraction in Lycoming County

In 2013, unconventional gas wells in Lycoming County, or wells that drill for natural gas in the deep Marcellus Shale formation, produced over 410 billion cubic feet of natural gas, the third highest amount for any county in the state. Among a long list of effects, this booming industry is estimated to have created 3,500 to 4,200 jobs in the county and significantly increased hotel occupancy rates across the county. From 2004 to 2011, over 9,600 Marcellus Shale and 49,500 non-Marcellus Shale permits have been issued (Slonecker et al., 2013). The sheer quantity of drilling and gas extraction has come to define this region to some capacity, yet there remains a heated debate over the impacts the industry has had on the environment.

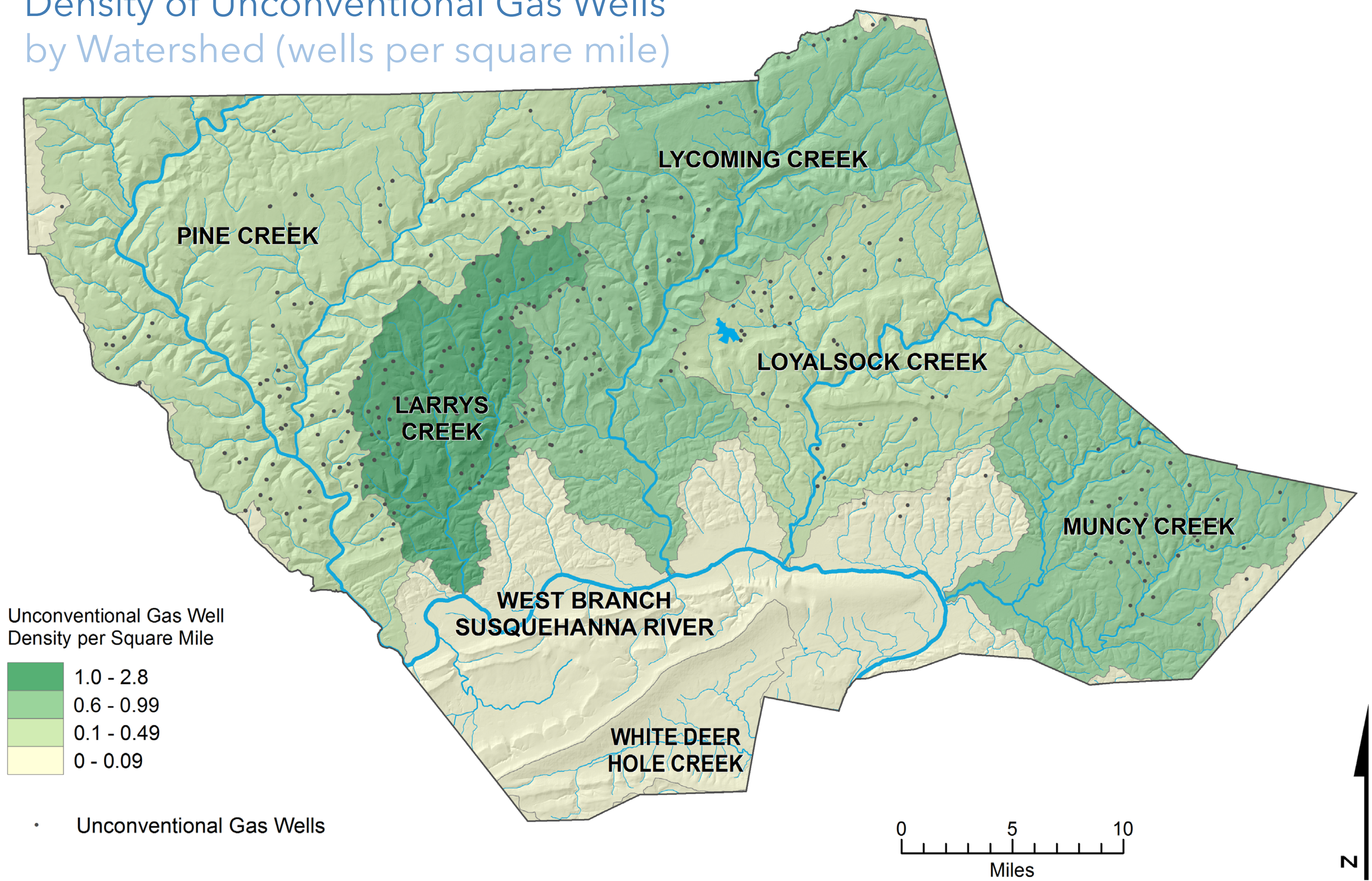
Lycoming County Reference Map



Density of Unconventional Gas Wells
by Municipality (wells per square mile)



Density of Unconventional Gas Wells
by Watershed (wells per square mile)



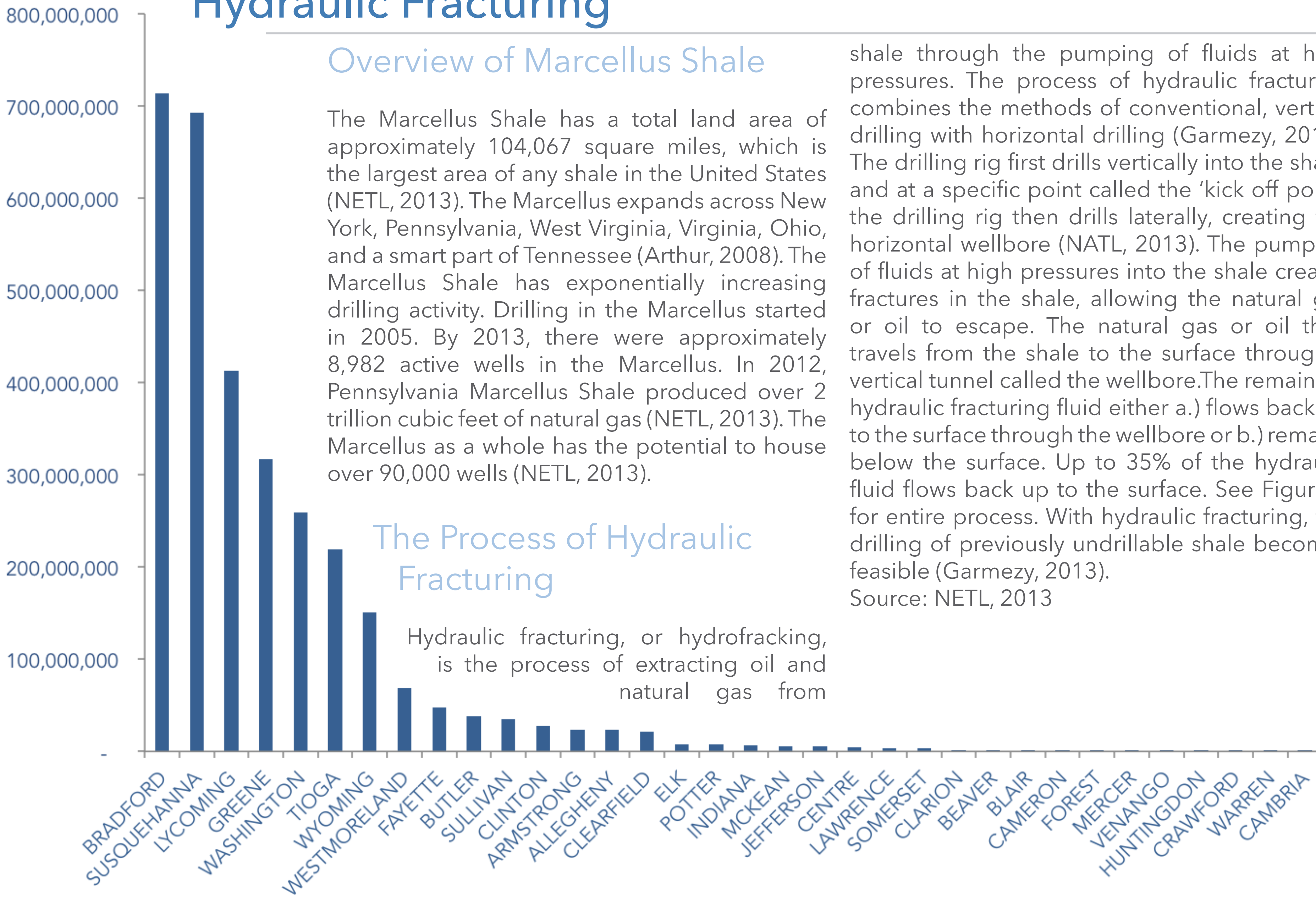
Hydraulic Fracturing

Overview of Marcellus Shale

The Marcellus Shale has a total land area of approximately 104,067 square miles, which is the largest area of any shale in the United States (NETL, 2013). The Marcellus expands across New York, Pennsylvania, West Virginia, Virginia, Ohio, and a smart part of Tennessee (Arthur, 2008). The Marcellus Shale has exponentially increasing drilling activity. Drilling in the Marcellus started in 2005. By 2013, there were approximately 8,982 active wells in the Marcellus. In 2012, Pennsylvania Marcellus Shale produced over 2 trillion cubic feet of natural gas (NETL, 2013). The Marcellus as a whole has the potential to house over 90,000 wells (NETL, 2013).

The Process of Hydraulic Fracturing

Hydraulic fracturing, or hydrofracking, is the process of extracting oil and natural gas from shale through the pumping of fluids at high pressures. The process of hydraulic fracturing combines the methods of conventional, vertical drilling with horizontal drilling (Garmezy, 2013). The drilling rig first drills vertically into the shale, and at a specific point called the 'kick off point', the drilling rig then drills laterally, creating the horizontal wellbore (NATL, 2013). The pumping of fluids at high pressures into the shale creates fractures in the shale, allowing the natural gas or oil to escape. The natural gas or oil then travels from the shale to the surface through a vertical tunnel called the wellbore.The remaining hydraulic fracturing fluid either a.) flows back up to the surface through the wellbore or b.) remains below the surface. Up to 35% of the hydraulic fluid flows back up to the surface. See Figure 1 for entire process. With hydraulic fracturing, the drilling of previously undrillable shale becomes feasible (Garmezy, 2013).
Source: NETL, 2013

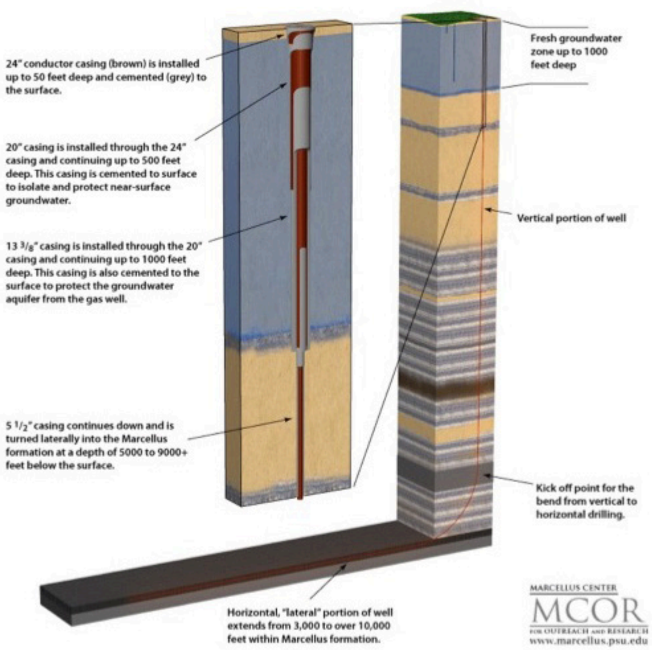


County totals of natural gas produced by unconventional gas wells in thousands of cubic feet for the year 2013. Source: Pennsylvania Department of Environmental Protection

Composition of Hydraulic Fracturing Fluids

The compounds contained within Hydraulic Fracturing fluids is a widely contested subject. The main components of Hydraulic Fracturing fluids are water, sand, and a variety of chemicals. Water is the primary ingredient in the hydraulic fracturing fluid. Sand is the main agent in the creation of the fractures in the shale.The chemical compounds used in hydraulic fracturing are categorized by function. The categories of hydraulic fracturing chemical compounds are acids, biocides, breakers, corrosion inhibitors, friction reducers, gels, iron controllers, oxygen scavenger, proppants, and scale inhibitors (Abdalla et al., 2011) The specific chemicals used in hydraulic fracturing fluids vary depending on the specific geologic composition of the shale (Garmezy, 2013). For example of Marcellus Shale, hydrochloric acid, ethylene glycol, and an antimicrobial agent are contained in the hydraulic fracturing fluid because of the specific composition of the Marcellus (Abdalla et al., 2011). The general purpose of the chemicals are to reduce friction between the fluid and the wellbore, deter bacteria contamination, and prevent wellbore infrastructure decay (Arthur, 2008). Table A provides explanations for chemicals and their purposes in Hydraulic Fracturing. The chemicals found in hydraulic fracturing fluids are also found in household items. For example, hydrochloric acid, an acid contained in hydrofracking fluids, is also contained in swimming pool cleaner.

The red line indicates path of vertical wellbore. Hydraulic fracturing fluid is pumped through vertical wellbore and then horizontal wellbore. The fluid within the horizontal wellbore forces the shale to fracture, permitting the natural gas or oil to escape. Source: NETL, 2013



Economic Considerations for Hydraulic Fracturing

Hydraulic Fracturing activities have proven profitable overall. In 2008 in the Marcellus alone, Hydraulically Fractured wells were estimated to be worth over $2.3 billion, created over 29,000 jobs, and brought in $240 million in tax revenues (Garmezy, 2013). Natural gas production in the Marcellus shale is projected to increase by 3000% as production furthers to develop in the region (Arthur, 2008). However, there are a few financial caveats to Hydraulic Fracturing. The main issue is much of the profit earned from Hydraulic Fracturing in the Marcellus leaves the region. This conclusion is derived from the fact that local residents only own 51% of the land in the Marcellus. The other 49% of the land is owned by other entities, such as oil companies (Garmezy, 2013). Nearly half of the Marcellus profits are carted away to other areas of the country by oil companies. Another way profit leaves the region is through those who work on Hydraulic Fracturing sites. Almost 40% of the Hydraulic Fracturing workers in the Marcellus originate from a different region of the country (Garmezy, 2013). The mass influx of new population can also cause problems for the endemic population of the Marcellus region. The existing infrastructure in natural gas "boom towns" cannot accommodate this quickly acquired population of workers. This leads to the overfilling of necessary public services, such as schooling and health care. Hydraulic Fracturing is generating employment, profit, and a higher quality of life, but not necessarily for the local residents.

Environmental Considerations for Hydraulic Fracturing

The main environmental issues to consider when talking about water quality in the context of Hydraulic Fracturing are:

1. Water contamination
2. Wastewater disposal
3. The required amount of water needed for Hydraulic Fracturing
4. Surface spills

Water Contamination

Water contamination is a concern because only 35% of the Hydraulic Fracturing fluid flow back to the surface, while the remaining fluid remains in the subsurface (Garmezy, 2013). The remaining fluid has the ability to climb the subsurface through fissures in the shale, possibly depositing chemicals into the groundwater. Wells located within one kilometer of a Hydraulic Fracturing site have methane levels over seventeen times higher than sites outside of the one kilometer radius. Water contamination is also more likely in water-rich states, like Pennsylvania, because of the resulting massive amount of groundwater . Hydraulic Fracturing fluid leakage from the wellbore can be mitigated by improved wellbore casing (Garmezy, 2013).

Table A: This table shows 15 types of chemical additives, their purpose in Hydraulic Fracturing, and the specific chemicals associated with certain additives. Source: (Chemical Disclosure Registry, 2014)

Additive	Purpose	Downhole Result
Acid	Helps dissolve minerals and initiate cracks in the rock	Reacts with minerals present in the formation to create salts, water, and carbon dioxide (neutralized)
Acid/Corrosion Inhibitor	Protects casing from corrosion	Bonds to metal surfaces (pipe) downhole. Any remaining product not bonded is broken down by micro-organisms and consumed or returned in produced water.
Biocide	Eliminates bacteria in the water that can cause corrosive by products	Reacts with micro-organisms that may be present in the treatment fluid and formation. These micro-organisms break down the product with a small amount of the product returning in produced water.
Base Carrier Fluid (water)	Create Fracture Geometry and Suspend Proppant	Some stays in formation while remainder returns with natural formation water as "produced water" (actual amounts returned vary from well to well)
Breaker	Allows a delayed break down of gels when required.	Reacts with the "crosslinker" and "gel" once in the formation making it easier for the fluid to flow to the borehole. Reaction produces ammonia and sulfate salts which are returned in produced water.
Clay and Shale Stabilization/control	Temporary or Permanent Clay Stabilizer to lock down clays in the shale structure	Reacts with clays in the formation through a sodium - potassium ion exchange. Reaction results in sodium chloride (table salt) which is returned in produced water. Also replaces binder salts like Calcium Chloride helping to keep the formation in tact as the Calcium Chloride dissolves.
Crosslinker	Maintains viscosity as temperature increases	Combines with the "breaker" in the formation to create salts that are returned in produced water
Friction Reducer	Reduces Friction effects over base water in pipe	Remains in the formation where temperature and exposure to the "breaker" allows it to be broken down and consumed by naturally occurring micro-organisms. A small amount returns with produced water.
Gel	Thickens the water in order to suspend the proppant	Combines with the "breaker" in the formation thus making it much easier for the fluid to flow to the borehole and return in produced water
Iron Control	Iron chelating agent that helps prevent precipitation of metal oxides	Reacts with minerals in the formation to create simple salts, carbon dioxide and water all of which are returned in produced water
Non-Emulsifier	Used to break or separate oil / water mixtures (emulsions)	Generally returned with produced water, but in some formations may enter the gas stream and return in the produced natural gas.
pH Adjusting Agent/Buffer	maintins the effectiveness of other additives such as crosslinkers	Reacts with acidic agents in the treatment fluid to maintain a neutral (non-acidic, non-alkaline) pH. Reaction results in mineral salts, water and carbon dioxide which is returned in produced water.
Propping Agent	Keeps Fractures Open allowing for hydrocarbon production	Stays in formation, embedded in fractures (used to "prop" fractures open)
Scale Inhibitor	Prevent Scale in Pipe and Formation	Product attaches to the formation downhole. The majority of product returns with produced water while remaining reacts with microorganisms that break down and consume the product.
Surfactant	Reduce Surface tension of the treatment fluid in the formation and helps improve fluid recovery from the well after the frac is completed	Some surfactants are made to react with the formation, some are designed to be returned with produced water, or, in some formations they may enter the gas stream and return in the produced natural gas.

Disposal of Wastewater

The disposal of Hydraulic Fracturing wastewater is also problematic. The 35% of the Hydraulic Fracturing fluid that does successfully flow back to the surface is contained in fluid capturing systems, such as containment tanks and storage trucks. The captured fluid is then transported to wastewater treatment facilities (Arthur, 2008). The main issue underlying wastewater is the failure to remove Total Dissolved Solids (TDS) from the water. The TDS is essentially the total amount of dissolved matter, such as sodium, calcium, and chloride, contained in the wastewater (Abdalla, 2011). TDS are considered to be benign to humans, but can have an extremely negative impact on aquatic life, such as the trout living in Pennsylvania's streams. In order to remove TDS from wastewater, the current wastewater treatment facility regime in Pennsylvania must improve. The main problem with current wastewater treatment facilities is that the facilities only offer to dilute the TDS, rather than remove the TDS content completely (Abdalla, 2011). Also, the wastewater facilities in Pennsylvania only have the ability to dilute a small amount of wastewater. Treatment facility infrastructure must be expanded in order to meet the demand for wastewater treatment. In 2011, there were twenty-five proposed new treatment facilities (Abdalla, 2011). These facilities would be able to meet the demand for wastewater treatment. The key to the success of these treatment facilities is their location to Hydraulic Fracturing sites. If the treatment facilities can be located in close enough proximity to extraction sites, the high cost of transporting waste water by storage trucks can be mitigated (Abdalla, 2011).

The Required Amount of Water Needed for Hydraulic Fracturing

Hydraulic Fracturing requires an enormous amount of freshwater, the amount ranging from two to eight million gallons. Because of the sheer amount of freshwater required for Hydraulic Fracturing, water supplies can be impacted. The immediate mass use of water can cause water withdrawals, which can in turn not only negatively impact human activities, but can also reduce stream activity for trout (Garmezy, 2013). Luckily, this is not an enormous problem in the Marcellus region. The Marcellus region receives about forty-three inches of precipitation per year, which equates to roughly 710,000,000,000 gallons per year (Arthur, 2008).

Surface Spills

The main reason for surface spills is the breakage of Hydraulic Fracturing containment tanks. Breakage in the tanks can occur when Hydraulic Fracturing wastewater is being transported to the treatment facility. Leakages can also be caused by outdated Hydraulic Fracturing equipment, along with poor usage practices of the equipment (NETL, 2013). The leakages of containment tanks introduces the wastewater directly into the environment, which can increase the probability of surface water contamination. Containment tank leakages can be mitigated through regular monitoring of wastewater extraction activities (NETL, 2013).

Land Use Changes

One major concern regarding Marcellus Shale drilling in Lycoming County is how changes in land use will affect the landscape. With approximately sixty percent of Lycoming County currently under lease for gas exploration, the potential for change is significant and widespread. Along with wells and drilling sites, development of Marcellus Shale gas extraction can bring with it new roads and new pipelines for servicing wells and transporting resources.

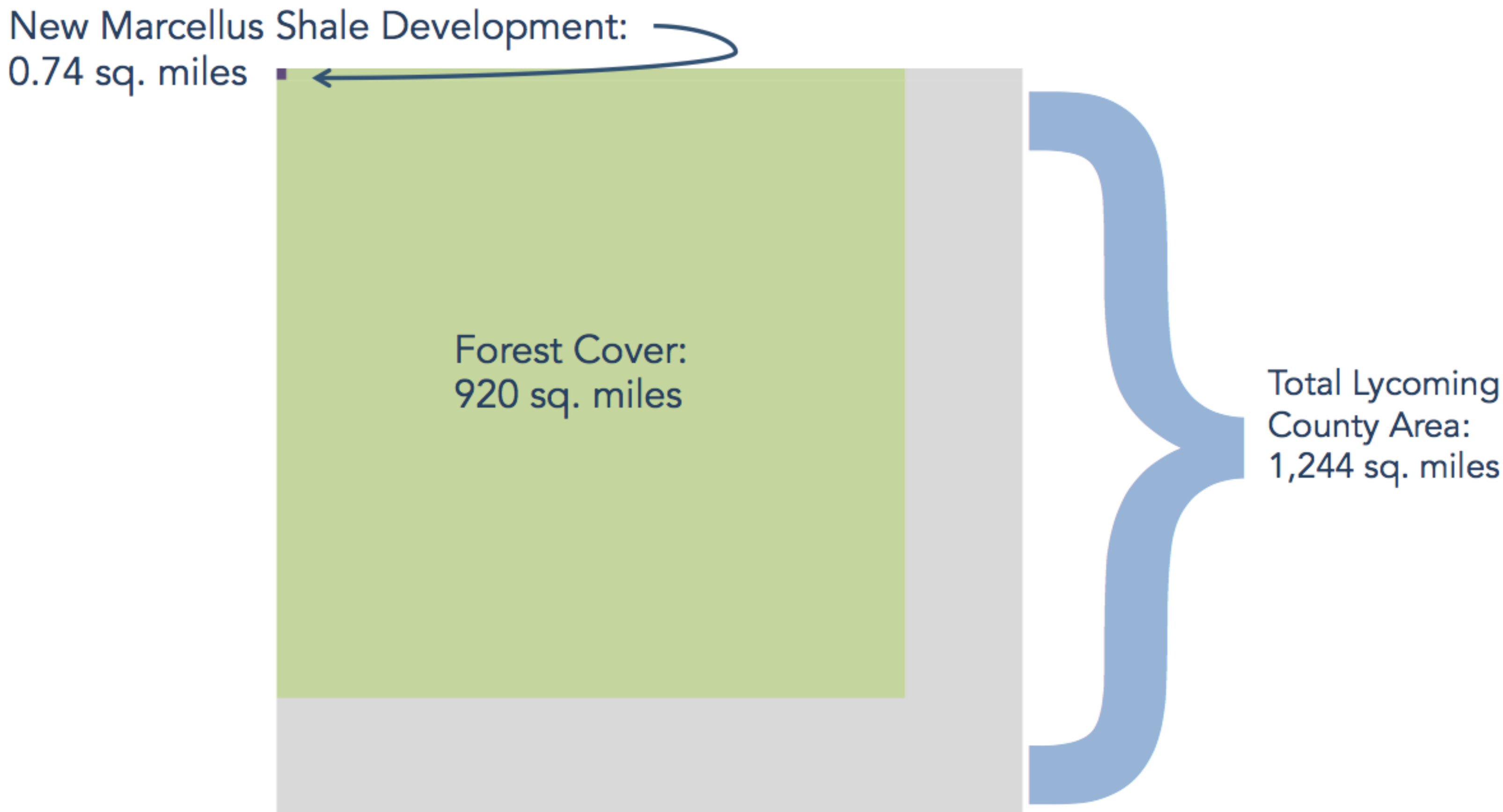
Drill pads, roads, and pipelines can cause an increase in local flooding conditions. One report found a highly significant correlation between gas well density and turbidity (Entrekin et al., 2011). This relationship almost certainly varies across the landscape and may be due to other land use characteristics in the watershed. The zoning ordinance in Lycoming County encourages screening of well sites to protect local natural habitat and it discourages the disturbance of trees or their root systems. This is an important measure for limiting the impact of Marcellus Shale gas development on the landscape. However, with gas well drilling requiring massive quantities of water, the relationship between wells and streams is sure to have its consequences. What is needed is more scientific data about surface water quality in unconventional gas well watersheds to better quantify these effects.

Direct Impact on the Landscape

The question of how Lycoming County's landscape has changed since the advent of the Marcellus Shale gas industry is more easily quantified, thanks to work done by the United States Geological Survey (2013). Both unconventional gas wells and conventional gas wells tend to co-occur in Lycoming County. In the USGS report, analysis of 2010 high resolution found that a total of 0.9 square miles were disturbed or developed since 2004 as a direct result of Marcellus Shale drilling. Of this area, 0.74 square miles was for the creation of new drilling sites, and the remaining was new roads, pipelines, or containment ponds. The average size of an unconventional gas well drilling site was 7.41 acres, or approximately 0.01 square miles. From 2004 to 2010, 22.49 miles of new roads were created to access drilling sites, with an average of 0.25 miles per site. These changes show that the impact of Marcellus Shale gas extraction, although present, remains relatively small, given the scope of Lycoming County as a whole. It is important to note, however, that these landscape changes may be more significant in some areas and changes in runoff and hydrological patterns remain uncertain.

Forest Fragmentation

The report by the USGS also looked at forest fragmentation with respect to Marcellus Shale gas extraction. Forest fragmentation refers to forest patches being split by roads, pipelines, impoundments, or drilling sites and results in a less functional forest at the ecological level with



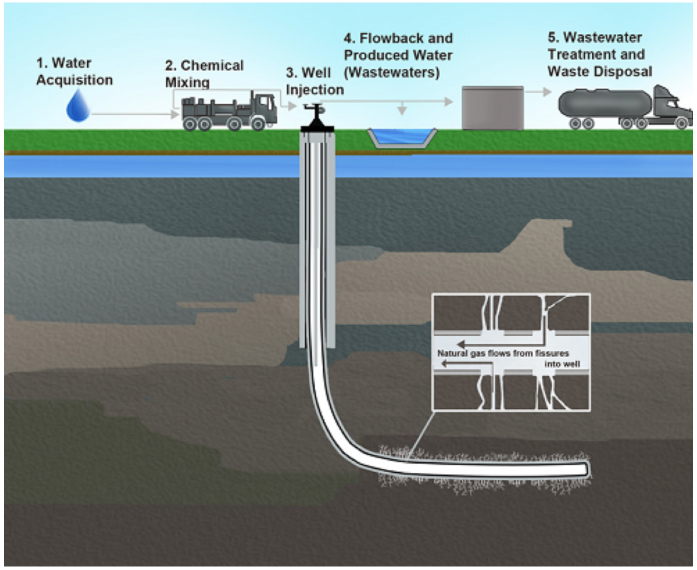
possible consequences to the health and quality of ecosystems.

Forest fragmentation refers forest patches being split by roads, pipelines, impoundments, or drilling sites and results in a less functional forest at the ecological level. In Lycoming County, approximately 74% of all land is covered by forest. Forest covers approximately 74% of Lycoming County. From 2004 to 2010, forest coverage declined by 0.04% due to Marcellus Shale gas extraction activity. Of all land categories–urban, agriculture, and forest–it was percent forest coverage that saw the greatest change. Perhaps more significantly, the construction of pipelines, roads, and drilling sites resulted in a 3% increase of forest fragmentation, which is an increase of total forest edge by 162.18 miles. The consequences of Marcellus Shale gas extraction are felt through a loss of interior forest, thereby changing the vegetation and ecosystem dynamics in some parts of the county.

Water and Waste Water

Surface Water Contamination

Wastewater is aggregated into a pond and then stored into a container, waited to be loaded on a truck to be treated at a treatment plant. Source: new.thomasnet.com



Hydraulic fracturing is an extensive water requirement process. 65% of injected water to fracture the rocks sometimes never makes it back to the surface. However, the water that comes back up, along with the natural extracted shale gas, is called flowback water or wastewater because it contains harmful chemicals, minerals, and other substances that are used to enhance the drilling process. Streams, creeks, rivers, ponds, wetlands, and lakes near Marcellus shale drilling sites are easily to get contaminated with wastewater if there are runoffs or leaching from storage tanks.

Marcellus shale gas extraction has raised concerns over possible contamination of drinking water resources in Pennsylvania. Surface water contamination seems to be the primary concern associated with hydraulic fracturing because it takes less time for contaminants to make it to the nearby water bodies.

Recovered hydraulic fluids can range from 15% to 80% of the volume initially injected, depending on the site. The wastewater or flow-back can be disposed in several ways. It may be injected back underground if such injection is permitted, it may be discharged to surface water body after treatment to remove contaminants, or it can be applied to land surfaces (Rahm, 2011). Federal regulation, such as Clean Water Act permits treated wastewater to release into the streams, rivers, or lakes if the chemicals content is less than 500 parts per million (ppm) or 500 mg/L.

Regarding to trout and their habitats, treated wastewater may be clean enough to meet the federal standard, however, the water generally is warmer after it goes through the treatment process. If the treat wastewater is released into the streams, it has the capacity to increase the overall temperature of those particular streams. Trout are cold water dwellers and they are very sensitive to the changes in water temperature. In fact, the warm water can damage trout habitats and makes it difficult for trout to survive and reproduce.

Groundwater Contamination

Aquifer systems are important supplies of fresh water for communities underlaid by Marcellus Shale formation in Pennsylvania. Typically, those aquifers are much more closer to the ground surface than the Marcellus Shale, which can be thousands of feet deep. The groundwater wells in Pennsylvania may reach only several hundred feet in depth.
The layers of rocks separating most fresh water aquifers from the Marcellus Shale are typically

siltstones and shales layered with minor sandstones and limestones. There layers of siltstones and shales generally acts as barriers to fluid flow. The layers of rocks can be several thousand feet thick in Lycoming county (Andrew et al, 2009).

Wastewater runoff poses potential contamination of chemicals and minerals to drinking water aquifers. Shallow aquifers, which typically are used for household cleaning and agricultural use, are vulnerable because the distance between the ground surface and shallow aquifers is much shorter. In fact, the top layers of soil are generally much more permeable for wastewater to seep through its way to shallow unconfined aquifers than deeper confined aquifers. Up to a million private wells in rural areas in Pennsylvania alone, that rely on shallow groundwater for household and agricultural use, have not been tested and regulated (Osborn et al., 2011). Most drinking water generally comes from confined aquifers because it tends to be cleaner and safer for human consumption. Confined aquifers are defined by the overlay or underlay layers of rock, silt, and clay, known as aquitard or aquiclude, which are impermeable for water to pass through. (Graphic 2)

One of the problems with water contamination is that flowback water from wastewater storage pond, generally located near the drilling site, potentially can be flooded after a heavy rainfall. The rain may increase the water volume in the pond. If the water level reaches the maximum storage pond's capacity, it will trigger the runoff of wastewater. Wastewater runoff can either find its way to the nearest stream or gradually permeate to local aquifers. The wastewater may take a few days in order to reach the shallow aquifers after the runoff. Layers of aquitard and aquiclude may filter some contaminants before reaching confined aquifers. However, shallow unconfined aquifers are likely and easily to be contaminated first regarding the short distance from the surface.

Unlike surface water contamination, groundwater contamination is much more challenging to solve once the drinking water aquifers are contaminated by chemicals because of limited movement and flow of water due to pressure and impermeability of rock formations. The concerns for impacts to groundwater resources are based on:

Fluid discharge to shallow aquifers due to high pressure of the injected fracturing fluids in the gas wells.

The toxicity and radioactivity of produced water from a mixture of fracturing fluids and deep saline formation waters that may discharge to the environment.

The potential explosion and asphyxiation hazard of natural gas, specifically methane gas.

Center for Rural Pennsylvania-sponsored research, which was done by a group of researchers from Pennsylvania State University in 2012, reported that dissolved methane in water wells have been reported in Pennsylvania as a result of Marcellus gas drilling. A recent study from Duke University found that dissolved methane gas concentrations in water wells were strongly correlated to the distance from the nearest Marcellus gas well (Osborn et al., 2011). Typical flow-back water is more than 99% water, but other substances are used during the drilling process. These substances may include potassium chloride, guar gum ethylene glycol, sodium carbonate, potassium carbonate, sodium chloride borate salts, citric acid, glutaraldehyde, acid, petroleum distillate, and isopropanol. These substances are added for a variety of reasons. For instance, acid helps dissolve minerals and assists with the fracturing process by creating fissures in the rock. Borate salts maintain fluid viscosity; other substances are added to prevent pipe corrosion, minimize friction between the pipe and fluid, and to prevent scale deposits on the pipe. Proponents of hydraulic fracturing practices largely argue that for the most part of these substances are non-toxic (Rahm, 2011).

Gas and fluid can migrate to drinking water aquifers. There are three possible mechanism for gas and fluid migration into drinking water aquifers that could explain the increase concentrations of gas near drilling wells. There mechanisms are:

- Physical displacement of gas-rich deep solutions from target formation
- Leaky gas-well casings - such leaks could occur at hundreds of meters underground with gas or fluid passing laterally and vertically through fracture systems.
- The process of hydraulic fracturing generates new fractures or enlarges existing ones above the target shale formation, increasing the connectivity of the fracture system.

Water Resources and Wastewater Disposal Practices

According to the United States Geological Survey (USGS), Hydraulic fracturing requires large volumes of water for drilling and stimulation of Marcellus gas well. Each well generally will use up to 2-8 million gallons of water. One drilling well may go through multiple stimulation treatments throughout its lifetime. Water withdrawal for hydraulic fracturing has raised concern on allocation of water resources. Large volume water withdrawal can have impacts on regional and local water supplies. If the withdrawal comes directly from the surface water, the alteration of ecosystem and natural habitats for freshwater organisms is likely to occur.

Arid and drought-prone areas seem to have higher risk of water shortages and tend to be problematic if drilling sites start pumping water from local water supplies, where areas in humid regions tend to have lesser risk of water shortages. In Pennsylvania, rivers, creeks, and lakes provide 65% of water used for Marcellus shale drilling. Only 35% is purchased from municipalities by drilling companies (Soeder and Kappel, 2009). Water can be transported from somewhere else by truck or temporary pipeline if the nearby water resources are not available for drilling shale gas.

Large amount of water is injected into drilling well for pressure and stimulation treatment. During the course of stimulation treatment, large volumes of fluids return to the surface. The returned fluid is referred to wastewater or flowback water.

Wastewater contains different types of water, chemical substances, and formation materials. Variety of formation materials; including brines, heavy metals, radionuclides, and organics which can make wastewater difficult and expensive to treat due to more energy requirement (Soeder and Kappel, 2009).

Pennsylvania requires wastewater from Marcellus shale drilling to be process and treated through treatment plants. Treating the wastewater from Marcellus shale drilling is one of the three practices of how flowback water and wastewater can be disposed. (INSERT Graphic 1)The second practice is to re-inject the untreated wastewater into the ground at a shallower depth. This practice is common in Texas for Barnett shale extraction but it concerns people in the Appalachian region because of possible drinking-water supply aquifer contamination. There is a proposed reinjection practice, which involves re-injecting wastewaters into a deeper formation below the shale layer. The downside of deeper re-injection practice is that it would cost more due to higher energy requirement. The third practices for disposing wastewater and flow-back water, generated during gas well stimulation treatment, is to place the untreated hydraulic fluids in an open tank to evaporate and the remaining solids can be disposed as dry waste (Soeder and Kappel, 2009). This practice has been effectively utilized in the arid and desert-like regions in American Southwest such as Texas but it might not be effective in the Appalachian regions due to year round precipitation and less arid climate.

Trout

There are several species of trout sport fish that reside within Lycoming County, PA. These species are brown, rainbow, and brook trout. Brook trout are the predominant native species, which means that they reproduce and flourish naturally without a need for stocking, and are a foavorite among anglers. Native brown and rainbow trout are also present, but a large portion of them are stocked by the PA Fish and Boat Commission to maintain species diversity and the availability of the sport fish to fisherman. Susceptible to the slightest of changes in water quality and temperature, brook trout lack the resiliency the non-native species have. 26% of the brook trout's native range overlaps with Marcellus Shale. The native range of brown and rainbow trout covers even more of that same area. Currently, Trout Unlimited opposes stocking of all non-native species into a native trout stream to prevent the competition for food and to preserve the natural species diversity. The trout within the county are found mainly in the smaller streams that are located within the Alleghenies. The Susquehanna River is one of the few water bodies that does not contain trout, but is used as a water source for the hydraulic fracturing. These species within the Marcellus drilling area are threatened by hydrological changes and runoff, as well as water quality and contamination.

Trout in Lycoming County

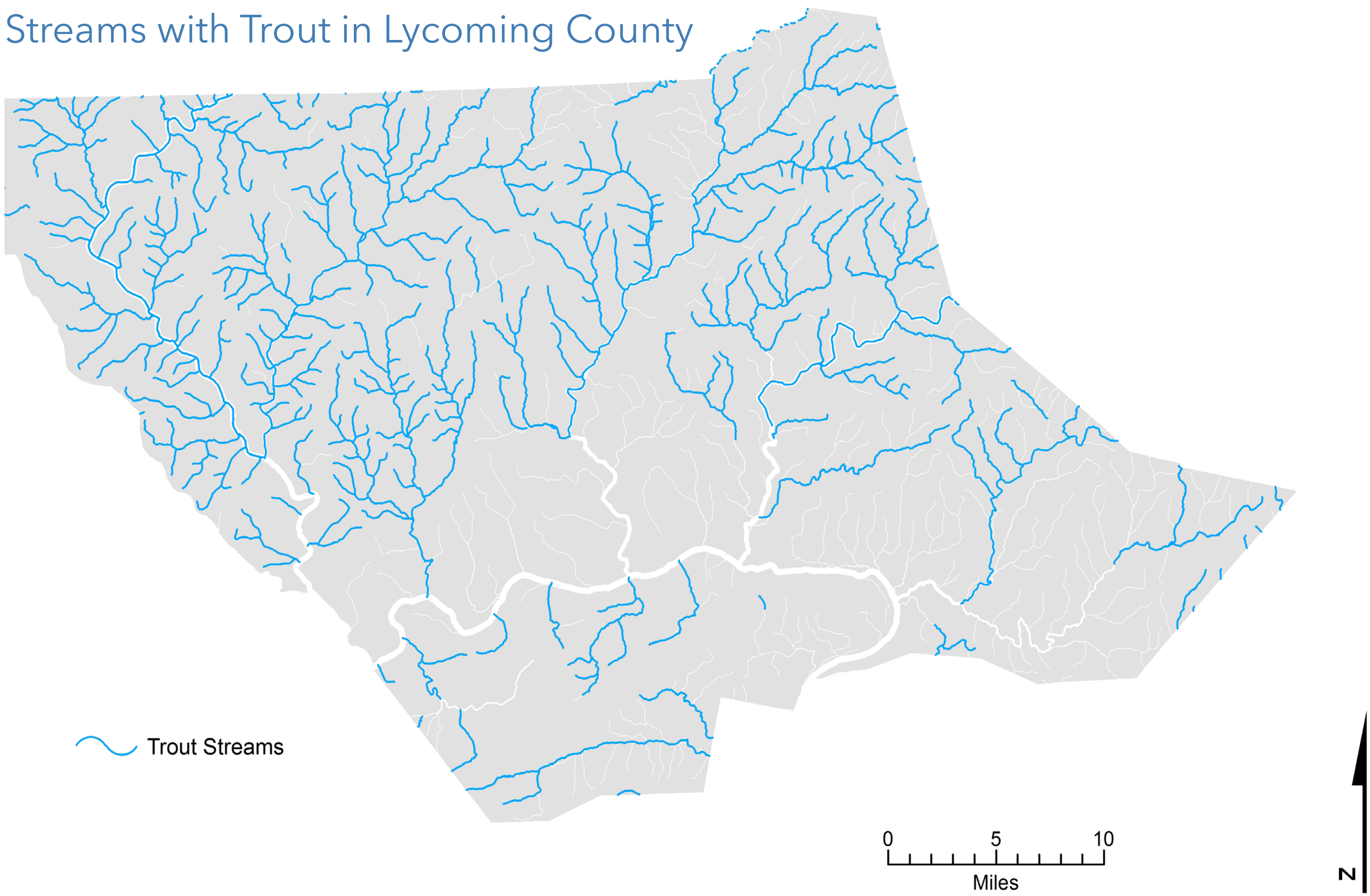
A defining characteristic of Lycoming County, beyond any other high producing Marcellus Shale gas counties in Pennsylvania, is its high quality trout streams. Figure (TROUT STEAMS AND STUFF) shows the prevalence of trout waters in Lycoming County. With 76% of streams featuring a naturally reproducing trout population and many of the remaining stocked regularly by the Pennsylvania Fish and Boat Commission, it is only the largest rivers that lack trout in their waters.

Class A and Wilderness trout streams are highly prized by anglers and environmentalists, so when the location of these streams is considered, specifically in relation to the Lycoming County's booming Marcellus Shale gas industry, there is reason for concern. The hills and forests of the Allegheny Plateau harbor some of the state's most productive Marcellus Shale gas sites as well as some of the state's highest quality trout fisheries. It is this proximity that forces a closer look at how the Marcellus Shale gas industry may impact trout streams, the regulations that are in place, and what can be done to assure that any negative impacts can be avoided or minimized.

Impacts of Marcellus Shale Industry on Trout

Since a lot of water is needed in each well for 'fracking', a large amount of it is taken from the freshwater table whether it be from underground water sources, such as wells, or directly from streams. Decreases in water amounts limit the flows and groundwater discharge sources into streams. Brook trout in particular require the colder water that comes from groundwater sources in order to survive. Deductions in cold groundwater inputs cause increases in stream temps slowing the growth rates and feeding activity of both fish and macroinvertebrate species. The reduction of water in streams limits the amount of water and the rate of flow, thus making it easier for the sun to further increase water temps. This is especially a problem in the summer months since this is when drilling activity is generally at is highest and the sun is

Streams with Trout in Lycoming County

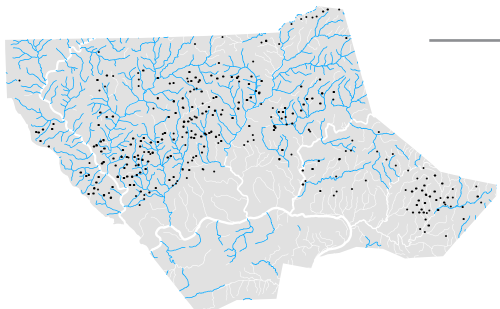


present in the sky for longer periods of time. The native brook trout desire stream temps between 50-60°F and temps above 73°F can cause heat shock and death if sustained for more than a few days. With the construction of well sites and roads there are new culverts and pipelines introduced where stream crossing is necessary. This in turn causes sections of streams or water sources to be detached or further limited. This then causes pinpoints and also puts limits on the available colder water areas that the fish have access to for spawning, therefore putting strains on future generation's population.

Another threat to the species is the occurrence of run-off and the particles that water from a drill site may bring into the streams. When a well is 'fracked' a variety of chemicals, both known and unknown, sand and water are forced down a pipeline and into the shale formation to release the natural gas. During this process the wastewater, which is sometimes re-used, is high in Total Dissolved Solids (TDS) such as 'frack' additives and toxic metals. These can sometimes escape into underground water sources or seep into the ground and then flow into a stream in the event of a rainstorm. A couple of the toxic metals in the water mixture are said to be aluminum and cadmium. Aluminum is known to cause growth stints in the trout throughout all stages of life and cadmium has been found to cause death in the adult fish before spawning. Elevated salt or bromine levels are also a big issue, since they reduce the fish's ability to tolerate temperature changes that may also be occurring in the water. After the 'fracking' process is complete the wastewater is then pumped out of the well and if it is not stored on site, it is then taken and treated elsewhere or directly injected into the earth under non-porous rock formations. If the wastewater is treated at a specific brine plant the water can be cleaned to the point of it exceeding the clean water quality standards. But if it is taken to a normal wastewater treatment plant it cannot be treated properly. In that case, it is diluted and released back into the streams at lower toxicity levels. This may limit the threats to the fish upstream that may be located in smaller more fragile stream environments but it does cause problems at the source of output and for those downstream. This increases the amount of contaminants that are introduced into a stream at one specific point, which leads to degradation of the water quality for all of those who reside further downstream. In the case of direct injection the wastewater can seep out around the rock formations and make its way to the groundwater table and contaminate cold-water sources that the trout rely on.

Although the effects on trout may not be directly seen, they are definitely present and are a current threat to the species. To relate the case to land mammals, "In western Pennsylvania, an overflowing waste pit sent fracking chemicals into a pond and a pasture where pregnant cows grazed: half their calves were born dead. The following year's animal births were sexually skewed, with ten females and two males, instead of the usual 50-50 or 60-40 split (The Nation, Fracking Our Food Supply)." In this instance, contaminants are seen to be able to affect species birth rates. Therefore, if the trout population is constantly constricted, this will eventually choke the species to the point of extinction.

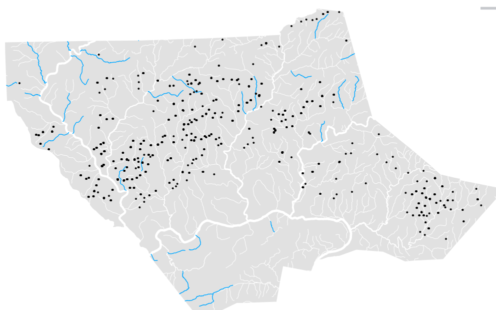
Pennsylvania Fish and Boat Commission Stream Designations and Unconventional Gas Well Distrubution



Natural Reproduction Trout Streams

Stream that have naturally reproducing trout. These streams may also be stocked by the Fish & Boat Commission.

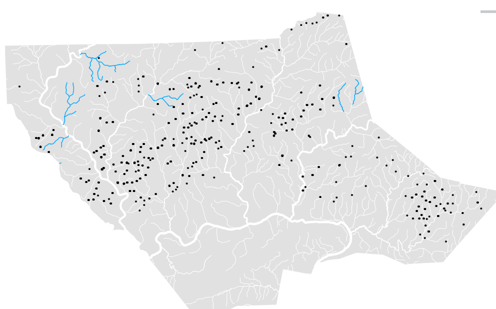
72% of streams
(766 miles)



Class A Trout Streams

Streams with wild, naturally reproducing trout of a large enough population to support a long-term fishery. These streams are not stocked by the PA Fish & Boat Commission.

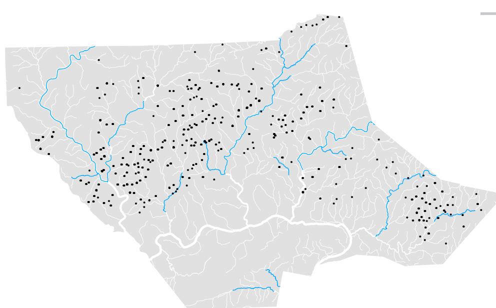
9% of streams
(100 miles)



Wilderness Trout Streams

Streams of superior quality that qualify for the Exceptional Value (EV) water classification from the DEP.

5% of streams
(50 miles)



Stocked Trout Streams

Streams that are annually stocked by the Fish & Boat Commission.

13% of streams
(137 miles)

* black dots represent drilling sites, blue lines represent trout streams

Existing Regulations and Recommended Practices

The following section will focus on some of the more commonly recommended practices, and existing regulations that are in place, with respect to the drilling of Marcellus Shale. The best starting point for the recommended standards can be found through the Marcellus Shale Coalition (MSC). It is important to note that the documents put out by the MSC are, according to the disclaimer found on each one, “not intended to establish or impose binding requirements.” In other words, these are just recommendations and are not enforceable by law. However, the first article that will be looked at, which was published by Penn State Extension, focuses more on the current regulations that are enforceable in PA, with an emphasis on water supplies. The three documents from the MSC that will be looked at are from the MSC Recommended Practices Series. They are titled:

1. Site Planning, Development and Restoration
2. Pre-Drill Water Supply Surveys
3. Water Pipelines.

Regulations

When it comes to drilling the Marcellus Shale, the first regulation that should be discussed is the need for a permit. In order for someone to get a permit, an application must be submitted to the Department of Environmental Protection (DEP) including a map of the proposed location and how close the site will be to coal seams, surface water, and water supplies. The proposer must also notify any drinking water supply owners and people with private wells or springs within a 1000 feet that they intend to drill.

While the drinking supply owners within a 1000 feet must be notified, the well can actually be drilled as close as 200 feet to the drinking water supply. As for other bodies of water, such as springs, streams, and wetlands larger than an acre, the well must adhere to a setback of only 100 feet.

The operator of the well is then responsible for any pollution that occurs in the water supplies within the 1000-foot radius of the well, for up to 6 months after the well is decommissioned. From Section 208 of the Pennsylvania Oil and Gas Act, if the water is deemed to be polluted, the operator must either replace or restore that water. However, if the owners of the well can prove that the pollution was there prior to the drilling, was the result of some other cause, occurred outside of the 1000 feet, occurred after the 6 month time frame, or were denied access to perform a water survey, which will be talked about in the water supply survey section, before the drilling occurred, then the operators do not need to replace or restore the water.

Of course, it is just as important to know what qualifies as polluted water. Through the Pennsylvania Clean Streams Law and a more recent revision of 25 Pennsylvania Code Chapter 95, the water is considered polluted if its total dissolved solids (TDS) levels exceed the determined standards. For well operators, their TDS levels in general, cannot exceed 500 milligrams per liter, with harsher TDS levels for any chlorides, barium, or strontium that is present in the water.

Switching from quality to quantity, the well operator is not held responsible for any change in water quantity or water flow. Instead, the local water supply owner would need to prove to a DEP inspector that the water flow has been affected. In order to prove that the change has occurred, the owner would have to hire a water consultant to monitor the water flow, since water flow data is not usually measured during the permit process.

Despite the fact that water flow data is not taken prior to drilling, well operators are still monitored with respect to their water withdrawal. While most streams have withdrawal limits based on the dependent life within the stream, the Water Resources Planning Act requires operators to register any withdrawal over 10000 gallons per day with the DEP. Also, depending on the location of the well, another permit is required to withdraw water from the local watershed. For example, in Lycoming County, the operator would need a to acquire a permit from the Susquehanna River Basin Commission (SRBC).

The Marcellus Shale Coalition (MSC) is an organization dedicated to providing in-depth knowledge of the Marcellus and Utica shale to all interested parties. In the process, they "encourage spirited public dialogue and fact-based education" and constantly strive to improve the transparency in their operations.

Recommended Practices

Site Planning, Development and Restoration

When it comes to selecting a site, it is important to plan ahead. Not only should the site meet local, official regulations, but the MSC recommends that it should also keep in line with any wishes the landowner may have. Operators should also keep in mind any future land uses that the area might go through. The MSC also recommends that both during and after site use, the site should be actively restored and not simply maintained.

Pre-Drill Water Supply Surveys

Before any drilling occurs, a water supply survey is highly recommended. In fact, performing a water supply survey prior to drilling is in the interest of both well operator and water supply owner since it provides a baseline of the water quality. With this baseline, any disputes that arise with respect to water pollution after drilling is completed, can be more easily settled. In order to remove possible biases between owner and operator, the MSC recommends that all water surveys be conducted by a certified and trusted third party.

Water Pipelines

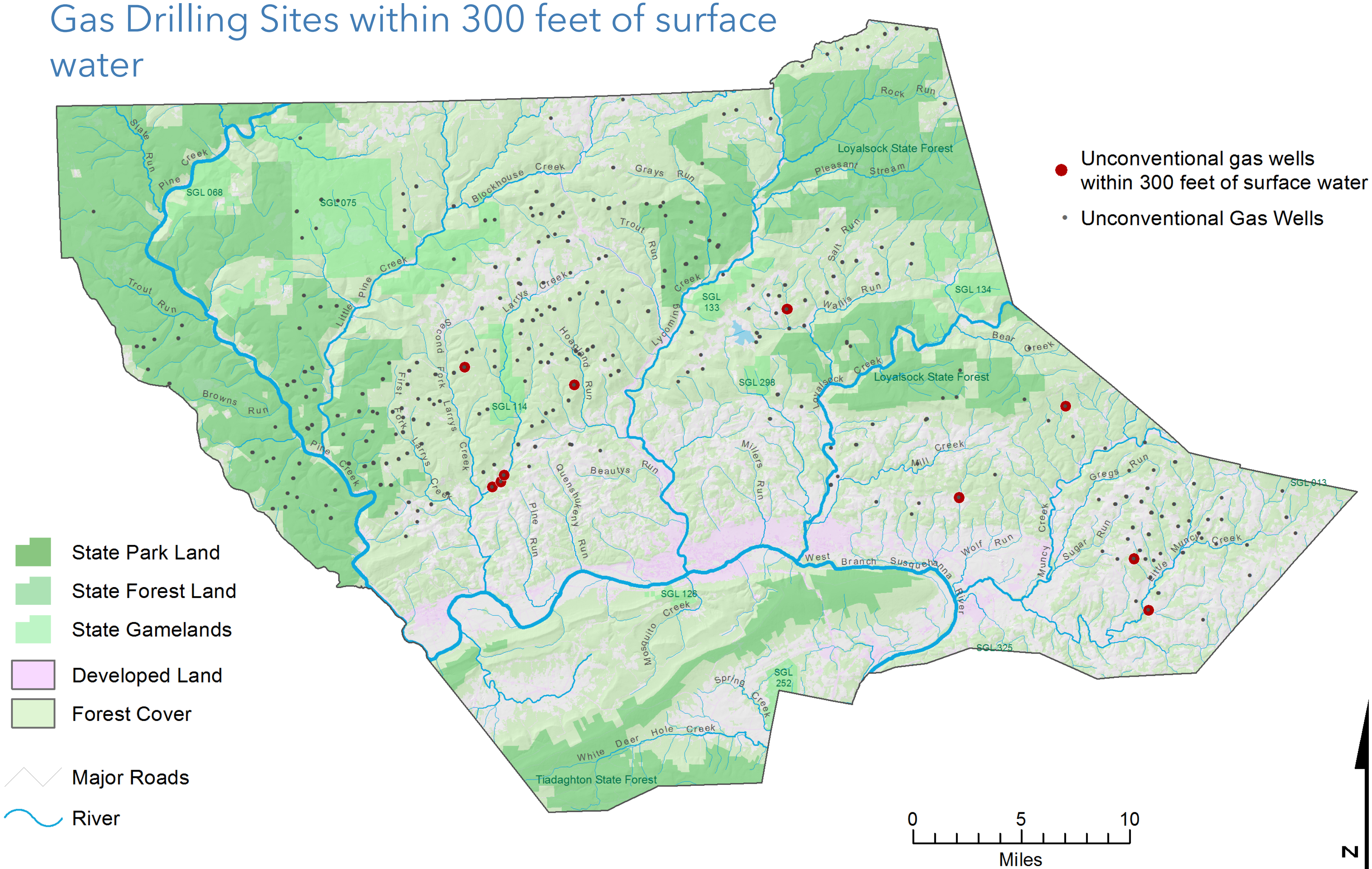
This particular MSC article takes a look at why water pipelines may be needed, how the pipeline should be built and operated, and a brief segment on what to do when it is no longer needed.

The MSC recommends that a water pipeline be built if large amounts of water is to be transported to and from a site often in order to reduce traffic and gas emissions that would be present if the water were to be trucked. Also, if a pipeline is to be built it should try to follow as close as possible to an existing corridor to minimize land disturbances. Furthermore, unless the pipeline will be used long term, it should be built above ground.

As for construction, the MSC suggests that the pipeline be constructed based on its intended use, whether that relates to material choice, diameter, valves, or restraints. For example, when it comes to the choice of materials, one such consideration is whether the water will be fresh or saline since some materials can be eroded by saline water. In the end, when the pipeline is deactivated, i.e. no longer to be used, the MSC states that the pipeline should be properly drained and then removed as best as it can be.

The Marcellus Shale Coalition (MSC) is an organization dedicated to providing in-depth knowledge of the Marcellus and Utica shale to all interested parties. In the process, they "encourage spirited public dialogue and fact-based education" and constantly strive to improve the transparency in their operations.

Gas Drilling Sites within 300 feet of surface water



Recommendations

Based on our findings, we have developed five recommendations for both Lycoming County and Trout Unlimited. These recommendations focus on the following five different areas; contaminants, possible spills/accidents, land use, trout streams, and drill site locations.

1. Contaminants

In order to minimize the chance of contaminants causing problems, we recommend that wastewater treatment only be done in fully equipped facilities. Also, we suggest that more brine facilities be built to the same end. Another piece of advice that we have is that the use of direct injection be lessened or stopped altogether to prevent future leaching.

2. Spills/Accidents

When it comes to possible spills and onsite accidents, we recommend that a team of workers be present during all drilling activities that is dedicated solely to monitoring and inspecting equipment. With this team present, should any faults begin to develop, they will be able to stop operations sooner. This same principle can, and probably should be applied during any inclimate weather that may pass through the area.

3. Land Use Change

The data we found leads to the conclusion that the effect Marcellus Shale is having on land use is minimal and therefore should not be considered a major factor in the decision making process.

4. Trout Streams

Since there is not much data currently available pertaining to trout streams being affected by Marcellus Shale, we recommend that monthly water quality tests be performed. Within one or two years, these tests should be able to show any changes that are happening. Since it would be difficult and costly to perform these tests for every stream, we further recommend that these tests be done in class A trout streams that are in watersheds with high well densities.

5. Drill Sites

For drill site locations, as mentioned earlier, current regulations state that sites must be at least 200 feet away from water supplies. We recommend that this distance be increased to 300 feet in order to reduce the possibility of surface water be contaminated by wastewater, should a spill occur.

Conclusion

While the energy issues surrounding Marcellus Shale tend to make the front pages much more often than impacts on water and trout, it is now apparent that these issues also deserve our attention. Issues of water quality and trout are not unique to Lycoming County, just as the Marcellus Shale industry and issues of natural resource extraction are not unique to Pennsylvania. More scientific research must be carried out with close attention to the results in order to fully understand what impacts Marcellus Shale may or may not be having on the health of our environment. Until then, we can be sure that the potential impacts may be significant and that Marcellus Shale gas extraction is already an integral part of Lycoming County that shows no signs of leaving.

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Spatial Data Sources

Name	Description Geography; Spatial rep.	Description	Geographic Extent	Temporal Frame	Data Format	Source	URL
Approved Trout Waters	Statewide vector center lines	Flowing public waters stocked with trout	PA	2014	Shapefile	PASDA - PA Fish and boat commission	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=Approved_Trout_Waters201401.xml&dataset=963
National Wetlands Inventory	Statewide polygons of wetlands and deepwater habitats	Classification of Wetlands and deepwater habitats (marshes, bogs etc.)	PA	2009	Shapefile	PASDA - U.S. Fish and Wildlife Service	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=NWI_PA.xml&dataset=1457
Networked Streams of PA	Statewide vector/string centerlines	Connected network of streams and waterways	PA	1998	Shapefile	PASDA – ESRI, PA DEP	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=netstreams1998.xml&dataset=16
PA County Boundaries	Statewide vector polygons of the counties	County boundaries based on PennDOT transportation map	PA	2013	Shapefile	PASDA - PennDOT	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaCounty2013_02.xml&dataset=24
Class A Wild trout Streams	Vector centerlines of class A qualified trout streams	Wild naturally produced non-stocked trout streams	PA	2014	Shapefile	PASDA – PA fish and boat commission	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=ClassA_Streams201401.xml&dataset=986
Oil and gas locations - conventional and unconventional	Statewide vector points of well head locations	All the oil and gas wells in PA located by DEP and their detailed information	PA	2014	Shapefile	PASDA – PA DEP	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=OilGasLocations_ConventionalUnconventional2014_01.xml&dataset=1088
Pennsylvania State Roads	Statewide vector centerlines of state road network	All state owned roads within PA	PA	2014	Shapefile	PASDA - PennDOT	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaStateRoads2014_02.xml&dataset=54
Pennsylvania Local Roads	Statewide vector centerlines of public road network	All public access roads within PA not maintained by PennDOT	PA	2013	Shapefile	PASDA - PennDOT	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaLocalRoads2013_02.xml&dataset=1038
Major watersheds of the Susquehanna River basin	Statewide vector line boundaries of watersheds in the basin	Catchment areas for official and un-official named streams	PA	2006	Shapefile	PASDA – SRBC (Susquehanna river basin com.)	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=wshedmjr_SRBC.xml&dataset=514
Nat'l Hydrography Dataset high res. Flowline features	Vector string centerlines of hydrography	Clipped to PA includes networked streams flow direction etc.	PA	2005	Shapefile	PASDA – U.S.G.S	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=panhdareahires.xml&dataset=334
7.5 Minute DEM for PA	State raster image of elevation in 10 meter intervals	Digital terrain and elevation information	PA	2000	Raster grid	PASDA – U.S.G.S	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=ned_10meter_quads.xml&dataset=10
PA Conservation Stewardship	Vector polygons of conservation lands in PA	Includes all lands from federal to privately owned as well as state parks etc.	PA	1998	Shapefile	PASDA – Joe Bishop- Penn State	http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=gapstewardship1999.xml&dataset=20