AN ABSTRACT OF THE CAPSTONE PROJECT OF

Fred Groh for the degree of Master of Natural Resources presented on January 8, 2018

Title: ***The Fracker's Figleaf: Booms and Busts of Sustainable Communities and Cohesive Water Governance***

Abstract approved:

____________________________________________________________ Major Professor – Todd Jarvis, Ph.D.

## Abstract

The Marcellus Shale Natural Gas play in Pennsylvania, since its inception, continues to be a source of contention for multiple Pennsylvania stakeholders. The issues that relate to natural gas extraction have seemingly impacted every community within the Marcellus Shale region in some form. As in most common pool resource communities the concept of community stability seldom reflects community welfare concerns. Thus, the Marcellus Shale exemplifies the forester's fig leaf with cycles of boom and bust which translate to socio-economic impact upon the community. The exploitation of the natural gas resources that lie beneath the region have left an indelible mark of environmental degradation and loss of well-being upon the community.

In essence, there clearly has been evidence of some haves and have-nots as a result of the extraction of natural gas in the region. Coupled with this social capital disparity is the ongoing concern of environmental degradation. This aspect is due to the use of hydro-fracking technology to extract the natural gas. Fracking (a term commonly used in the industry), which is short for hydro-fracking, is the process in which oil and gas companies drill into the ground to extract natural gas from the shale rock that lays thousands of feet underground.

Once the natural gas has been reached, gallons of water, sand, and extensive list of synthetic chemicals are injected into the well under high pressure. There are more than 50 known chemicals that may be added to the water that is used. These chemicals generally represent less than 1% of the total composition of the fracking fluid. Subsequently, a portion of the water used in the drilling process is returned to the surface. The water (called flowback or frackwater which are general terms used within the industry) upon return to the surface represents a serious a contamination concern for groundwater, streams, and soil. Thus, the context of this environmental degradation paradigm amplifies the need for socio-economic and ecological sustainability.

This paper will serve to illuminate the geology of the Marcellus Shale in Lycoming County, Pennsylvania and specifically, the issues of water withdrawal from waterways within the Lycoming County, Pennsylvania region for the purpose of natural gas extraction. In addition, the socio-economic issues will be explored as well as the issues of mineral rights, landowner royalties, and water quality/quantity protection. Also, the issues of frackwater disposal will be presented. Lastly, the recommendation of a Water Action Team approach will be discussed as a plausible solution for bridging and bonding the various stakeholders into a cohesive and collaborative water management alliance.

***The Fracker's Figleaf: Booms and Busts of Sustainable Communities and Cohesive Water Governance***

by

Fred Groh

A CAPSTONE PROJECT

submitted to

Oregon State University

in partial fulfillment of

the requirements for the

degree of

Master of Natural Resources

Presented January 8, 2018

Commencement June 2018

APPROVED:

Troy Hall, Ph.D., Program Director, Master of Natural Resources

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Fred Groh, MNR, Author

# ACKNOWLEDGEMENTS

I wish to express to my professors at Oregon State University my profound and sincere gratitude for inspiring me with world class instruction. My major advisor Dr. Todd Jarvis has provided patience and guidance from the inception of my academic journey. Dr. David Stemper and Dr. Shireen Hyrapiet have been very instrumental in providing me with not only an academic foundation but, also contributed to my ongoing interest in the subject matter. Of significance as well are professors Dr. Mark Harmon, Dr. David Turner, Dr. Bruce Shindler, and Dr. Glenn Howe. Each of these professors have been a very positive influence in my academic journey at Oregon State University.

In my personal life, I thank my loving wife, Lise, for her support and encouragement in my pursuit of the Master of Natural Resources. In addition, my family-children- extended family have been most supportive as has been my mother-in -law, all to whom I am eternally grateful. Also, my dear friend and former supervisor, Jack Cantwell, has been a source of wisdom and encouragement, our frequent talks while playing golf provided the impetus for me to dig deeper. Lastly, I have dedicated this Capstone to my parents who instilled in me a desire to pursue my dreams, and while they have both passed on, their spirit has been a source of comfort in this journey.

# Table of Contents

## List of Figures

## List of Tables

The Marcellus Shale of Pennsylvania

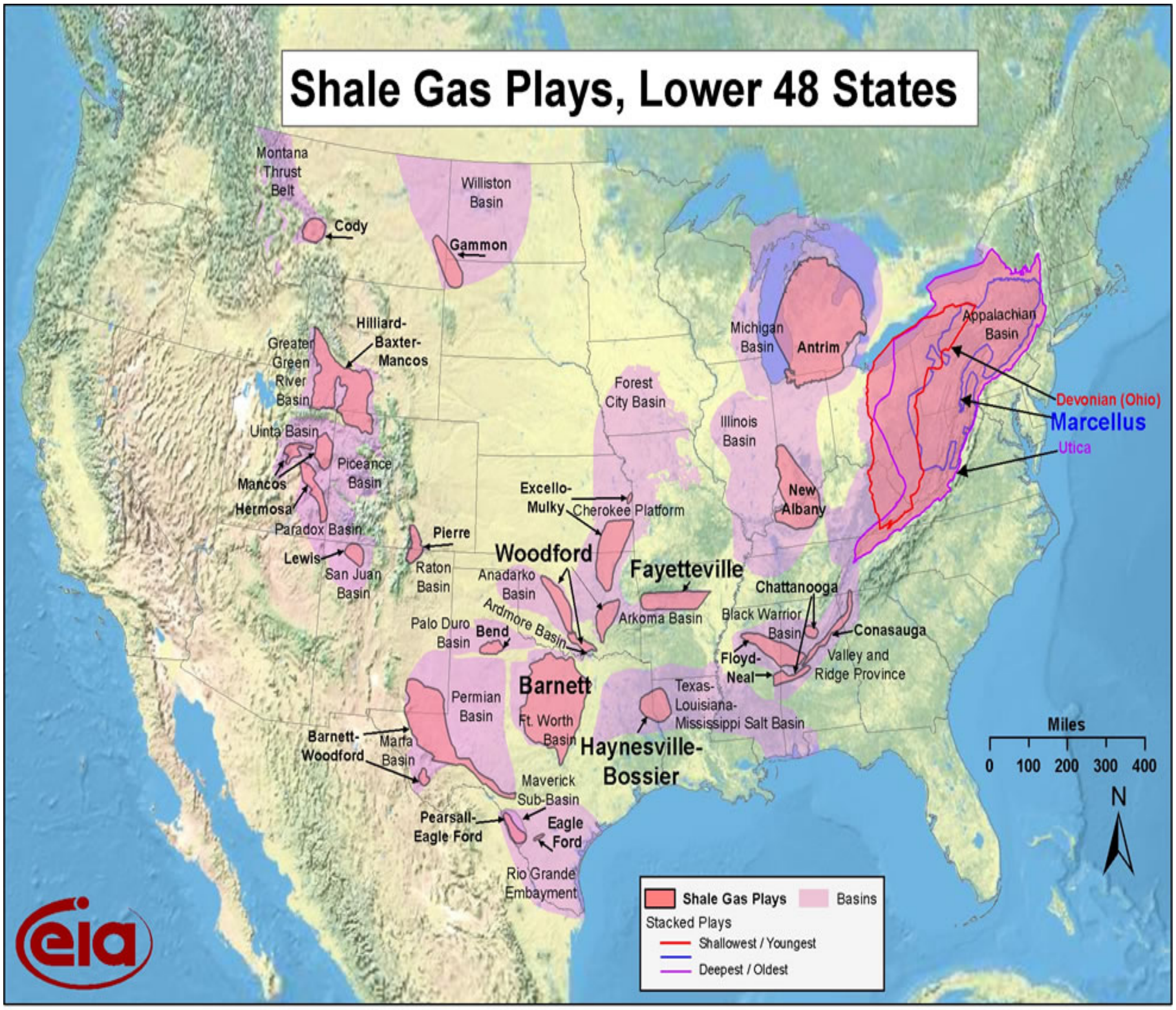
*"Never doubt that a small group of committed citizens can change the world; indeed, it's the only thing that ever has"*

*Margaret Mead*

## Chapter 1: Introduction

Hydro-fracking has played a vital role in the development of unconventional (low permeable shale gas plays) shale gas development over the course of the past decade. Due to the need to extract the shale gas from significant depth, the use of hydro-fracking has been employed in areas where conventional drilling-extraction processes are not effective. According to an estimate by the United States Geological Survey, there is a total of approximately 750 trillion cubic feet natural gas located in the contiguous United States, and roughly 86 % of the total is in the Northeastern United States (Meng 2015).

Figure 1, as shown on page 3, serves to illuminate these significant quantities of natural gas as specifically contained in the Marcellus Shale relative to the Northeastern United States region. Thus, the hydro-fracking process has greatly improved the ability to profitably extract natural gas from low-permeability geological shale plays (Meng,2015).




Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

**Figure 1.** Map of Natural Gas Plays in the Contiguous United States (King 2017).

Hydro-fracking has presumably increased the socio-economic-human capital quotient in the Pennsylvania (PA) Marcellus Shale, generating about 245,000 new direct and indirect jobs as well as the aspect that tens of billions of dollars have been invested directly and indirectly into Pennsylvania's economy (Meng 2015). For example, Williamsport, Pennsylvania, as located within Lycoming County, was once a ghost town due to the lumber industry depression, however the town has now become one of the fastest growing cities in the United States (Meng 2015).

The cyclical transition from ghost town to boom town epitomizes areas where natural resource extraction frequently occurs. The legacy of these occurrences and impacts due to extraction and processing of natural resources has a range of implications. The communities with greater dependence on a single natural resource extraction industry tend to experience lower levels of well-being. In addition, the dependence, coupled with a lack of control over the natural resource, leads to uncertainty and concern over future economic prospects (Bugden et al. 2017).

The legacy of natural resource extraction also embraces a biophysical component. Environmental impacts for example, such as acid mine drainage in Pennsylvania, have imparted an indelible footprint of ecosystem degradation upon the state. The impacts from natural resource extraction industries (mining, timber, oil, and natural gas) have reduced "local amenity values, surface and subsurface freshwater pollution in the oil, gas, and mining industries, local air pollution from oil, gas, and mining industries, and the destruction of wildlife habitat" (Bugden et al. 2017).

This natural resource extraction legacy not only impacts the ecosystem but also, contributes to the structural character of the local community political sphere and the perceptions of the residents. In essence, not only can communities come to depend on the industry, but their sense of its impacts can be actively constructed by the natural resource extraction industry to create a more positive image of the industry's impacts on the community (Bugden et al. 2017). For example, research studies have shown how extractive energy companies successfully frame themselves as the socio-economic backbone of the community (Bugden et al. 2017).

The boom and bust cycle of the coal industry upon Pennsylvania is a classic example of how experiences with natural resource extractive industries serve as essential frameworks for our understanding of how local, formal and informal, community leaders perceive the impacts of extraction activity in their communities (Bugden et al. 2017).

The assertion being that the natural gas extraction companies would fail to develop the Marcellus Shale in a responsible and environmental conscious fashion but would display the tendency to extract the resource for profit and leave in their wake a plethora of environmental degradation for future generations (Bugden et al. 2017). This premise suggesting that many areas across the United States that experience hydro-fracking "have substantial natural resource extraction industry legacies" (Bugden et al. 2017). For example, one research study noted that the focus and concerns over environmental impacts from natural gas extraction and the hydro-fracking process evolved from living in a town and region whereby the environmental scars from a long history of coal mining are visibly evident (Bugden et al. 2017).

The advocates of hydro-fracking argue that it will bring significant economic benefit while the opponents dispute that claim and point to the significant environmental risks associated with the process. The debate on both sides equates to differing projections of supplies, jobs created, tax revenues, water usage, wastewater created, and the limit of groundwater and surface water pollution (Nolon & Gavin 2013).

While there is uncertainty and potential impacts with unconventional drilling or hydro-fracking to obtain shale gas, the process is expected to increase recoverable natural gas resources globally by over 40 percent (Rahm & Riha 2012). For the Commonwealth of Pennsylvania, the construction of natural gas well pads, gathering pipelines, and access roads results in approximately 94,000 acres of land disturbance (Hanson et al. 2016). Over half of this land disturbance area, or approximately 51,000 acres, would impact agricultural land while roughly 28,000 acres would comprise the clearing of forest cover. Of the 28,000 acres of forest that would be cleared, research indicates that 12,700 acres are core forest areas. Also, over 88,000 acres of core forest would be fragmented by access road and natural gas pipeline development and ultimately converted to edge forest (Hanson et al. 2016). In essence, over 100,000 acres of core forest would be lost due to the combination of clearing and fragmentation (Hanson et al. 2016).

From a human capital impact perspective, estimates suggest that there are approximately 100,000 Pennsylvania residents who reside within one-half mile of a natural gas well pad (Hanson et al. 2016). In addition, the number of residents in close proximity to natural gas well pads could increase to 639,000 within the full build out time period (Hanson et al. 2016). The reference to full build out being the time frame when natural gas extraction is maximized and the infrastructure pipelines are in place. The exact time frame of build out at this point infers conjecture due in part to the lack of infrastructure pipelines. Likewise, research studies indicate that the number of residents who reside within one mile of a natural gas well pad could increase substantially, from 311,000 to roughly 1.8 million at full build-out (Hanson et al. 2016). These statistics illuminate the potential for environmental degradation at the land-human interface from natural gas extraction processes in the Marcellus Shale, and specifically the Lycoming County region.

These attributes formulate the basis for the contentious issues which constitute drilling for natural gas in the Marcellus Shale of Pennsylvania. The boom to bust cycle has once again manifested itself relative to the extraction of a natural resource, natural gas in this case. This premise is suggestive of the question: has Pennsylvania, and the United States in general, become better off socio-economically in gaining natural gas independence from foreign sources due to the Marcellus Shale.

## 1.1 Lycoming County, a historical perspective

The focus of this paper embraces the Marcellus Shale of Pennsylvania and specifically, the Lycoming County, Pennsylvania region. Millions of years ago the Lycoming County region was part of a great sea. By virtue of geological processes, most of the rock in the region is sandstone, shale, and limestone which formed from sediment on the sea floor (WLCC 2017). The combination of these geological processes has contributed to the evolution of the largest natural gas play in the world, the Marcellus Shale (WLCC 2017).

The Susquehanna River is the most prominent feature in Lycoming County and bisects the city of Williamsport, which is the county seat (WLCC 2017). In the 1800's, logging was the primary industry for the county and sawmills sprang up along the river. The vast tracts of pine, hemlock and hardwood which comprised the local forest made Lycoming County and the city of Williamsport a hub for commerce (WLCC 2017). In fact, "Williamsport became the Lumber Capital of the World in the 1870's" (WLCC 2017).

However, the denuding of the forest and the disastrous flood of 1889 resulted in the decline of the lumber industry (WLCC 2017). As a result of this decline in the lumber industry, the area turned its efforts to diversifying its industrial base with manufacturing firms engaging in airplane motors, valves, furniture, apparel, boilers, wire rope, electronic components, and metal fabrication (WLCC 2017). In addition, Williamsport is home to the Little League World Series which provides economic revenue each August. Also, and in view of the Marcellus Shale natural gas play, Williamsport could be considered as the capital of the shale revolution (Meng 2015).

## Chapter 2: Geology of the Region

Over twenty years ago, geologists who researched the Appalachian Basin for natural gas reserves where keenly aware of the Devonian black shale called the Marcellus Shale. The distinctive black color and slightly radioactive signature of the Marcellus Shale made it easy to locate in the field (King 2017). However, few if any at that time realized the magnitude of natural gas that was contained within the Marcellus Shale. In 2008, Dr. Terry Engelder of Penn State University and Dr. Gary Lash of SUNY stated that "the Marcellus Shale conservatively contains 168 trillion cubic feet of natural gas" (Engelder 2017). In addition, they inferred that this black shale reservoir could boost proven United States reserves by trillions of cubic feet, as dependent upon horizontal drilling technologies (Engelder 2017).

The first hint of big production from the Pennsylvania Marcellus Shale came from a well located in western Pennsylvania in 2005. Over the course of the next two years, more than 375 natural gas wells had been permitted in Pennsylvania's Marcellus Shale region (King 2017). The Marcellus Shale is nearly a mile or more below the surface and the structure map, as shown in Figure 2 on page 9, shows the elevation of the top of the Marcellus Shale in comparison to the Utica Shale.

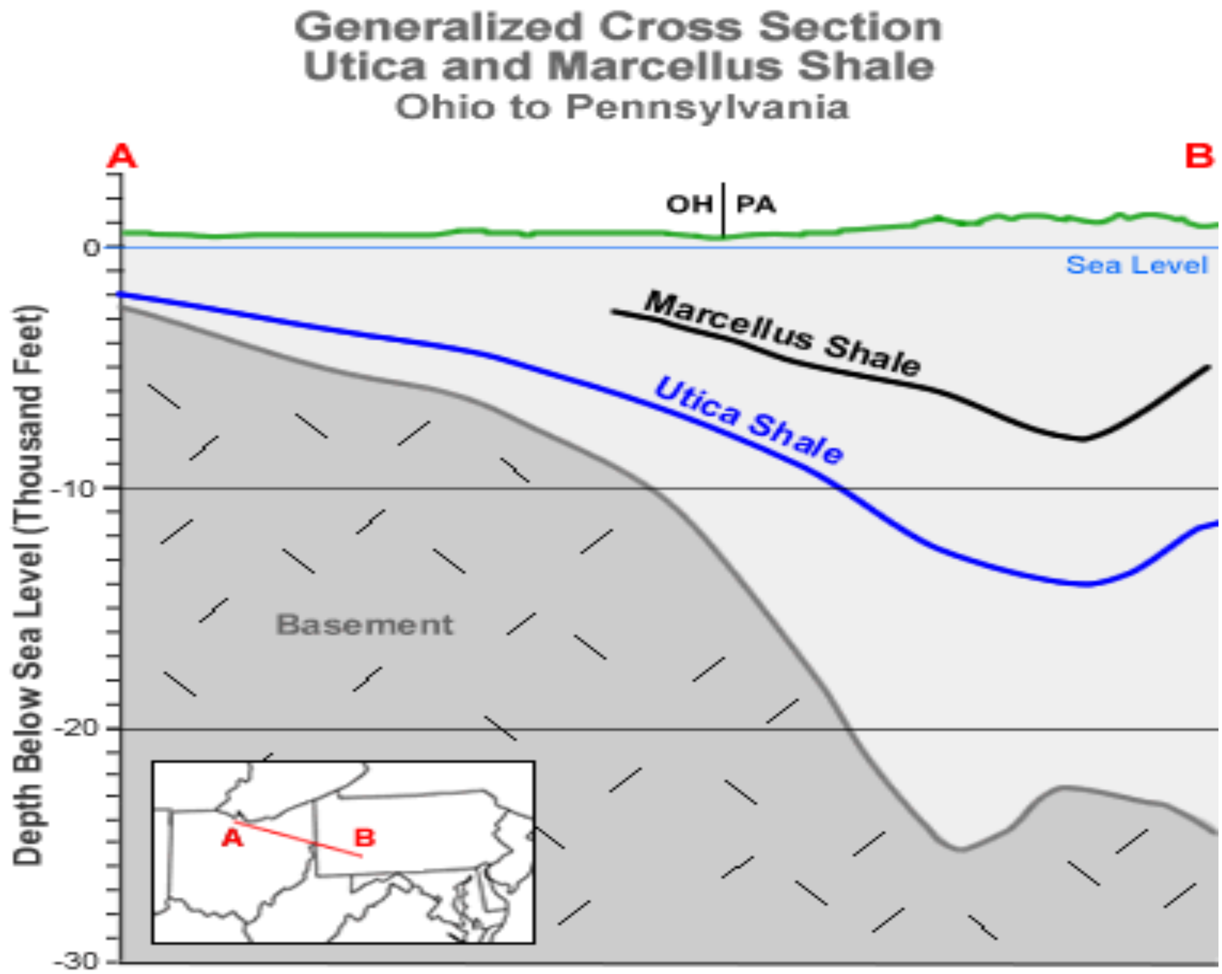



**Figure 2**. Cross-section, depth of the Utica and Marcellus Shale (King 2017).

The significance of Figure 2 is that in southwestern Pennsylvania the Marcellus Shale is very deep and then rises toward the surface in the Ohio region. This depth distinction minimizes the drilling depth to this type of shale rock formation, but it also modifies the amount of heat and pressure to which the shale rocks have been subjected (King 2017). In essence, the Utica Shale contains both oil and natural gas because the rock formation has not been destroyed by heat and pressure. As the Utica Shale plunges into the subsurface toward Pennsylvania, the amount of heat and pressure due to depth, to which the Utica Shale has been subjected dramatically increases, with the oil being destroyed and only natural gas remaining (King 2017).

The Utica Shale is an organic-rich rock formation and like the Marcellus Shale, it is the organics which give the Utica Shale a dark gray to black color, and hydrocarbon potential. The significance of the Utica Shale and its formation due to heat and pressure as the result of burial depth correlates to conodont alteration. Conodonts are the microfossils of ell-like animals that lived during the Cambrian through the Triassic geological time periods (King 2017). These microfossils are useful in determining the age of a rock unit and when heated, change color according to the temperature of the surrounding rocks. The progressive color changes have been linked to rock temperatures by the Conodont Alteration Index or CAI (King 2017).

The color progression does not reverse itself and as such, records the maximum temperature to which the rocks have been heated. The significance of which is that as the rocks are heated, organic materials in the rocks become modified due to rising temperature. At a CAI magnitude of 1, organic rocks yield crude oil and at a CAI of 2, oil is transformed into natural gas (King 2017). Thus, and as Figure 3 on page 11 illustrates, at a CAI between 1 and 2 crude oil is most likely to be found in the Utica Shale (King 2017). While at a CAI of 2 and greater, natural gas will most likely be found due to greater pressure, heat, and depth during formation (King 2017).

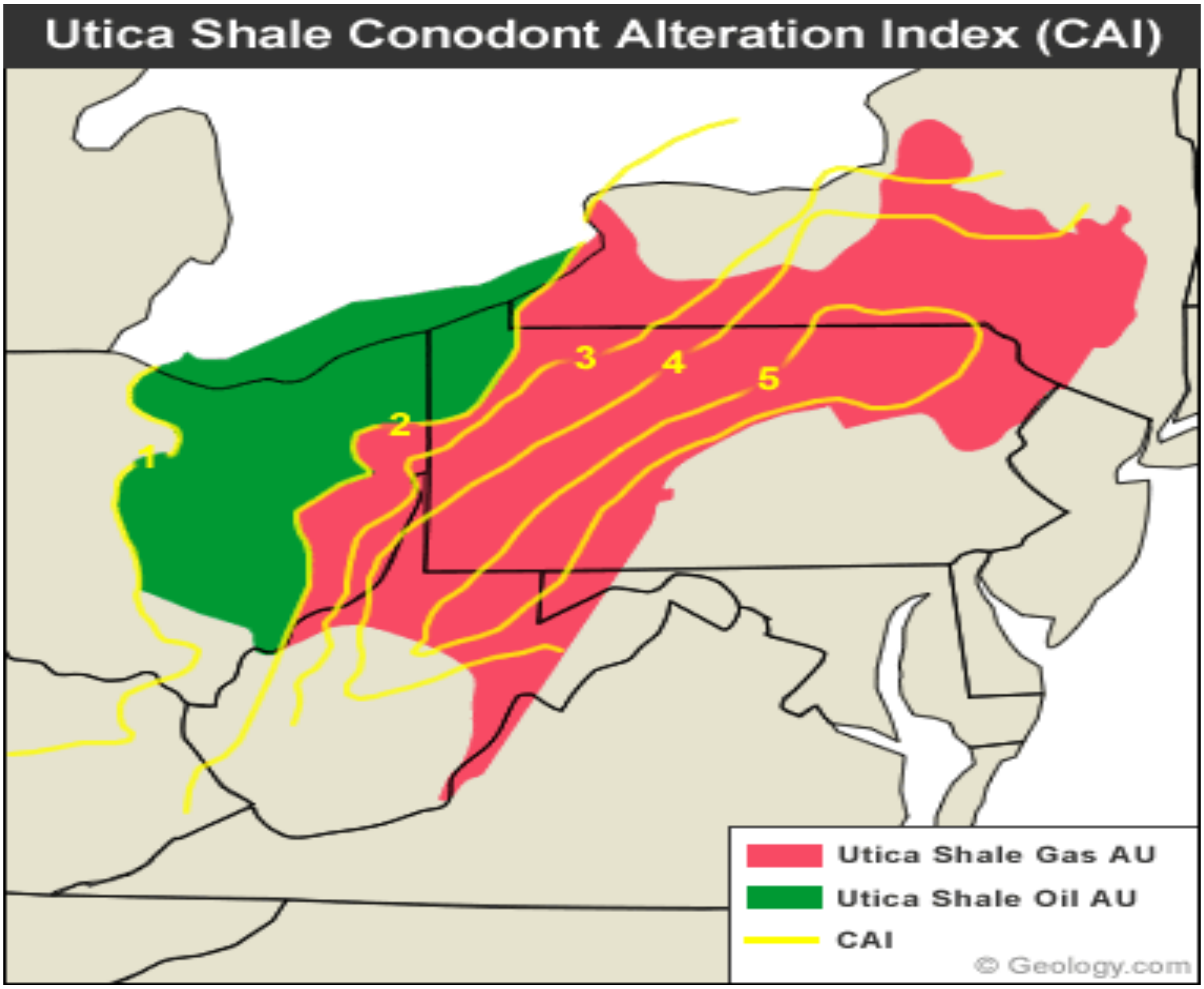



**Figure 3.** Conodont Alteration Index (CAI) Map. CAI correlates with the thermal maturity of the rocks. CAI values between 1 and 2 are normally associated with the presence of crude oil, while CAI between 2 and 5 are normally associated with the presence of natural gas, which correlates to greater depth greater depth (King 2017).

## 2.1. The Marcellus Shale and its natural gas composition

From a geological perspective, rock units are not homogeneous. The natural gas contained in the Marcellus Shale is the result of the organic matter contained therein. This infers that rocks with higher amounts of organic material will possess the ability to generate natural gas at depth (King 2017). Figure 4, as shown on page 12, illuminates the relative thickness of the Marcellus Shale throughout Pennsylvania and of significance, northwestern Pennsylvania has thick intervals of organic content and thus, the wells located in this region are the most prolific producers of natural gas.

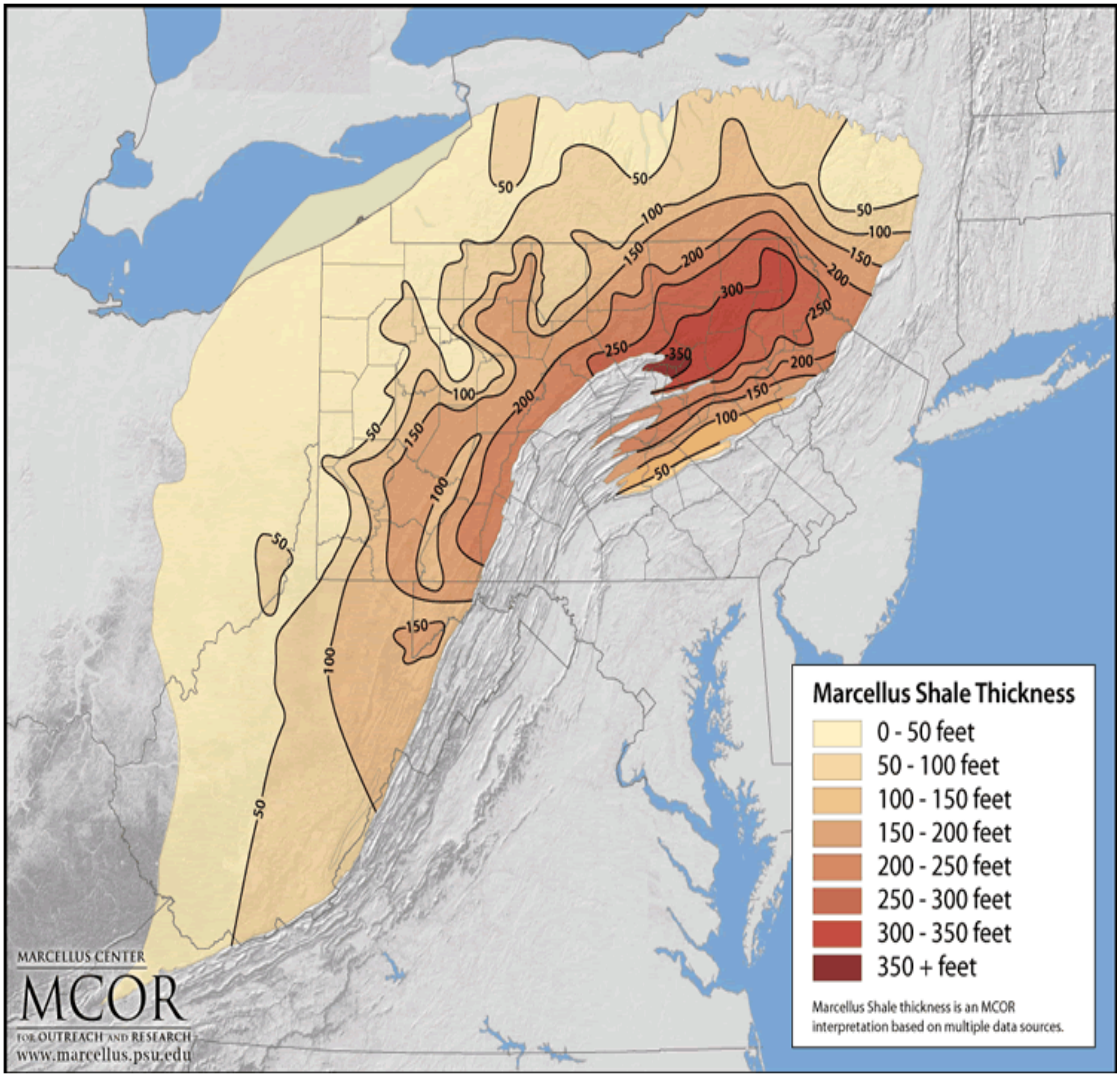



**Figure 4**. Thickness of the Marcellus Shale in Pennsylvania (Sites.psu.edu ND).

Natural gas occurs in the Marcellus Shale in three distinctive ways: 1) inside the shale pore spaces; 2) inside the vertical fractures or joints that materialize in the shale; and. 3) adsorbed on the mineral grains and organic matter contained in the shale (King 2017). The majority of the recoverable natural gas is contained in the pore spaces. However, the pore spaces are very tiny and the natural gas has difficulty escaping. Figure 5 below illustrates the tiny pore spaces between the clay particles of the shale wherein the natural gas is found.

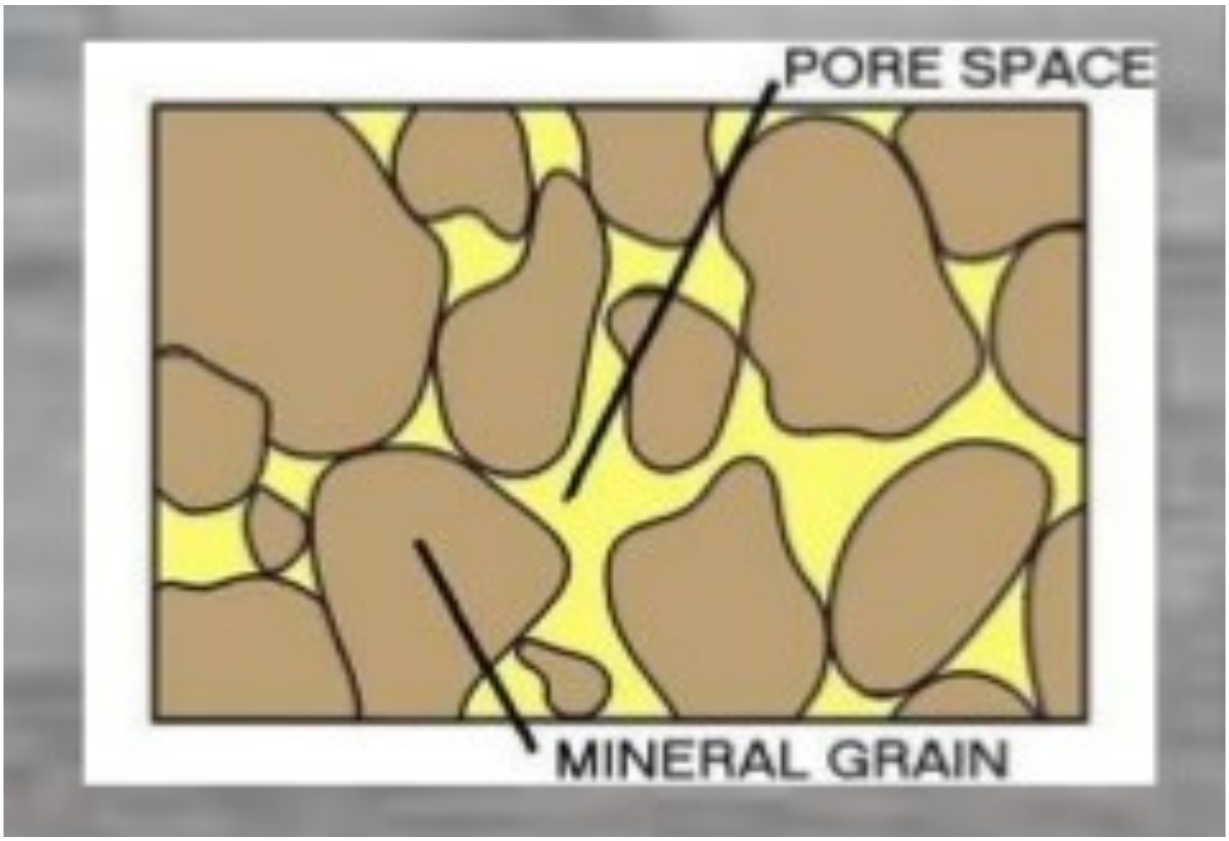



**Figure 5.** Illustration of the Tiny Pore Spaces (Slideshare.net, ND).

Most of the wells in the Marcellus Shale produce natural gas at a very slow rate due to the low permeability, as in tiny pore spaces. While this is typical for natural gas shale plays, a few of the most successful wells in the Marcellus Shale from a historical perspective share a common characteristic: they tend to intersect numerous fractures.

In general terms, the Marcellus Shale is a naturally fractured rock due to the combination of the quantity of organic matter trapped in the rock, as well as the historical plate tectonic activity (PRI 2011). The conversion from organic material to natural gas created pressure in the fluids trapped in the rock formation, which enabled the creation of fractures or joints (PRI 2011). The joints as found in the Marcellus Shale run in parallel sets in either one of two directions. For example, joints termed J1 run east-northeast while J2 style joints run north-northeast (PRI 2011). Of significance, the J2 joints have been healed which means they have been filled in with minerals and are not considered as a pathway for gas (PRI 2011).

These fractures or joints enable the gas to flow precipitously through the rock unit and into the natural gas well bore (King 2017). Of importance, the fractures in the Marcellus Shale are vertical. This lends itself to the aspect of horizontal drilling (as used to great success in the Marcellus Shale) and the process of drilling perpendicular to the most common fracture orientation. This provides for the intersection of the maximum number of fractures and increasing natural gas capture rates (King 2017). Figure 6, as shown on page 15, illustrates the aspect of horizontal drilling and the intersection of the well bore into the fractures or joints, as compared to a vertical only, or traditional, natural gas drilling process.

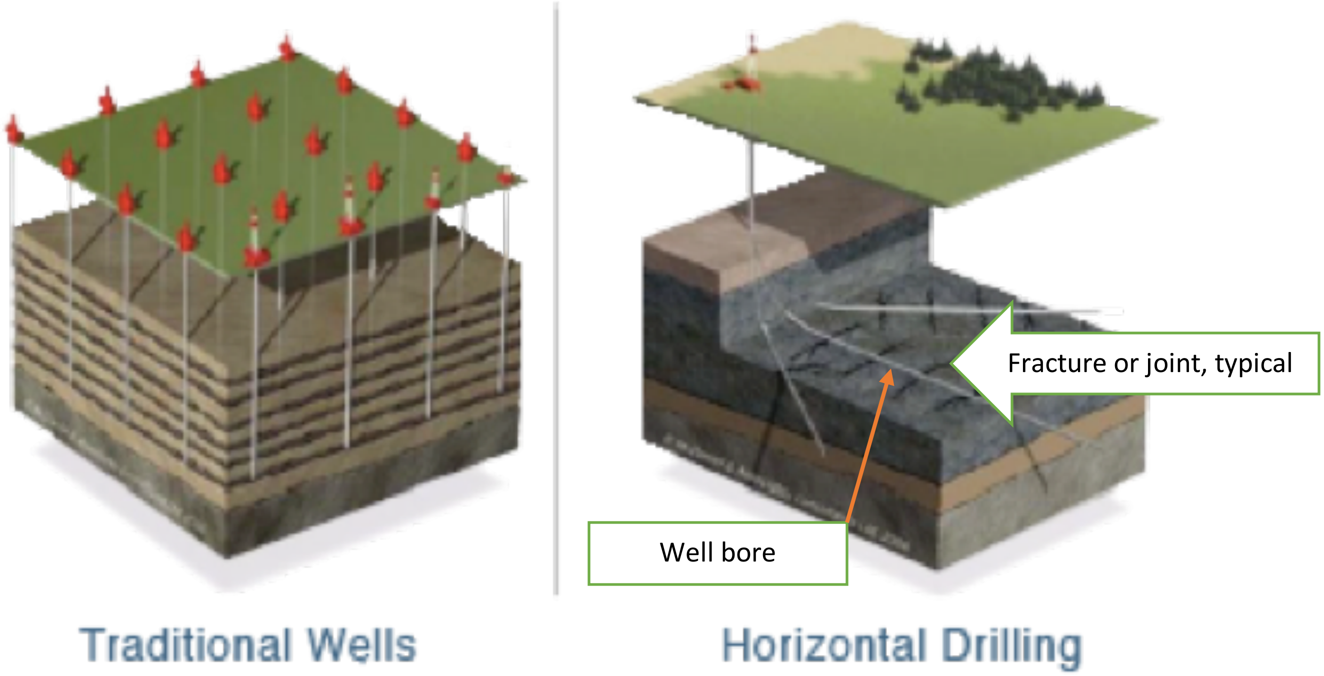



**Figure 6.** Comparison of Vertical to Horizontal Drilling (SEC 2014).

## 2.2. Hydro-fracking Methodology and Process

The methodology of hydro-fracking as employed in the Marcellus Shale increases the productivity of the natural gas well. By using high pressure water to induce fractures in the rock surrounding the well bore, the productivity of the natural gas well is increased dramatically. In an effort to sustain the fractures, and prevent fracture closure when the pressure is reduced, several tons of processed sand or other proppant is pumped down the natural gas well and into the pressurized portion of the hole. Thus, by virtue of this process millions of sand grains are forced into the fractures. Provided that enough sand grains are trapped in the fracture, it will be propped partially open when the pressure is reduced. This will enable an improved permeability for the flow of gas to the well (King 2017). Figure 7, as shown on page 16, illustrates the use of processed sand to prop open the fracture and improve natural gas flow.

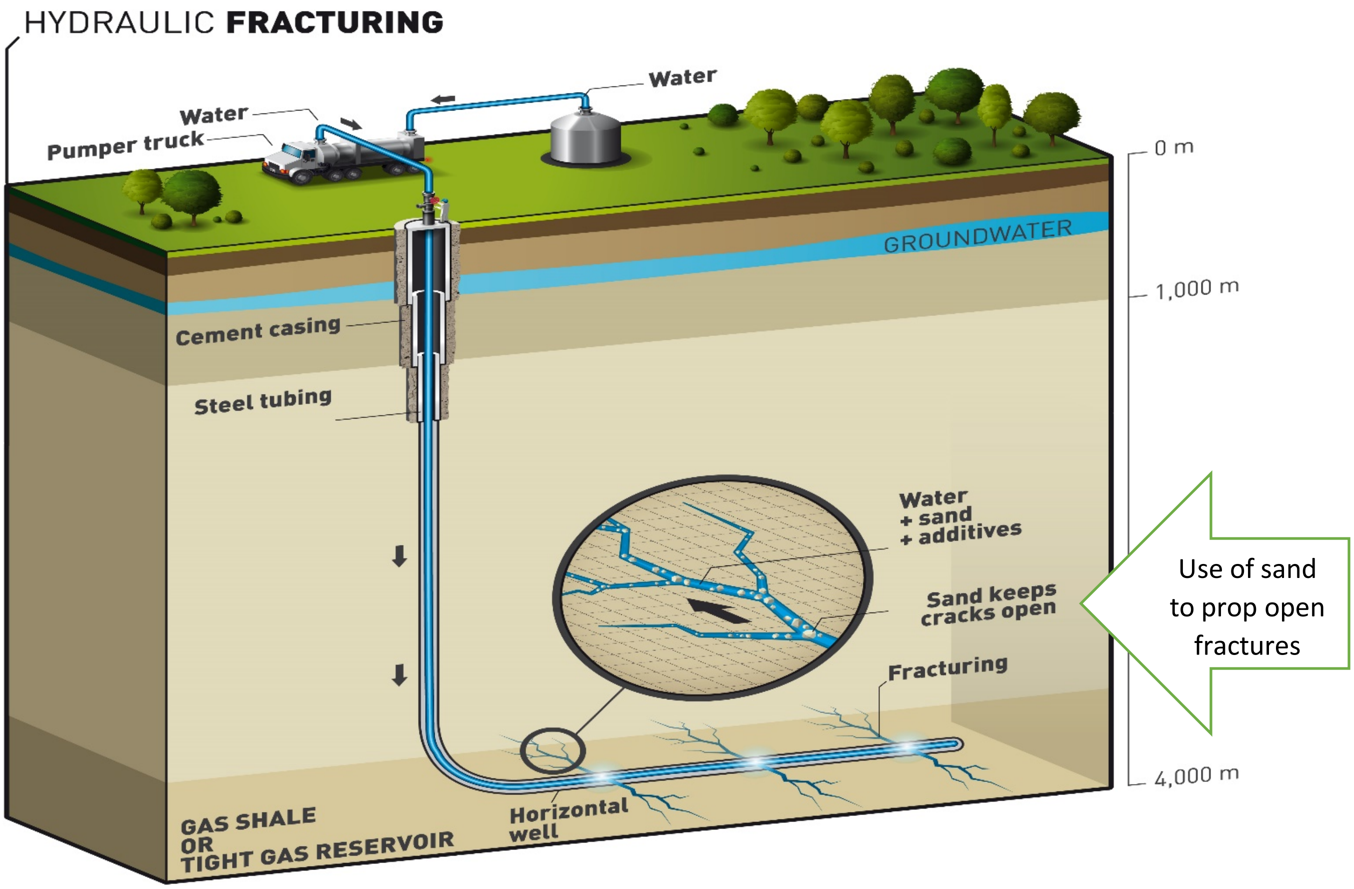



**Figure 7**. Use of Sand to Open Fractures (World Press 2014).

## Chapter 3: Context of the issue

The Marcellus Shale is located within the mid-Atlantic region of the United States and eastern Ontario, Canada. Its name was derived from the town of Marcellus, New York at which location the shale outcrops, see Figure 8 below for map.


**Figure 8**. Map of the Extent of the Marcellus Shale (MDN 2015)

The Marcellus Shale, also known as the Marcellus Middle Devonian-age organic rich formation, has an overall geological structure and thickness which was influenced by basement type tectonic patterns (EIA 2017). The Marcellus Shale was formed as a result of the continual process of sedimentation and thrust faulting over time (Arthur et al. 2008). Thrust faults occur when younger rocks are pushed above older rocks, as Figure 9 below illustrates. This type of geological action "eventually resulted in the sediments surpassing the temperature and pressure of the oil window leading to the formation of large quantities of natural gas entrained in the shales porosity" (Arthur et al. 2008).

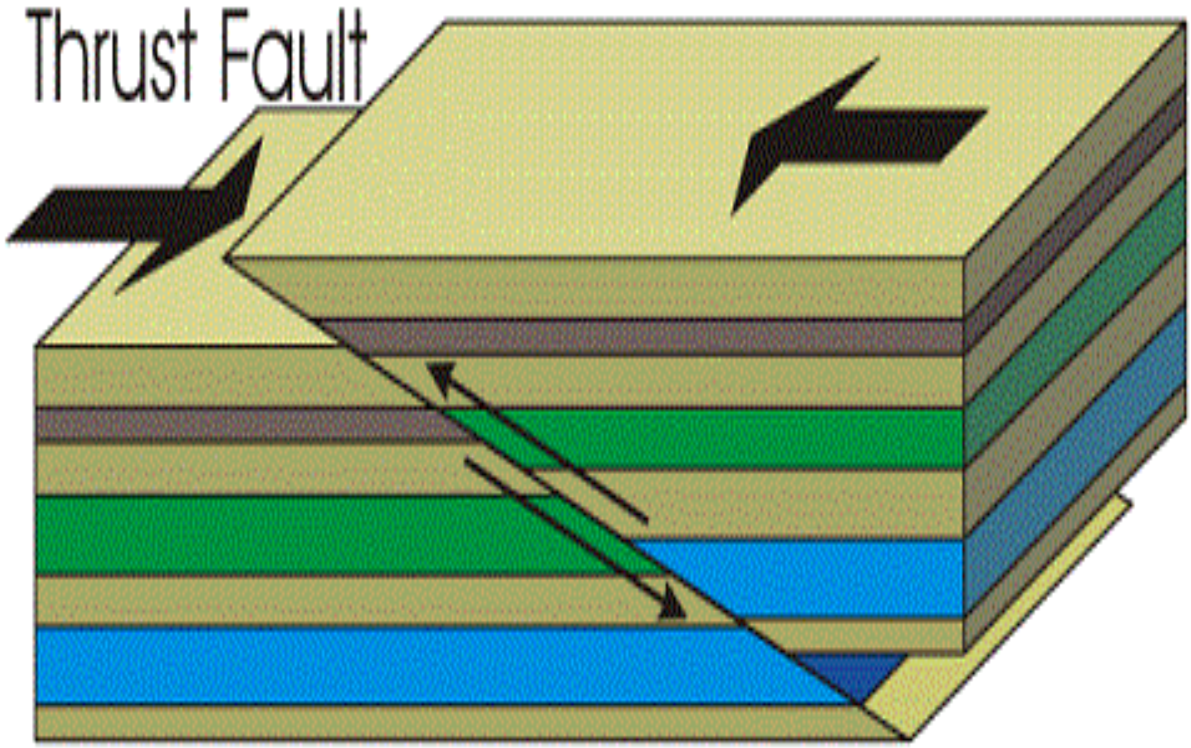
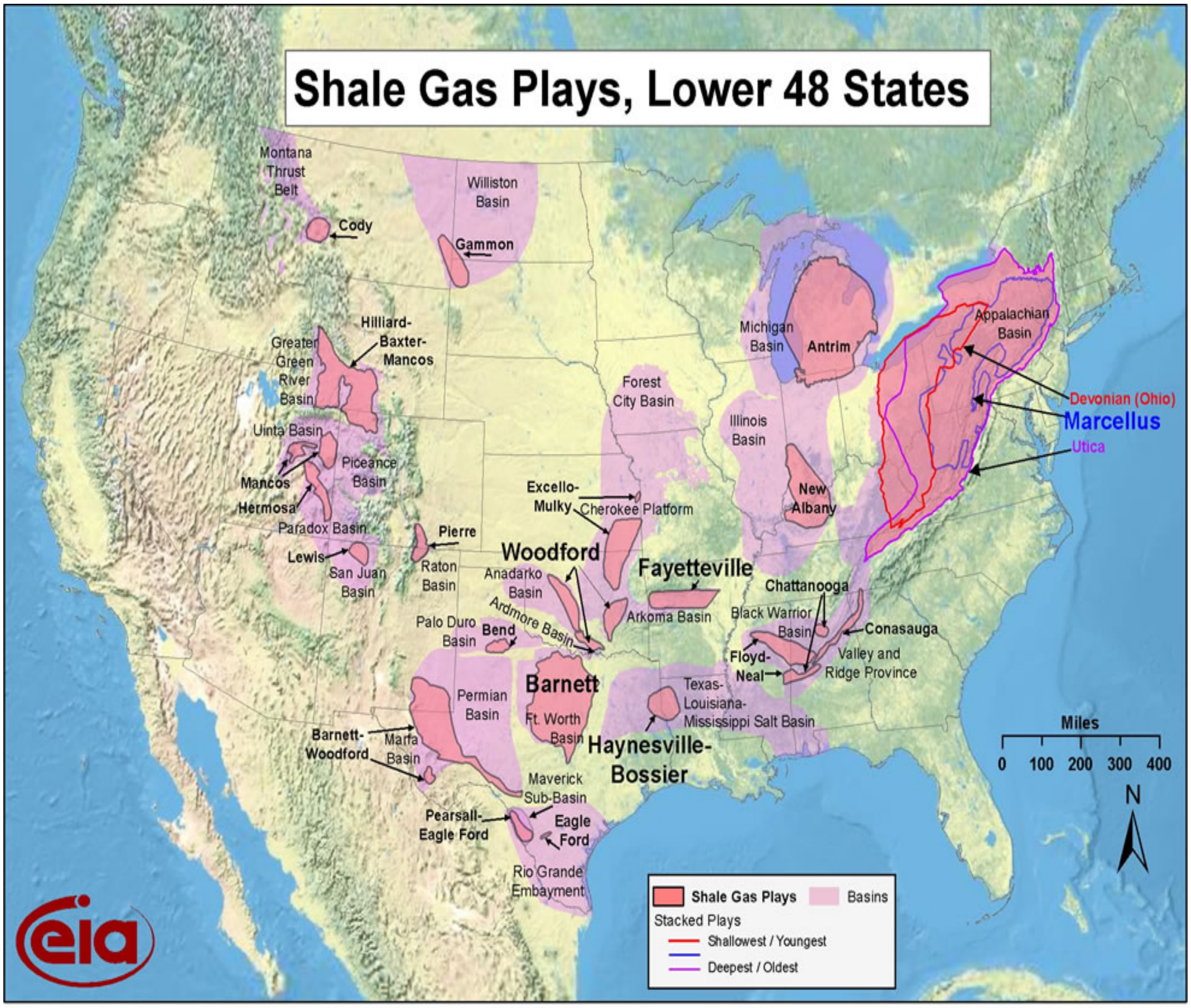



**Figure 9**. Thrust Fault Illustration. (Queens University, 2014).

The United States Energy Information Administration estimates that proven reserves in the Marcellus Shale equate to 77.2 trillion cubic feet at year end 2015. The significance of this staggering amount of natural gas makes the Marcellus Shale one of the largest of the numerous natural gas plays in the United States (EIA 2017). The map in Figure 10 on page 19 provides a pictorial perspective of the extent of natural gas plays in the United States.




Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

**Figure 10.** Map of Natural Gas Plays in the Contiguous United States (King 2017).

The Lycoming County, Pennsylvania area is the primary focus of this research effort concerning the Marcellus Shale of Pennsylvania. From a general perspective, Lycoming County has 837, 336 acres of total land of which 609, 502 (or 72 %) acres are forest and approximately 92, 107 (or 11 %) acres are crop land (Jacobson and Kovach 2007). Thus, and in consideration of drilling for natural gas within Lycoming County, land use and the accompanying natural resource interactions and linkages is of importance for ecosystem and socio-economic sustainability.

From a land study perspective, the Lycoming County region contains numerous thrust faults that compartmentalize the natural gas reserves and aquifers (PSU, 1986). Thus, and in consideration of the aquifers within this region, water quality is an ongoing concern. Groundwater can be easily polluted because of rapid permeability in the subsoil. Also, groundwater may be polluted in areas underlain by fractured shale bedrock or bedrock that has solution channels near the surface (PSU, 1986).

Water quantity and water quality are areas of interest for the Lycoming County region. Of significance, is the fact that the Pennsylvania Fish Commission stocks three of Lycoming County's five major streams with trout and bass. In addition, of the three-creek's stocked, Pine Creek has the reputation for being one of the best trout fishing streams in the United States (PAVistornetwork, ND).

These aspects illuminate the need for uncompromising regulation of land use and water quality in consideration of any natural resource extraction efforts within Lycoming County, the Marcellus Shale being no exception. The risks associated with all aspects of hydro-fracking have been investigated from a variety of perspectives, "but most concerns revolve around the use of water resources and their potential contamination" (Hatzenbuhler & Centner 2012). The obvious conclusion being that hydro-fracking potentially poses threats to local environmental conditions as well as to the health and safety of persons who depend on sustainable natural resources (Hatzenbuhler & Centner 2012). As was previously mentioned, for example, the flowback or frackwater upon return to the surface as a result of the hydro-fracking process represents a serious contamination concern for groundwater, streams, and soil.

## 3.1. The Geopolitical Context

Russia is a major player in the global natural gas market and currently slightly behind the United State as the world's second largest producer of natural gas (Phillips 2014). However, Russia's global position will not remain completely stationary in view of the shale boom in the United States (Phillips 2014). In addition, the shale boom in the United States has increased the competitive advantage of the United States and has precipitated the revitalization of domestic manufacturing capabilities (Phillips 2014). This postulate infers that the United States will reduce the need to import natural gas (Phillips 2014).

The Marcellus Shale has been a major contributor to the current global position of the United States in the natural gas market. Because of the huge quantities of shale gas that are now available, due to hydro-fracking, the strategic picture for the United States is one of self-sufficiency (Jaffe & O'Sullivan 2012). This development in and of itself has resonated globally, causing shifts in trade patterns and leading other countries in Europe and Asia to explore and develop their own shale gas potential (Jaffe & O'Sullivan 2012).

Between the time period of 1980 to 2010 dry natural gas production globally increased from 53 trillion cubic feet to 112 trillion cubic feet (EIA 2012). In North America the growth of natural gas production has equated to a 24 percent increase since 1980 to 2010 (EIA 2012). This increase correlates to the extraction of natural gas from shale plays across North America and with specific reference to the Marcellus Shale, hydro-fracking technology making this possible. Figure 11, as shown on page 22, illustrates the increase in dry natural gas production per region globally from 1980 to 2010.

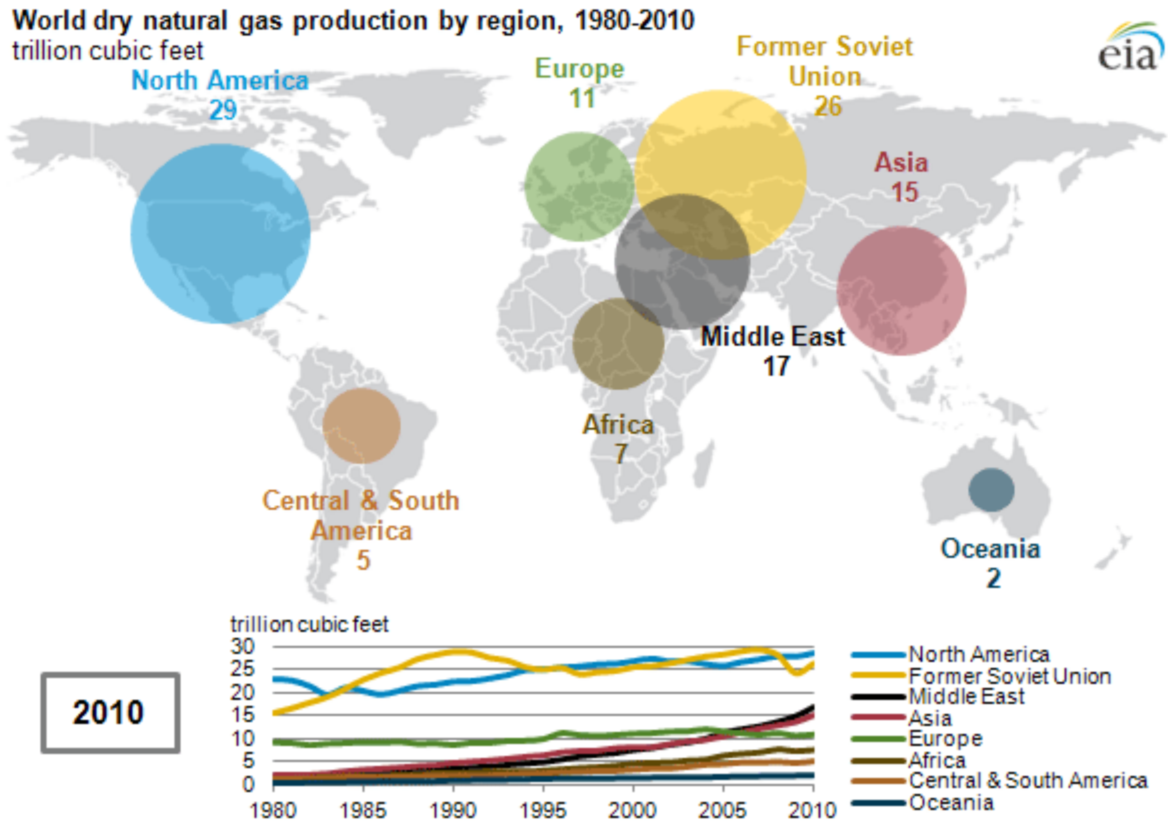



**Figure 11.** Global Dry Natural Gas Production (EIA 2012).

Geopolitics are essentially influenced by the trajectory of the natural gas market. Thus, geopolitics play a significant role in whether a number of gas projects come to fruition and where pipelines are constructed (Jaffe & O'Sullivan 2012). This aspect is most pronounced in the Pennsylvania Marcellus Shale as numerous natural gas pipeline projects have come to fruition. The basic premise being the need for infrastructure pipelines transport the natural gas to market and consumers.

The real impact of the shale boom is its ultimate influence upon the oil market (Riley 2012). Shale gas, such as the Marcellus Shale, enables the means by which to greatly increase the supply of fossil fuels for transportation, as in the use of natural gas for powering vehicles. While this ability suggests less dependence upon oil, many energy independence supporters miss a key point: the major geopolitical impact of shale gas extraction technology lies less in the fact that the United States will be more energy self-sufficient than in the consequent displacement of global oil markets by a sharp reduction in United States imports (Riley 2012).

There are two factors which are at play in this matter. First, hydro-fracking technology can be utilized for either oil-bearing or natural gas-bearing extraction processes. The second factor is the potential to use natural gas within the transportation sector, which is an immense advantage as a transportation fuel for the United States. The combination of these factors, in a broad sense, provides the United States with a greater range of options when dealing with foreign sources of natural gas. Thus, the shale revolution in the United States and shale gas plays like the Marcellus Shale serve to strengthen the United States geopolitically.

## 3.2. The significance of drilling: natural gas as a natural capital resource with socio-economic implications

The Marcellus Shale is of interest to the northeast region of the country due in part to the fact that it lies under the Appalachian Basin. This aspect implies that shale basins within this region typically yield significant quantities of natural gas (Wilkes University, 2012). The importance of shale gas drilling (and the significance of the hydro-fracking process) for the United States is because 87% of our natural gas is drilled domestically. Drilling in the Marcellus Shale enables the United States to maintain this statistic because it is now able to support its own natural gas needs (Wilkes University, 2012).

Supporting the United States natural gas needs using domestic natural gas sources, like the Marcellus Shale, is of primary importance. Natural gas has a multitude of industrial uses, as well as providing the basic ingredients for products such as plastic, fertilizer, anti-freeze, and fabrics.

In fact, industry is by far the largest consumer of natural gas, accounting for 43 percent of natural gas use across all industrial sectors (Natgas. 2013).

Within the Marcellus Shale region of Pennsylvania novel uses of the natural gas have evolved. For example, the Proctor and Gamble plant located in Mehoopany, Pennsylvania realized it was sitting on a gold mine: the Marcellus Shale. The facility tapped into the natural gas beneath the plant and as of February 2013, Pampers and Luv's diapers, as well as Charmin toilet paper and Bounty paper towels have been manufactured off the grid, using the facility's own power plant now powered by natural gas (Phillips 2012).

Pennsylvania's Marcellus Shale, and specifically the Lycoming County region, conceivably represents a positive effort to counter the demands from non-domestic resources. Yet the exploration and developmental process of a natural resource is conceivably indicative of the ultimate paradoxical potential for environmental and ecological destruction. In essence, "if the environment is considered to be a fundamental part of the human right to life, a right entails a correlative duty or obligation on the part of someone or some group to accord an individual a certain mode of treatment or to act in a certain way in a legal sense" (Susskind et al, 2002). Considering this premise, the concept of ecological uncertainty regarding the environmental issues of the Marcellus Shale hydro-fracking paradigm, become increasingly pertinent as society seeks regulatory policy prescriptions (Moss & Schneider, 1996).

From a natural resource perspective, the Marcellus Shale can be considered as a double-edged sword (Kelsey, ND). Alluding to the premise that many post-energy boom communities are no better off as a result of the natural resource extraction experience. These communities tend to display a realm of poorer economic and social well-being (Kelsey, ND). A good example of this type of paradigm can be illustrated by a study of western United States. Western United

States communities learned over twenty years ago that the boom to bust cycle of natural gas extraction is problematic. While their mat be new jobs and income flowing into the community, communities experiencing a boom in natural gas extraction experience great social upheaval as the natural gas extraction crews migrate into the community. Thus, housing becomes unaffordable and difficult to find, crime rates increase, and a financial burden is placed upon the local government (Haefele ND).

The sustainability of the Marcellus Shale providing long-term economic boom to Pennsylvania, and specifically Lycoming County, Pennsylvania is of concern. The paradigm being that, the natural gas industry is not like a long-term slow, measured manufacturing industry. If anything, the natural gas industry can be likened to the financial services industry. This implies a very speculative high-risk, short-term industry (Barlow 2014). Thus, the underlying questions from a natural resource, social sustainability, and community resilience perspective are: (1) how will the pace and scale of the drilling for natural gas impact socio-economic costs to the communities and the environment? (2) what should be the expectation regarding long-term economic development and ecological sustainability in the region? and (3) what will the communities in which drilling occurs look like in 20 years or sooner?

## 3.3. The Issue of Mineral Rights

Mineral rights comprise a key element of the socio-economic construct of the Marcellus Shale. Hydro-fracking operations are typically located in desolate and remote type areas, as there are many practical reasons explain this trend. In essence, it is advantageous to locate a natural gas well on rural land because of land-use needs (Castelli 2015). In addition, the monetary incentive to lease land from the poor in these rural areas is high, “as their marginal utility for the signing payments and potential royalties is higher than the marginal utility of the wealthy for the same amount of money" (Castelli 2015). Thus, rural property owners tend to enter into mineral right lease agreements with natural gas drilling companies.

In natural gas extraction, the surface above the natural gas is utilized to facilitate the production process. The use of the land surface is generally not (or should not be) as much of a consideration when the land owner jointly possesses the surface and mineral rights (in fee simple). This premise being based upon the fact that the owner can (though they do not always effectively) set the contractual terms of use of his/her property with a prospective natural gas drilling company (Fershee & Shay 2015).

In Pennsylvania, the property owner has the ability to sever ownership of the property's surface from ownership rights to the subsurface, which includes the right to extract natural gas (Schlegel et al. 2017). This unique legal transfer, called the Dunham Rule, is a century old rule "creating a rebuttable presumption that reservations of minerals in property conveyances do not include oil or natural gas-may not apply to natural gas found in the unconventional Marcellus Shale play" (Schlegel et al. 2017). If this ruling was not applied to unconventional shale gas plays like the Marcellus Shale, the result could have upended thousands of Marcellus Shale natural gas leases signed in Pennsylvania (Schlegel et al. 2017).

Most property owners make the assumption that they own the mineral rights below their property's land surface however, that isn't always the case (SNS 2011). The caveat being that if the property owner wants to obtain a monetary benefit by leasing property to a natural gas drilling-extraction company in the Marcellus Shale, the property owner must own the mineral rights (SNS 2011). In addition, if the property owner wants to protect his/ her land from being drilled upon by a natural gas extraction company, they must claim the mineral right before the natural gas drilling company does (SNS 2011).

Considering these aspects, drilling companies within the Marcellus Shale region have at their disposal multiple mechanisms that can be used to gain access to a property owners' mineral rights. For example, using a simple fee approach the mineral rights can be bought from the property owner and the connection between the mineral and property rights can be severed. When mineral and property rights are severed, the mineral rights can then be bought or sold without consulting the property owner. In effect, and using the simple fee system, property owners may not necessarily retain mineral rights to their property (Weidner 2013).

In many areas of Pennsylvania, as well as Ohio, natural gas companies will lease mineral rights, because it can be difficult, perhaps costly to get full mineral rights, and the profitability of a mineral right can be uncertain. In a leasing system approach, the leasing system property owners are paid for temporary access to their mineral rights. There are three ways property owners get paid for leasing their land: 1) a bonus as in a one-time payment; 2) royalties for a share of the profits with respect to the mineral extraction; and 3) as rent. In Pennsylvania, for example and by law, the minimum royalty is 12.5% of the value of gas produced minus marketing deductions, though higher rates may be negotiated (DEP 2007, Weidner 2013).

The issue of mineral rights, while applicable to private property as previously mentioned, is also of relevance to public land. In this case public land as owned by the government can be leased to natural gas drilling companies for mineral extraction. However, these leasing agreements on public lands have been controversial. For example, in Pennsylvania in 2010 and again in 2015 moratoriums were placed on the leasing of public land to gas companies for hydro-fracking purposes (Associated Press 2015).

In many states, mineral rights also include the caveat to an associated land right which includes the use of much of the surface as is reasonably needed to extract the natural gas. In Pennsylvania these rights are usually specified in the land-lease agreement. This added land surface is necessary for natural gas extraction purposes and includes such aspects as area needed for analysis of the subsurface as in seismic analysis and infrastructure such as roads and pipelines. Due to the horizontal drilling process whereby, extraction could entail sequestering the natural gas from as far as 10,000 feet horizontally underground, the amount of disturbance that property owners face is heterogeneous and localized (Weidner 2013)

Hedonistic property value has been used to measure the cost of the hydro-fracking process. Property within close proximity to a hydro-fracking location typically illustrates a decreased net worth value (Muehlenbachs et al. 2015). This decrease is heterogeneous and depends on how close the property is located to highways and other natural gas infrastructure.

## 3.4. The Economic Incentive

The substantial increase in economically recoverable natural gas reserves has enabled lower prices for residential and commercial consumers, increased reliance on natural gas to generate electricity, and heightened reliance on natural gas for industrial production (Mason et al. 2015). Thus, the economic incentive to utilize hydro-fracking is justified by the demand and price for natural gas. Natural gas prices increased and peaked in a 2005-2009-time frame as Figure 12 on page 29 illustrates. This price increase was due in part to the high demand for natural gas, since it is a cleaner burning source of energy than other fossil fuels like coal. However, due to the significant amount of hydro-fracking and subsequent natural gas extraction there was more supply than demand which resulted in a price decline in the 2016-time period.

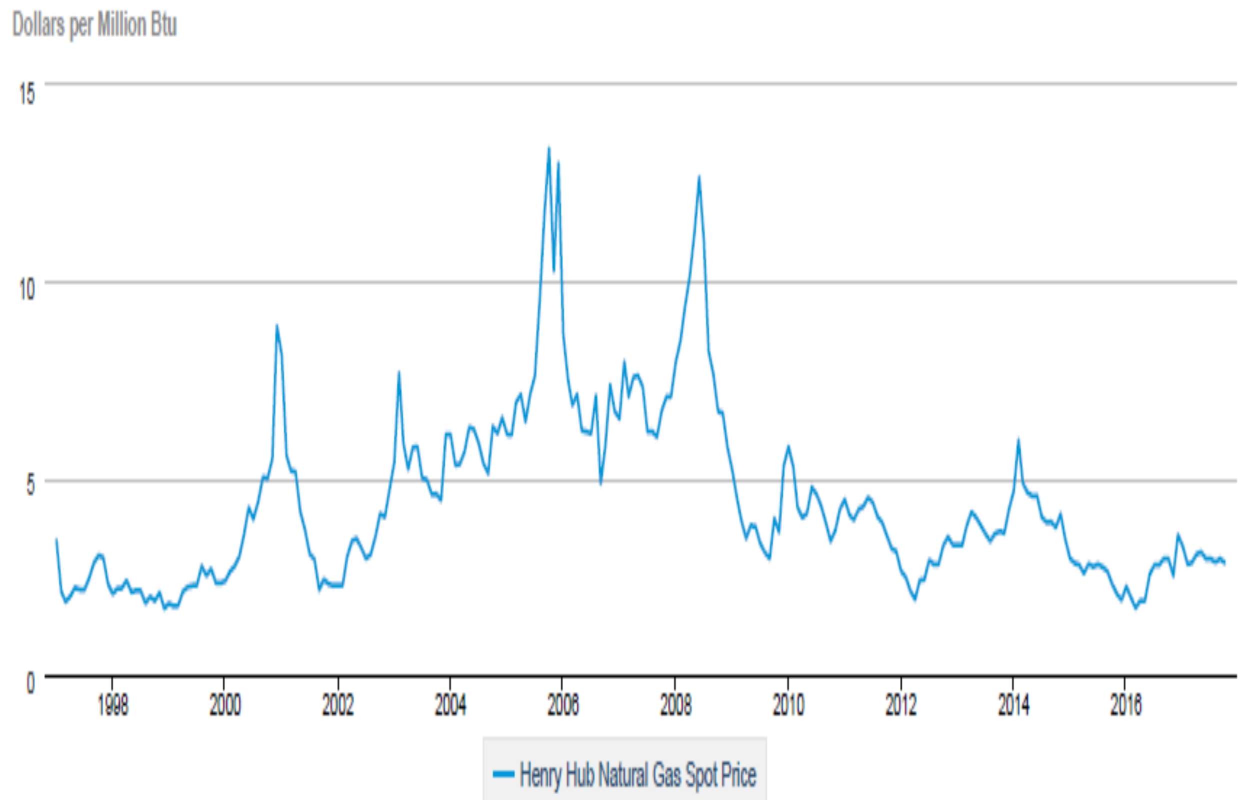



**Figure 12.** Henry Hub Natural Gas Price (EIA 2017).

Of consequence for the natural gas drilling and extraction companies was the fact that a decline in demand for natural gas occurred, due to negative externalities such as warmer winters and a glut of natural gas on the market (Woodall 2016). As a result of this decline in demand, the vast majority of natural gas companies faced declining stock prices. For example, and as shown in Figure 13 on page 30, Chesapeake Energy (a major natural gas energy company) realized falling stock prices, from a high of $70.71 on July 2, 2008 to a low of $1.50 on February 8, 2016 (Nasdaq 2017). Also, is the fact that many of the natural gas extraction companies incurred large debts as a result of the land-property-mineral right attainment process, the economic cost of the hydro-fracking process, and fines and violations. The decline in pricing also impacted the amount of drilling, as an example in 2012 Chesapeake Energy had 115 active drilling sites and by 2016 that number declined to 25. (Woodall 2016).

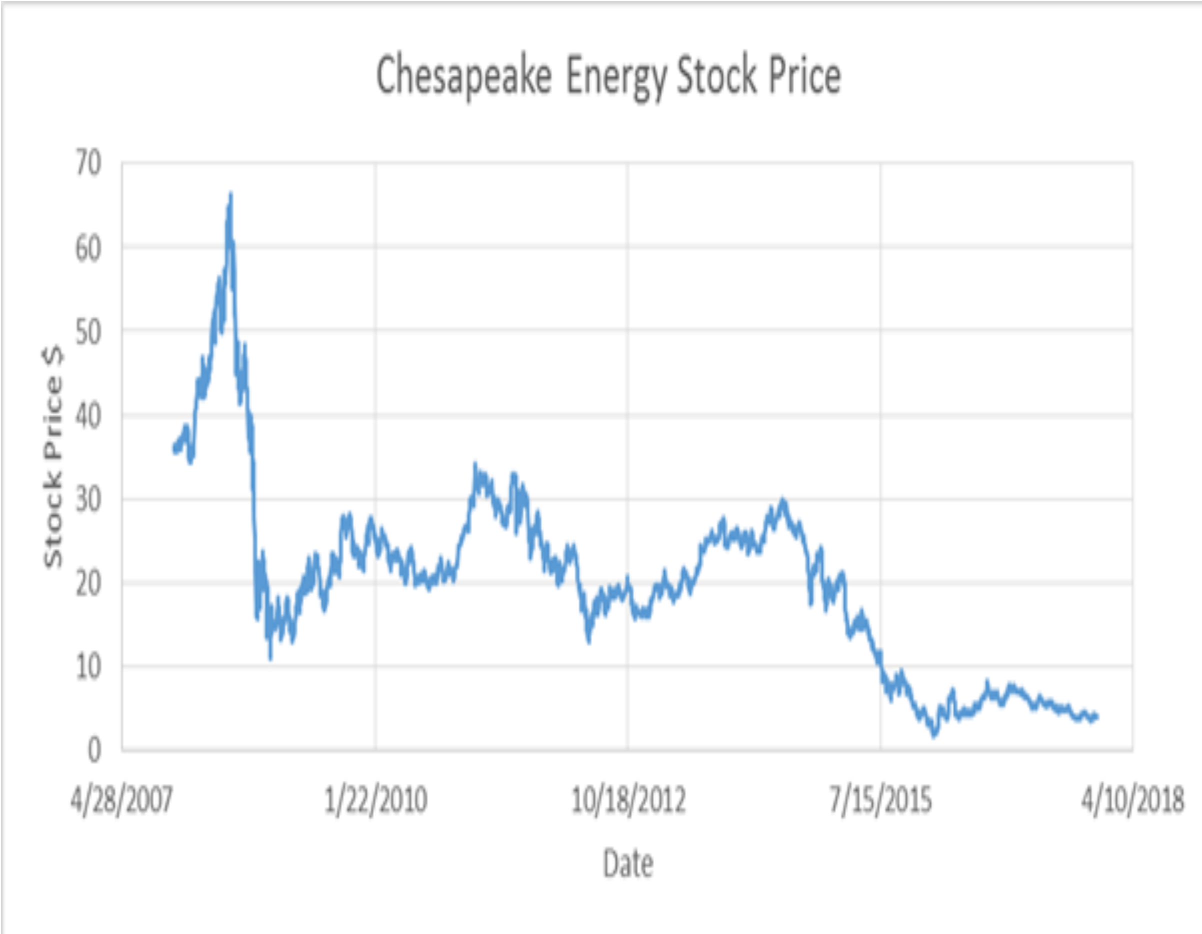


**Figure 13.** Chesapeake Energy Stock Price (Nasdaq 2017)

Regarding the discussion of economic consequences, is the aspect that Lycoming County, Pennsylvania has often been referred to as the northern hub for the Marcellus Shale. Lycoming County is located in northeastern Pennsylvania with a population of approximately 116,048 people and an unemployment rate of 5.9 % in comparison to a U.S. benchmark of 5.3 % (EPS 2017; Census.gov. 2017)

The situation in Lycoming County, and the Pennsylvania Marcellus Shale region in general, has been placated by the government (at both the federal and state levels) and the natural gas industry in a commanding fashion. This premise embraces sustainable yield for natural gas, which implies that the dependent industrial sectors may run at consistent capacity, and thus provide the maximum in attainable employment, as well as the economic contribution to local markets (Fortmann et al. 1989). However, sustainable yield seemingly neglects the well-being of the community in the aggregate.

Conversely, Ohio, as a component of the Marcellus Shale, is poised to become a significant source of natural gas for the nation as well as Pennsylvania, with a concern for community well-being. As one member of the Ohio Oil and Gas Association stated concerning drilling for natural gas in Ohio, "it's one of the most significant economic events to occur in Ohio in decades" (Hargreaves 2011). However, as Ohio engages in the drilling effort for natural gas, the concern exists to develop the proper mix of regulations to tap the natural gas yet avoids the environmental contamination that has plagued other states, like Pennsylvania.

Concern for community well-being in Ohio, as a result of the drilling for natural gas, has been exemplified by new rules being developed for hydro-fracking. These new rules have resulted in the state of Ohio having some of the robust natural gas regulations in the United States (Hargreaves 2011). However, out of concern for community well-being, some policy analysts claim that the new regulations do not go far enough in protecting the community (Hargreaves 2011).

Ohio residents have the same concern for water supplies as those of Pennsylvania. For example, in Belmont County, 63 permits to drill for natural gas using hydro-fracking technology were issued in 2013 (Page 2015). Belmont County is of significance as the county has seen the most active drilling for natural gas in the state. However, in 2013 twenty-five families were evacuated from their homes in Belmont County where a hydro-fracking well sprung a leak (Page 2015). Also, it has been reported that hydro-fracking in Ohio has been a trigger for recent earthquakes, and there is additional concern about how wastewater from the drilling process is treated and stored (Page 2015). In similar fashion to Pennsylvania, the Ohio Supreme Court has ruled that towns in Ohio cannot ban fracking by virtue of local zoning laws (Page 2015).

The good news for Belmont County is that the shale gas revolution is changing America and the county is at the heart of it all (Favede 2014). The resulting economic growth from shale gas development in Ohio is illuminated by the fact that more hotels are now opening up to accommodate workers and travelers alike. These new hotels are teeming with activity, which is providing additional growth for local economies (Bennett 2014). In addition, a multi-million-dollar ethane cracker plant is being considered for construction in Belmont County (Baker 2015). The ethane cracker facility would attract the plastics and petrochemical industries which is an added economic perk for the community, bringing jobs as well.

The basis for this economic growth from natural gas in Ohio is predicated upon the fact that, "Ohio has the cheapest natural gas in the United States, and the state needs to use that to attract manufacturers that use that product" (Baker 2015). This economic attribute suggests the question, what makes this portion of the Marcellus Shale different from that of Pennsylvania and Lycoming County?

Underneath the Marcellus Shale lies the Utica Shale which is a black, calcareous, organic-rich shale of Middle Ordovician age that underlies significant portions of Ohio, Pennsylvania, West Virginia, New York, and Quebec (King 2017). The Utica Shale is located a few thousand feet below the Marcellus Shale and contains significant amounts of natural gas liquids (NGL), as opposed to the northern portion of the Marcellus Shale which is more of a dry gas consistency (King 2017). The United States Geological Survey's mean estimates of undiscovered, technically recoverable unconventional resources indicate that the Utica Shale contains about 38 trillion cubic feet of natural gas, about 940 million barrels of oil, and 208 million barrels of natural gas liquids (King 2017).

Figure 14 below provides a graphical illustration of the Utica Shale in comparison to the Marcellus Shale. While the Utica Shale is at a greater depth than the Marcellus Shale, and thus costlier from a drilling perspective, it is never the less yielding greater economic benefits due to the dry versus wet gas current market demand.

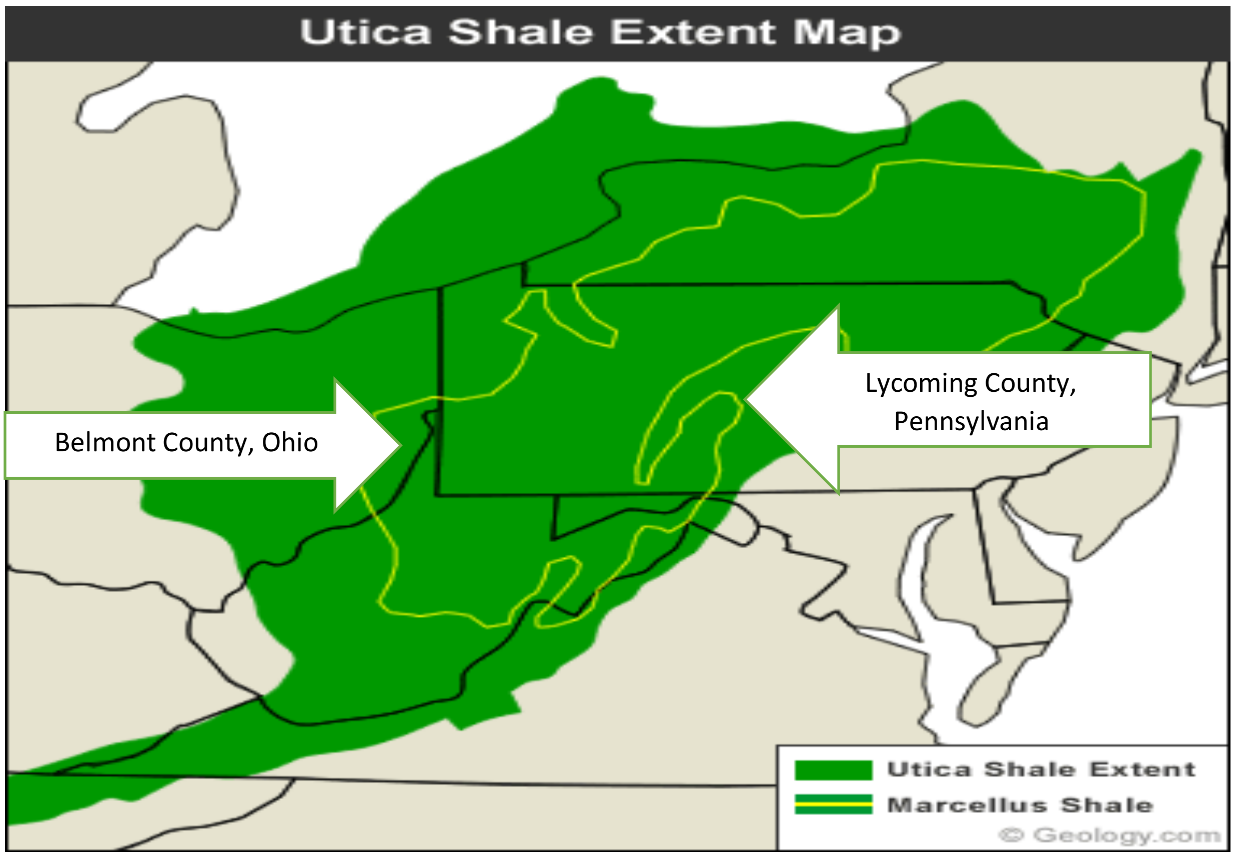



**Figure 14**. Comparison of the Utica Shale to Marcellus Shale (King 2017).

The issue of wet natural gas versus dry natural gas is of importance. Natural gas liquids, or wet natural gas, are comprised of ethane, propane, butane, and pentane (Brockett, 2015). Thus, the significance of wet natural gas for Belmont County, Ohio and the economic benefits relative to an ethane cracker facility is that, ethane crackers process ethane into ethylene, which is the starting point for a broad array of chemical products (Brockett, 2015). While an ethane cracker facility is of economic significance and potential for the region, it also conjures concern from an environmental perspective. For example, large facilities of this type "are known to produce sizable unplanned releases of carcinogenic benzene and other toxic pollutants" (Fractracker 2018). Thus, the need for the community to look closely at the cost-benefit analysis of the facility versus the environmental hazard potential. Figure 15 below illustrates the final product diversity that ethane from natural gas liquids provides, as a result of an ethane cracker.

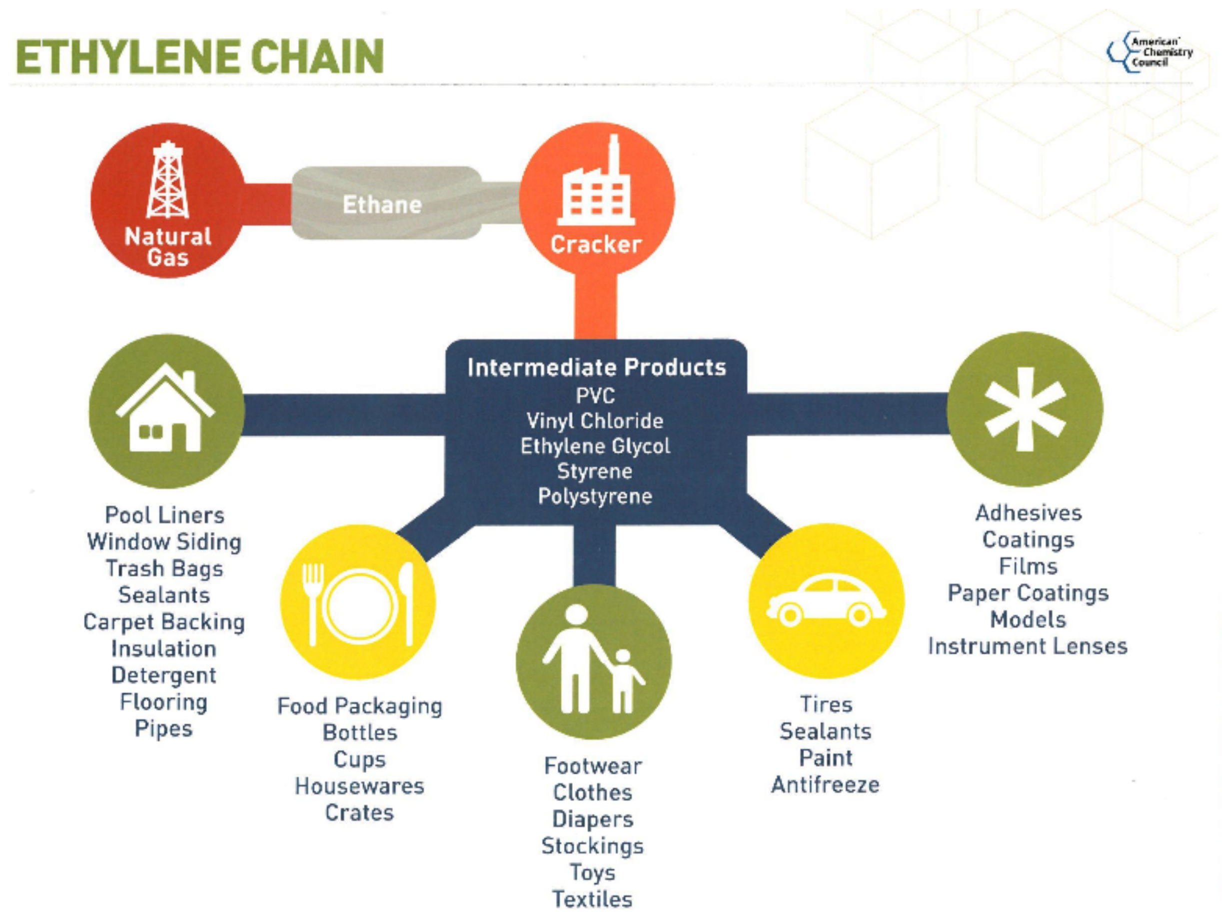



**Figure 15**. Natural Gas Liquids, Wet Gas, Final Product Diversity (Brockett, 2015)

Interestingly, and of relevance, as of September 2017, Belmont County has an unemployment level of 5.3% and Lycoming County has a similar unemployment rate of 5.9%, despite the influence of the natural gas industry upon either community (Homefacts.com. 2017; EPS 2017). The national average for unemployment is 4.1% as of October 2017 (Tradingeconomics. 2017).

The higher unemployment rates for either Lycoming County or Belmont County as compared to the national average is indicative of the skill set demands for working in the natural gas industry. The most difficult jobs to fill include drillers, drilling and service rig hands, equipment operators, geologists, production workers (pumpers and well tenders), engineers, and landmen (Chesapeake Energy ND). Which infers that many of these types of jobs will be filled by trained-skilled workers through a work force pool that is external to the community.

## Chapter 4: The Economic Negative Externalities of Hydro-fracking

Environmental degradation due to hydro-fracking is problematic and an ongoing negative externality for communities within the Marcellus Shale. For example, in Lycoming County in 2011, of the 832 active natural gas wells drilled, there were 636 violations as issued by the Pennsylvania Department of Environmental Protection (Stateimpact 2011). In addition, groundwater contamination due to flowback water spills or discharge has "caused concern regarding the potential for various forms of water pollution. Two potential pathways-advective transport through bulk media and preferential flow through fractures-could allow the transport of contaminants from fractured shale to aquifers" (Myers, 2012).

There is no data compiled to date which verifies the pre-or-post fracking properties of the shale. However, there is evidence for potential vertical contaminant flow, but there are also virtually no monitoring systems that would detect contamination transport (Myers, 2012). One very serious concern is vertical contaminant flow, where there exists the potential for contamination from natural gas drilling activity within the newly fractured shale or out-of-formation fractures which come close to contacting fault fracture zones. In these instances, it is postulated by research studies that the contaminant could reach soil surface areas in tens of years, or less (Myers, 2012). Thus, impacting soil nutrients and the possibility of detrimental effects upon crops.

Also, groundwater contamination due to the hydro-fracking process infers that the most useful evidence for incidents directly links contaminants directly to the source with a reasonably high degree of certainty (Llewellyn et al. 2015). The implication being that contamination to groundwater, streams, and drinking wells is conceivably the result of the vertical flow of fluids along gas well boreholes and through shallow to intermediate interconnecting flow paths as the result of bedrock fractures (Llewellyn et al. 2015).

Perhaps indicative of the economic benefits of natural gas extraction, Belmont County, Ohio has the distinction of having the number one producing natural gas well in either Pennsylvania or Ohio. For example, a gas well located in Kirkwood Township, Ohio was tested at an initial rate of 20 million cubic feet of natural gas per day, plus 144 barrels of condensate per day and 2,002 barrels per day of natural-gas liquids as initial production rates (Akron Beacon Journal 2012).

These facts illuminate both the positive and negative feedback loops that exist. In the case of Lycoming County, more hydro-fracking has resulted in a positive feedback loop equating to more violations. While in Belmont County, more drilling has presumably resulted in a negative feedback loop per se of virtually no violations, yet a positive feedback loop for more natural gas extraction potential. The violations in Lycoming County are of interest with relevance to groundwater and surface water contamination. The Pennsylvania Department of Environmental Protection has stated that “it received-1,000 complaints about possible impacts to water supplies from 2008 to 2012” (Brantley et al. 2014). Ironically, approximately 17% of the complaints led state regulators to implicate Pennsylvania Marcellus Shale hydro-fracking companies (Brantley et al. 2014).

While hydro-fracking technology is not necessarily a new technology, its advent in the Marcellus Shale region of the mid-Atlantic States has yielded mixed reviews; equating to economically beneficial for some communities yet, having implications to environmental degradation for others. Thus, negative externalities exist within the context of hydro-fracking and many of these externalities are associated with the three main categories of pollution such as water, air, and land. Each of these forms of pollution has the capability to devalue affected properties and the potential to cause adverse community health effects (Castelli 2015). In addition, and of significance, negative externalities disproportionately impact members of lower socio-economic classes (Castelli 2015).

## 4.1. The application of the Coase Theorem

Considering the Coase Theorem, as long as property rights are well-defined and transaction costs are low, the parties (these lower income classes) involved should be able to resolve conflicts without government involvement. This infers that a Coase solution is attainable in the shadow of regulations. However, and as has been illuminated in this paper, regulations in Pennsylvania especially have been rather nebulous, short sighted, and slow in implementation. In addition, the natural gas extraction hydro-fracking companies have considerable economic leverage over communities. This postulate serving to illuminate that there are many potential externalities associated with hydro-fracking (Bennear 2011).

These aspects and specifically the negative externalities infer the premise that social externalities also exist which serve to complicate the issues. Any economic analysis (such as integrated valuation) and the ultimate solution to the hydro-fracking-ecosystem services paradigm should reasonably consider any and all unfavorable impacts to the quality of life, social capital and standard of living, as well as the perception of rising economic inequality within a framework of uncertainty about the future (Phelan & Jacobs 2016). This postulate also suggests that an integrated valuation approach of ecosystem services will serve not only to improve environmental decision-making and planning, but also justifiably support efforts to minimize negative social externalities for natural gas extraction purposes (Phelan & Jacobs 2016).

In summary then, the positive externalities from shale gas development embrace the lower price of natural gas (relative to other fuels) from increased supply, which provides the inertia for the substitution from coal to natural gas in electricity generation (Mason et al. 2015). In addition, an abundant natural gas supply may also preclude the reduction of national security externalities associated with natural gas imports (Mason et al. 2015). Of importance, as well, is the aspect that an abundant natural gas supply-reserve may enable a reduction in consumer and producer supply markets for other fuels and energy technologies.

However, the negative externalities of shale gas development, as this paper has illuminated, have been the focus of concern. The most often cited concern being the impact to water and property values. In an effort to quantify these concerns, a benefit-cost analysis approach is suggested. Using benefit-costs analysis the intent would be to clearly identify the physical impacts of a policy and also monetize those physical impacts as a result of the selected policy (Mason et al. 2014)

Figure 16 on page 39 illuminates the attributes of positive and negative externalities and their influence upon natural gas extraction. Thus, the graphical analysis illustrates the influence of negative externalities upon natural gas prices as shown in the left-hand graph. As these negative externalities impact the extraction process, prices rise and supply declines. Conversely, the right-hand graph illuminates positive externalities whereby prices would decline as the supply increases.

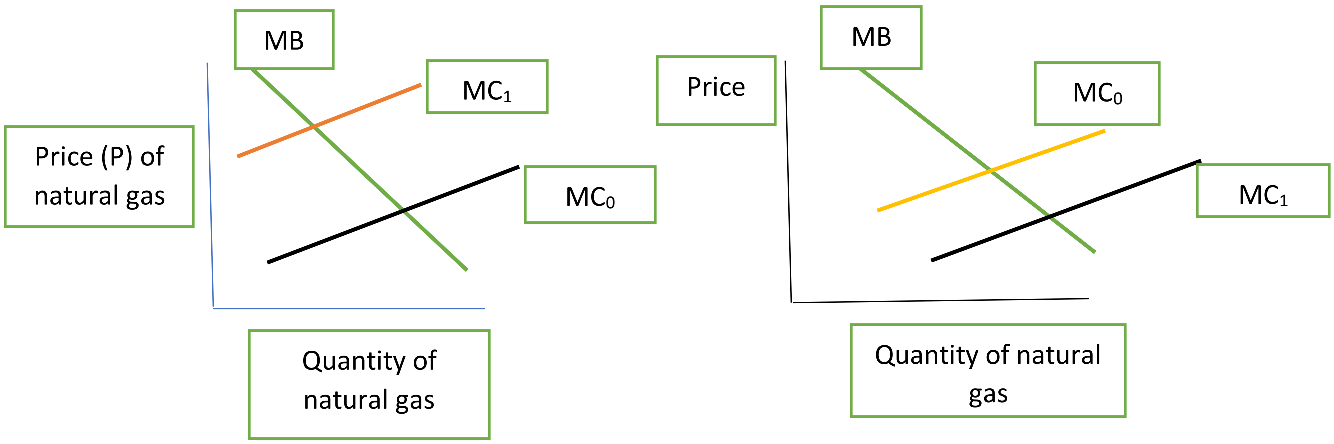



**Figure 16.** Negative Externalities Diagram. The left-hand graph illustrates the negative externalities of natural gas extraction. The supply curve, marginal cost or MC. MC is driven upwards as prices rise, and supply declines accordingly. The right-hand graph illustrates positive externalities and lower natural gas prices due to the increase of supply. In the figure, MC represents Marginal Cost and MB represents Marginal Benefit. $MC_0$ is the Marginal Cost before the change, $MC_1$ is the Marginal Cost after the change

## Chapter 5: Stakeholder management issues of natural resource extraction and questions of sustainability

In 2005, the state government of Pennsylvania enacted the Energy Policy Act. (Phillips 2011). This legislation enabled unprecedented permission for the natural gas drilling companies to use hydraulic fracking (or simply fracking) under the guise of questionable enforcement. For example, the Auditor General of Pennsylvania at that time, Eugene DePasquale, stated, "the biggest problem that Pennsylvania confronted was there were no rules in place on the front end of this" (Pressconnects.com 2015).

In essence, the state government of Pennsylvania was taking the management approach of a learn as you go and subsequently, as environmental degradation events ( such as failed or improper well casings leading to aquifer contamination, traffic and highway degradation from increased truck traffic, compressor station noise, large amount of acreage needed for natural gas well pads, and natural gas migration causing methane contaminated water) increased, anti-fracking activism mounted and the record illuminates a culture of deference with the Environmental Protection Agency, putting the natural gas extraction industry over public welfare concerns (Pressconnects.com 2015; Stolz, 2011). This last statement offers a profound perspective of the power and leverage taken by the state government in conjunction with the natural gas industry realizing one sole purpose, monetary gain at the expense of Pennsylvanians. A severance tax has been hotly debated as legislation that would be imposed upon the drilling companies to provide revenue for Pennsylvania.

The concept of a severance tax or energy taxation "is generally perceived as extremely difficult politically in the American federal system, reflecting considerable sensitivity to direct cost imposition on highly visible energy sources such as gasoline, diesel, oil, and natural gas" (Rabe & Hampton 2015). In its basic structure, a severance tax is designed to impose a cost on the extraction of natural resources, in this case natural gas, as those natural resources are being extracted from beneath the surface of the earth (Rabe & Hampton 2015).

Severance taxes have received intense political scrutiny as a consideration for implementation by state governments. The context of that scrutiny within the paradigm of governance being relative to what to do with the massive revenue bounties that account for significant portions of state tax revenue (Rabe & Hampton 2015). The federal government's role in this area remains limited and is largely confined to oversight of drilling on federal lands given a series of exemptions for natural gas in many potentially applicable federal statutes (Rabe & Hampton 2015). However, severance taxes are only one of a portfolio of funding options available to state legislatures. Also, of consideration are property taxes and state leases as well as state increase taxes, local government leases, and federal government leases (Rabe & Hampton 2015).

Despite the potential negative externality issues that exist with hydro-fracking, the shale boom offers the potential for significant growth in existing state severance tax revenue and revenue to seemingly offset the negative externalities (Rabe & Hampton 2015). Pennsylvania did not adopt a severance tax however, the state election of 2010 yielded executive and legislative branch leaders who preferred an impact fee as opposed to the severance tax. The impact fee has been warmly embraced by the natural gas industry.

The impact fee system imposed an initial rate per well between $40,000 and $60,000 per year during its first year of operation but declining steadily in subsequent years of operation. Then phasing out entirely after 15 years even if production continued (Rabe & Hampton 2015). In addition, the fee approach was integral to a major 2012 Pennsylvania shale legislative reform known as Act 13 (Rabe & Hampton 2015). Thus, and as is widely known, Pennsylvania is the only state that does not impose a severance tax on its natural-gas producers. That does not mean the state has restrained from taxing the industry — there are impact fees and the usual business taxes.

In addition, Pennsylvania State Act 13 legislation was designed to enable the local community governing body to have the ability to regulate fracking but not ban fracking. This in effect being representative of a boiler plate planning model for community development. In essence, Act 13 was considered as a solution to the problem of uncoordinated planning, as well as a solution to the problem of communities that may not have enough resources to come up with a comprehensive and cohesive plan for shale gas development (Murtazashvili 2016). The legal provisions of Act 13 seemingly are representative of a confiscation of the autonomy at the community level.

Also, and of concern, the assertion is made that as the economic value of natural gas production increases in the Pennsylvania Marcellus Shale, the local impact fee created by Act 13 is failing to keep pace (PA Budget and Policy Center 2013). While the total value of the gas produced in the Pennsylvania Marcellus Shale has increased the fee revenues have remained flat. For example, in 2013 the Pennsylvania Public Utility Commission reported that drilling impact fee revenue for wells drilled in a 2012-time frame was $202 million, an amount that is essentially unchanged from the prior year (PA Budget and Policy Center 2013).

Concern exists that over the next decade, the value of the natural gas produced from the Pennsylvania Marcellus Shale will grow much faster than the impact fee revenue. This premise suggests that Pennsylvania should adopt the approach taken by other natural gas energy-producing states by enacting the severance tax model that is based on the economic value of gas produced (PA Budget and Policy Center 2013). For example, and based upon moderate forecasts, the United States Energy Information Administration and the Pennsylvania Budget and Policy Center estimates that in the 2019-2020 time frame a 4 % natural gas severance tax could generate $1.2 billion annually, three times as much as the $382 million that would be realized under the current impact fee (PA Budget and Policy Center 2013). Figure 17, as shown on page 43, illuminates the modest 4 % severance tax in comparison to the impact fee.

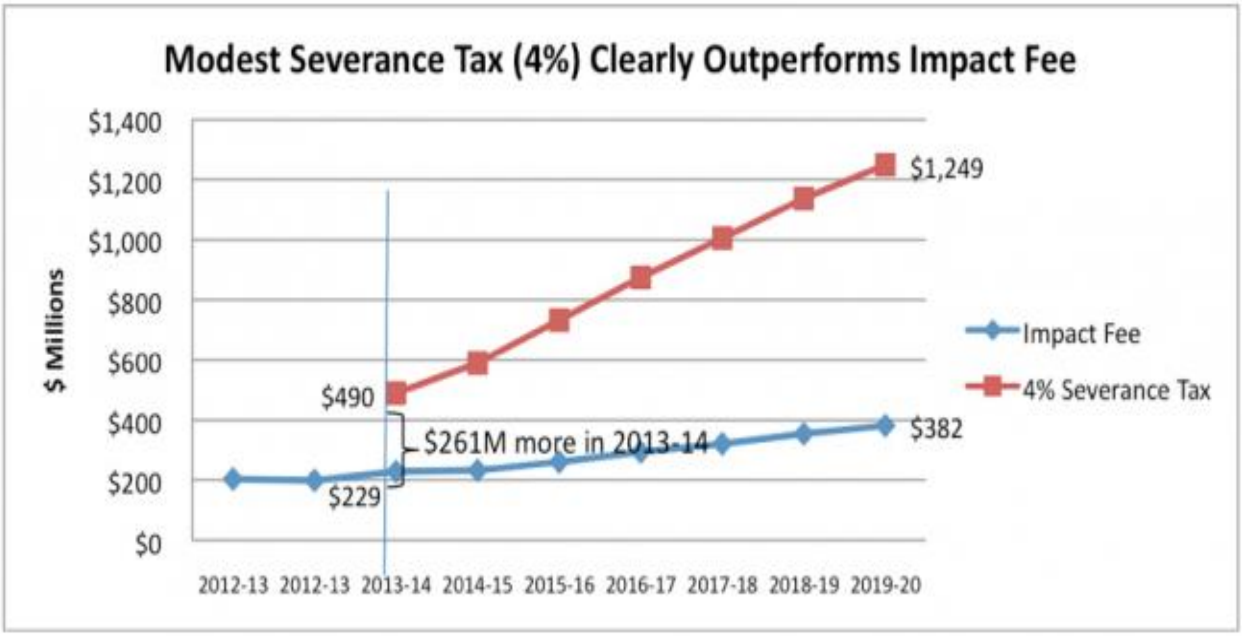



**Figure 17.** Severance Tax Comparison to Impact Fee (PA Budget and Policy Center 2013).

Some people suggest that the impact fee model is a good deal for the natural gas drilling companies, as it leaves more money in their pockets than the more modest natural gas severance tax. However, it is not such a good deal for those living in communities affected by drilling (PA Budget and Policy Center 2013). A report made in 2016 reveals that the impact fee approach has generated more than $856 million in revenue, and while the majority of the money is distributed to counties and municipalities where drilling occurs, a portion of the revenue does benefit all of Pennsylvania's 67 counties in total (Jacobs 2016).

The amount of revenue obtained from the impact fees in 2016 is significantly higher than that of 2015 where the total amount was $223.5 million (Jacobs 2016). In addition, of the total amount of revenue obtained in 2015 from the impact fee, approximately $96 million was distributed to the most heavily drilled counties in the Pennsylvania Marcellus Shale region (Jacobs 2016). For example, Lycoming County received $12.07 million (Jacobs 2016). Also, and according to the Pennsylvania Department of Revenue, the Marcellus Shale industry itself (inclusive of employees) has contributed additional taxes to the state for over a decade, including corporate and personal income taxes, state taxes, and others, that add up to more than $2.1 billion, which is above and beyond the impact fee monies (Jacobs 2016).

## 5.1. Community Autonomy Concerns

The expropriation of autonomy at the community level is of concern. In many regards, this can be seen viewed as a risk to the rural way of life as well as the environmental quality many value about the places where they live (Brasier & Filteau 2010). In addition, the confiscation of autonomy represents the potential for increased inequality among the community stakeholders-described as the haves and have-nots (Brasier & Filteau 2010). These attitudes are perhaps reflective of Lycoming County's past experience with the extraction of natural resources and the timber industry which once thrived in the region (Brasier & Filteau 2010). In correlation with community autonomy, is the aspect that in general, population is in decline in the region. While one would assume that the Marcellus Shale natural gas drilling would instill a realm of autonomy and community unity, just the opposite has transpired.

The autonomy of the community has been splintered by a prolonged history of economic strain and unsustainable development. This economic instability coupled with a fluctuating job market has, historically, caused out-migration (Barrett 2010). Of consequence for a rural boom community like Lycoming County, is the aspect that more of the county's youth are moving out of the area and the region faces an aging labor pool (Barrett 2010). This aspect is perhaps a validation as to the reason for the consistent trend of population decline in the Lycoming County region. Which also implies a disruption to community autonomy despite the rather grandiose notion that the Marcellus Shale would bring job opportunities and alleviate poverty.

Economic stagnation has plagued the region for many years and thus, local opportunities for youth have dwindled and enabled outmigration, coupled with shrinking communities. In a late 2000-time frame, many communities in Pennsylvania had been transformed by the Marcellus Shale gas development, Lycoming County being one of those communities. For example, the Census Estimates for 2009 indicate that Lycoming County had a population of 116,840 people, which was a 2.67 percent decline from the 2000 Census (JUSC, 2008).

The Lycoming County region experienced not only rapid change but changes that were distinctively mixed in social, economic, and environmental implications (Schafft & Biddle 2015). In addition, and despite the proclamations of the potential for novel economic growth with minimal environmental consequences, opponents warned that the development of the Marcellus Shale could result in degradation of land and water resources, weakened communities, as well as the potential for boom-bust economies and economic exploitation (Schafft & Biddle 2015).

This postulate reasonably forms the foundation upon which young people make sense of local community changes and consequently perceive their futures, weighing the relative risks and opportunities within the context of long-term economic stagnation (Schafft & Biddle 2015). The school system provides a sense of shared local identity, but also whose basic institutional function within society is in large part to create human capital in the form of educated youth to enter a 21$^{st}$ century workforce (Schafft & Biddle 2015). Of importance is the concept that rural young people's experiences of the boom-bust development are to a certain extent "inseparable from the complex relationships they already must navigate with regard to education and career pathways, attachment to place, and long-term community well-being" (Schafft & Biddle 2015).

For the youth of the Lycoming County region and Pennsylvania in general, the Marcellus Shale gas development, while providing new opportunities, has been accompanied by substantial costs, perceived risk and numerous uncertainties. For example, research studies have revealed that youth expressed uncertainty about the natural gas industry's long-term effect on the social and environmental well-being of their communities (Schafft & Biddle 2015).

In addition, many youths expressed doubts that the jobs being created by the industry today were truly local or had long term benefits (Schafft & Biddle 2015). Rather than encapsulate the neoliberal narrative of the Marcellus Shale as an economic crusade for Pennsylvanian's communities, youth within those areas experiencing the most intensive shale gas development weighed what they understood as limited, finite, and ultimately uncertain economic benefits against an array of socioecological costs and sociopolitical constructions of vulnerability (Schafft & Biddle 2015).

## 5.2. Social-human capital implications

The questionable sustainability of the Marcellus Shale and the social-human capital implications, as well as the contextual framing of the frack water issue, suggest the elements of a wicked problem. Which implies that the problems are malignant and tend to generate waves of consequences over an extended period of time (Rittel & Webber 1973). The well-known author Miles Howe offers validity to this notion stating that "environmental impacts, socio-economic effects, water resources and health impacts do concede that hydraulic fracturing does present a wicked problem of which little to nothing is known of the long-term impacts" (Howe 2014).

Wicked problems tend to lack agreement as to resolution and also illuminate the lack of technical ability to solve the problem. They also are illustrative of a dysfunctional state with low levels of networking social capital. In addition, the solutions to wicked problems are not true or false, but good or bad. This premise also suggests that within the construct of a dysfunctional state with low levels of networking capital an environmental calamity is perhaps inevitable as the most marginalized sections of society are made vulnerable (Adger 2003). Evidence of this aspect is prevalent within the poorer communities in the Marcellus Shale region of Pennsylvania. Specifically, those communities whose well-water has been contaminated, or have suffered socio-economic-political impacts due to their vulnerability.

Vulnerability is a function of the exposure and sensitivity of the socio-economic system to hazardous conditions and the capacity or resilience of the system to cope, adapt and recover from the effects of those conditions (Smit & Wandel 2006). In effect, adaptations are a demonstration of adaptive capacity and serve as the mechanism to reduce vulnerability. In essence, the forces that tend to influence the ability of the system to adapt are also the determinants of adaptive capacity (Smit & Wandel 2006).

The hydro-fracking process has conceivably been the driver of both environmental and community desecration and reduction in adaptive capacity. However, and perhaps more insidious, have been the elements of social capacity and economic capital, or lack thereof. These socio-economic factors are plausibly bottom-up but with the realization that they are also a manifestation of top-down marginalization. In addition, in certain locales of the Pennsylvania Marcellus Shale region a low-income issue prevailed, which was problematic prior to the inception of the Marcellus Shale exploration and development for natural gas.

It was the assumed opportunities that would potentially avail themselves as a result of the Marcellus Shale (and the drilling and hydro-fracking process) in the region that would hopefully alleviate the low-income situation for many of the residents. However, the natural gas extraction boom has transformed some rural communities and imparting the innate potential to disrupt the fabric of the community at large (Food & Water Watch 2013).

One thing is certain, 50 percent of a shale gas well's production is realized within its first year, and with production beyond five years uncertain. Thus, most of the jobs related to natural gas extraction arrive early-when exploration and drilling is being accomplished. Production jobs that remain after a well is drilled are minimal (Barlow 2014). In addition, and from a perspective of the community, small rural communities will perhaps be impacted the most where very low governance-management capacity exist. These small rural communities typically being those in which the community leaders are unpaid and lack staff.

The deterioration of land-based resources, and the elements of frackwater disposal and treatment, is the result of a complex series of interactions between competing interests. Within this realm exists the notion that an environmental solution to environmental degradation cannot exist apart from the people and societies who use that environment; environmental degradation itself is a value and interest laden term. In essence, the analysis of sustainability must include social and political sustainability as considerations (Peluso 1992).

This aspect illuminates the premise that the highest levels of poverty in the United States, and long-term poverty, tend to be found in the very places that were once the locations of thriving natural resource extractive industries (Freudenberg & Gramling 1993). While the general association between equity and sustainability is thought of in terms of a Third World condition, the postulate is most applicable to the plight of the rural communities of the Marcellus Shale whose well-water and ecosystem has been compromised by frackwater degradation.

There is also a close linkage between equity and empowerment as well as procedural justice. The latter, procedural justice, having relevance with the legitimacy for which actions at the community level manifest. In a similar context, empowerment or self-empowerment has a basis in strategies that secure livelihoods, decrease poverty, and enhance the understanding of fairness. The need to adapt at the community level is synonymous with the concept of creating headroom or room to maneuver. In essence, the notion of creating and facilitating head room or maneuverability enables adaption options in the face of a disruption to community autonomy or disturbance. Creating headroom suggests the need to advance appropriate, innovative and creative adaptation, that commands the principles of equity and social justice at its core (Thomas & Twyman 2005).

Communities that create headroom ultimately are on a trajectory of adaptation in the face of a disturbance within a context of equity and sustainability. This also suggests that equitable communities are sustainable communities, or at least on a pathway to sustainability. Realizing the current slowdown of natural gas drilling in the Lycoming County region of the Marcellus Shale, the question that begs an answer is just how sustainable are the local communities in the aftermath of the effects of fracking?

The answer to this question perhaps can be answered rather succinctly: “the industry pulled out almost as quickly as it came, gains were reversed, businesses closed and unemployment returned” (Sungazette 2014). In essence, the Marcellus Shale is similar in its framework of the forester’s fig leaf, whereby extractive industries move into a community, exploit the natural resources, and then abruptly depart the community in a worse state than it was previously. This postulate being exacerbated by the frackwater issue as plausibly an ongoing threat to the community and ecosystem well-being.

## 5.3. The economic capital tradeoffs of natural gas extraction upon the community

The situation in Lycoming County, and the Pennsylvania Marcellus Shale region in general, has been placated by the government (at both the federal and state levels) and the natural gas industry in a commanding fashion. The contrived premise embraces sustainable yield for natural gas, so that dependent industry may run at a constant level of capacity, furnishing the maximum in employment, and within generalized local markets (Fortmann et al 1989). However, sustainable yield seemingly neglects the well-being of the community in the aggregate. This supposition existing within the context of households below the poverty line, present households on welfare, average education, infant mortality, per capita income, the percent of high school graduating classes who stay in the community, and the incident of social pathologies such as spousal abuse, alcoholism and crime rates (Fortmann et al 1989).

The notion of an economic tradeoff is perhaps compromised when, as Lycoming County illustrates, 2 in every 5 children are participating in a school lunch food program, over one quarter of the population is considered as low income, the population itself has been steadily declining (percent change, 2000 to 2015 is -3.2 %) since the inception of the Marcellus Shale, and the unemployment is at 5.9% (Places.findthehome.com 2017; EPS 2017).

It is easy to surmise that the Marcellus Shale would have brought prosperity to the Lycoming County region. However, the shale gas boom is in many ways a déjà vu for the region. Interestingly, in the mid-19th to early 20th century the region experienced a similar boom with the timber industry (Hammond 2016). The timber industry has somewhat disappeared and the shale gas boom in many ways is seemingly following a similar trajectory. Perhaps surprisingly in 2010 Williamsport "was the seventh fastest growing metropolitan area of its size in the country"

(Hammond 2016). At that time, new lodging companies came to the region, including new restaurants, and small businesses.

However, there were those within the Lycoming County community who were critical of the expansion and intrusion. As one citizen remarked, “I’m not going to say what is better for the community, what I can say is if we want to survive as a society we have to look at our dependence on natural resource extraction. We can’t sustain the way we have been doing things.” (Hammond 2016).

## Chapter 6: The essence of the frackwater problem: natural and social capital impacts

The majority of water being utilized in the hydro-fracking (or fracking) process for the Pennsylvania region of the Marcellus Shale is obtained from local waterway sources. Research studies have concluded that approximately 72% of the water used for Marcellus Shale drilling comes from rivers, creeks, lakes, and groundwater in Pennsylvania (Penn State 2014). Veil (2010) states that “the average total volume of fluid used per well is 2.7 million gallons, with 2.2 million gallons of that coming from freshwater sources and 0.5 million gallons coming from recycled flowback. As an example, specific to a freshwater source in Lycoming County, the Pennsylvania Bulletin reports that Keystone Clearwater Solutions, LLC, a natural gas drilling company, extracts surface water of up to 1.292 mgd from the Lycoming Creek (mgd = million gallons per day, PA BULLETIN 2011).

In consideration of this magnitude of water withdrawal, the American Rivers organization has identified two of Pennsylvania’s largest rivers on its 2010 annual list of the ten most endangered rivers in the United States (Dillon 2011). American Rivers named the Upper Delaware River as the most endangered river and the Monongahela River as the ninth most endangered river, the reasoning based upon each river's location relative to extensive drilling in the Pennsylvania Marcellus Shale region (Dillon 2011).

In addition, the Susquehanna River Basin Commission or SRBC (a Pennsylvania based organization) which has continuously monitored water withdrawals by the natural gas drilling companies, delineates that the amount of water necessary for hydro-fracking in the Marcellus Shale ranges from four to seven million gallons of water per natural gas well (Dillon 2011). However, water withdrawal amounts tend to vary depending on the research source. For example, the USGS reports three million to five million gallons of water for hydro-fracking per natural gas well (Williams ND). Of importance is the fact that the SRBC is the regulating body and ultimately determines how much water natural gas drilling companies can take out of the Susquehanna River and its tributaries (Detrow 2012). This aspect was of significance when a severe drought in April 2012 impacted the Marcellus Shale Lycoming County region and the SRBC suspended water withdrawals for several of the natural gas drilling companies (Detrow 2012) The SRBC suspends water withdrawals when streams drop to a pre-determined protected low flow level. At this point, water withdrawal is not permitted until the stream has recovered above the protected level for at least a 48-hour time period (Detrow 2012).

Also, and of long term relevance, is the fact that some natural gas wells will need to be hydro-fracked more than others, as the life expectancy of a well may range from five to thirty years (Dillon 2011). The ecological and socio-economic implications range from not only stressing local water supplies but also water tank truck traffic. For example, a single hydro-fracking operation might require as many as seven hundred tank truckloads per natural gas well, which is an aspect that adds to traffic congestion, air quality issues, and community disruption (Dillon 2011).

The use of hydro-fracking and horizontal drilling enables a reduced land usage footprint, roughly 85% less surface disturbance as compared to pure vertical wells (Chesapeake Energy. ND). A typical natural gas drill pad site entails 6 to 8 horizontal wells on a one to three-acre area (Chesapeake Energy. ND). This approach minimizes the environmental damage as one access road is necessary as well as only one pipeline. For example, using a vertical drilling approach, up to 16 well pads would be required to recover the natural gas from 640 acres, inclusive of multiple access roads and pipelines (Chesapeake Energy. ND). The total amount of land usage disturbance using a vertical well drilling approach is considerable, approximately 45 acres of land surface disturbed area (Chesapeake Energy. ND). Figure 18, on page 54, illustrates the comparison between horizontal drilling and pure vertical drilling, and the extent of land disturbance.

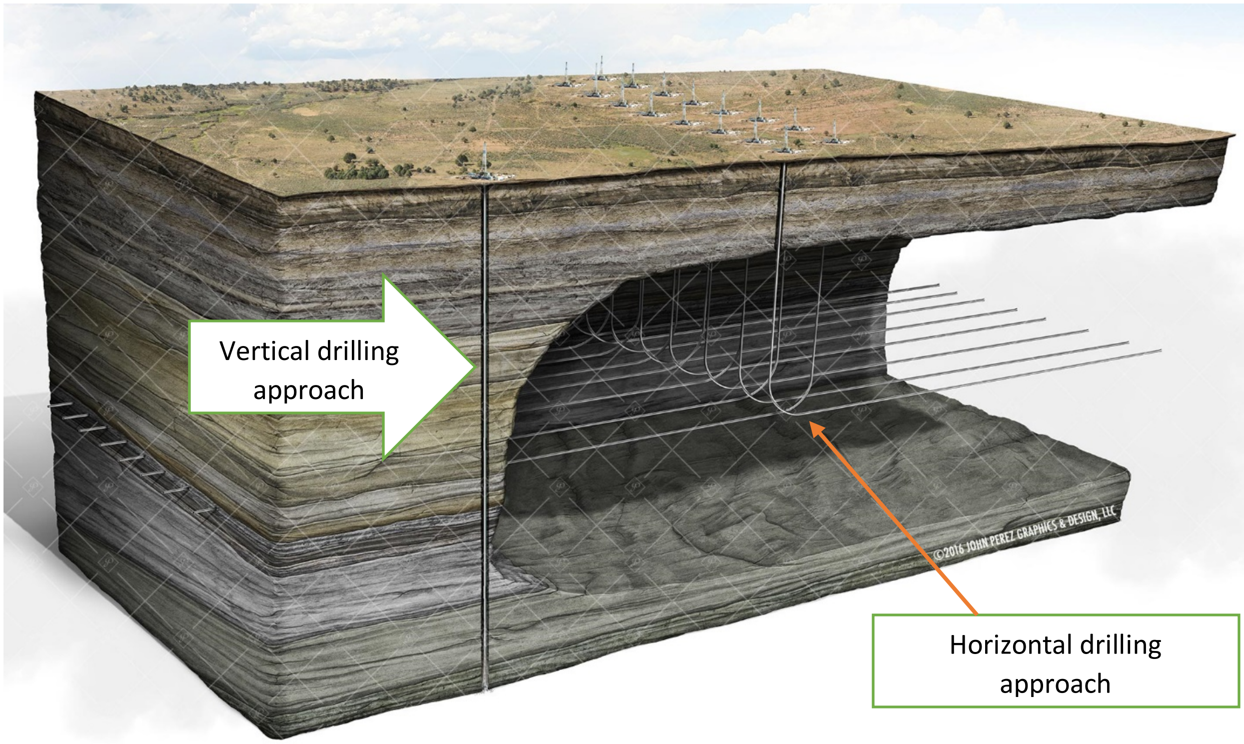



**Figure 18.** Vertical Drilling Compared to Horizontal Drilling (Perez, 2018).

Concerning land usage and land surface disturbance, well pad site selection is a critical determinant. The natural gas well pad location is determined by a number of factors such as favorable geology of the area and its topography. In addition, the drilling company must consider available access roads as well as routes for pipelines and utilities. The human and social capital aspects are also of significance such as the proximity of the natural gas well pad-drilling rig to schools and residential areas. Also, and of equal importance, environmental factors such as wetlands, sensitive habitat areas for wildlife must be considered. Lastly, the natural gas drilling company must have access to available water sources such as streams/rivers, therefore reasonably close proximity to these sources is critical and logistically prudent.

The natural gas well pad site preparation effort requires approximately one to three weeks and the sites can be located in either rural or urban areas (Chesapeake Energy. ND). Of significance, and one of the inherent benefits of the horizontal drilling approach, the process enables avoidance of disturbance near homes and schools. In essence, the use of computerized horizontal drilling and hydro-fracking allows for access to a greater volume of the shale gas reservoir. Likewise, access to a greater volume of the natural gas reservoir makes shale gas development in the Marcellus Shale economically beneficial. Figure 19 below illustrates the concept of horizontal drilling into deep sedimentary shale rock.

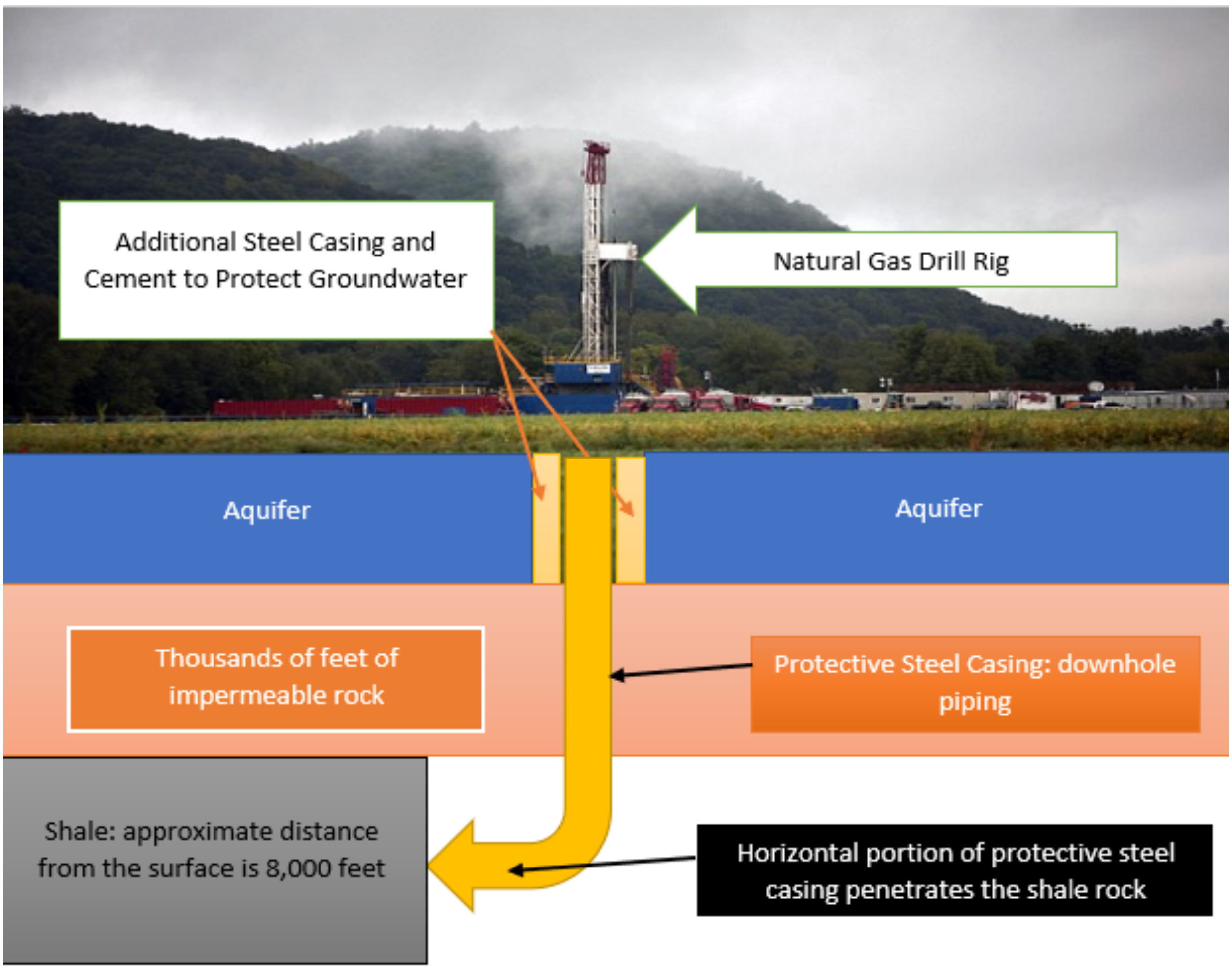



**Figure 19.** Diagram of the Drilling Process (Cfact. ND).

As a clarification, hydro-fracking does not represent the actual drilling process itself. Hydro-fracking is used after the drilled hole is completed. Rather simply, hydro-fracking is the use of fluid and material to create or restore small fractures in the sedimentary shale rock formation in order to stimulate production from the natural gas well. This essentially creates pathways that increase the rate of which the natural gas flows to the surface.

The downhole drilling process includes steps to protect water supplies that might be contained within the rock. To ensure that neither the fluid that will be eventually pumped through the well, nor the natural gas that is collected, enters the groundwater supply, steel surface or intermediate casings are inserted into the well to depths of 6,000 to 10,000 feet, until the natural gas bearing reservoir is reached (Fracfocus 2010). The placement of the natural gas well pad and drill rig are basically sequenced to meet the needs of the particular geological formation. Figure 20, as shown on page 57, illustrates the various components of the hydro-fracking process and the general layout of the natural gas well pad.

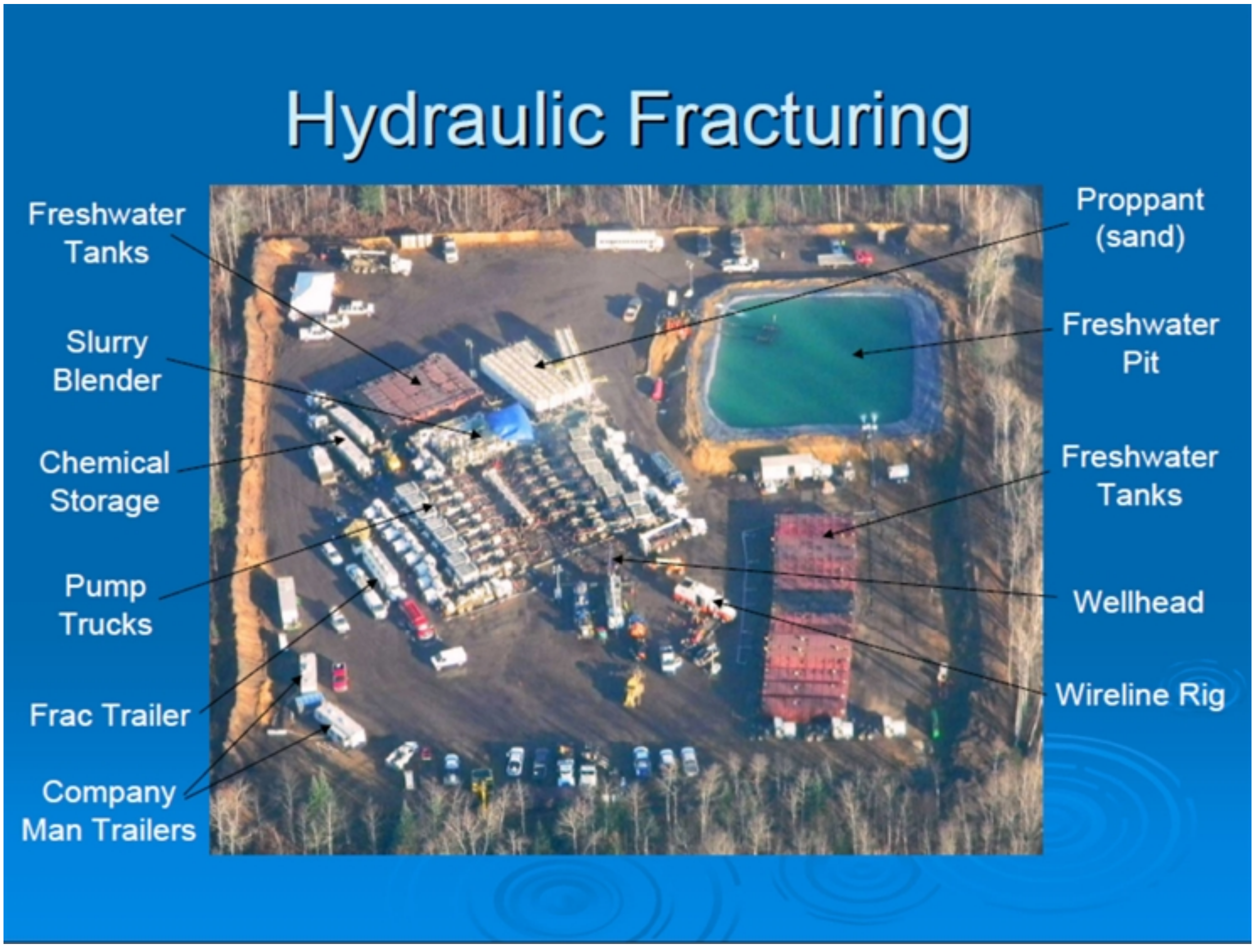



**Figure 20**. General Layout of the Natural Gas Well Pad (WatershedCouncil 2017).

While the natural gas drilling process remains the same, the sequence of drilling may change depending on the uniqueness of the local formation. The following steps illuminate the process (Fracfocus 2010):

1. An acid stage, which consists of several thousand gallons of water mixed with a dilute acid such as hydrochloric or muriatic acid. This step serves to clear cement debris in the wellbore and provide an open conduit for other fracking fluids by dissolving carbonate minerals and opening fractures near the wellbore.

2. A pad stage, which entails approximately 100,000 gallons of slick water without proppant material: The slick water pad stage fills the wellbore with slick water solution and opens the shale rock formation. This step also helps to facilitate the flow and placement of proppant material.
3. The prop sequence stage, step three, may consist of several substages of water combined with proppant material (consisting of fine mesh sand or ceramic material, for the sole purpose to keep open, or prop, the fractures created and /or enhanced during the fracturing operation after the pressure is reduced. This stage requires the use of several hundred thousand gallons of water. In addition, the proppant material may vary from finer particle size to a coarse particle size throughout the sequence of this step.
4. The flushing stage, step four, consists of a specified volume of fresh water which is sufficient to flush the excess proppant from the wellbore.

With these steps in place, high volumes of frack fluids (comprised of water and various chemicals) are forced into the well at pressures sufficient to create fractures in the reservoir sedimentary shale rock (Fracfocus 2010). Water and sand comprise 98 to 99.5 percent of the frack fluid with the use of chemical additives the remainder (Fracfocus 2010). The fracturing of the sedimentary shale rock is formed in the direction perpendicular to the least stress.

Horizontal fractures occur at shallow depths less than roughly 2,000 feet because the Earth's overburden at these depths facilitates the least principle stress. If pressure is applied to the center of the shale formation under these relatively shallow conditions, the fracture will most likely result in a horizontal plane, because it will be easier to separate the rock in this direction than in any other. In general terms, these fractures run parallel to the bedding plane of the shale formation (Fracfocus. 2010). Figure 21, as shown below, illustrates bedding planes in a shale rock formation.

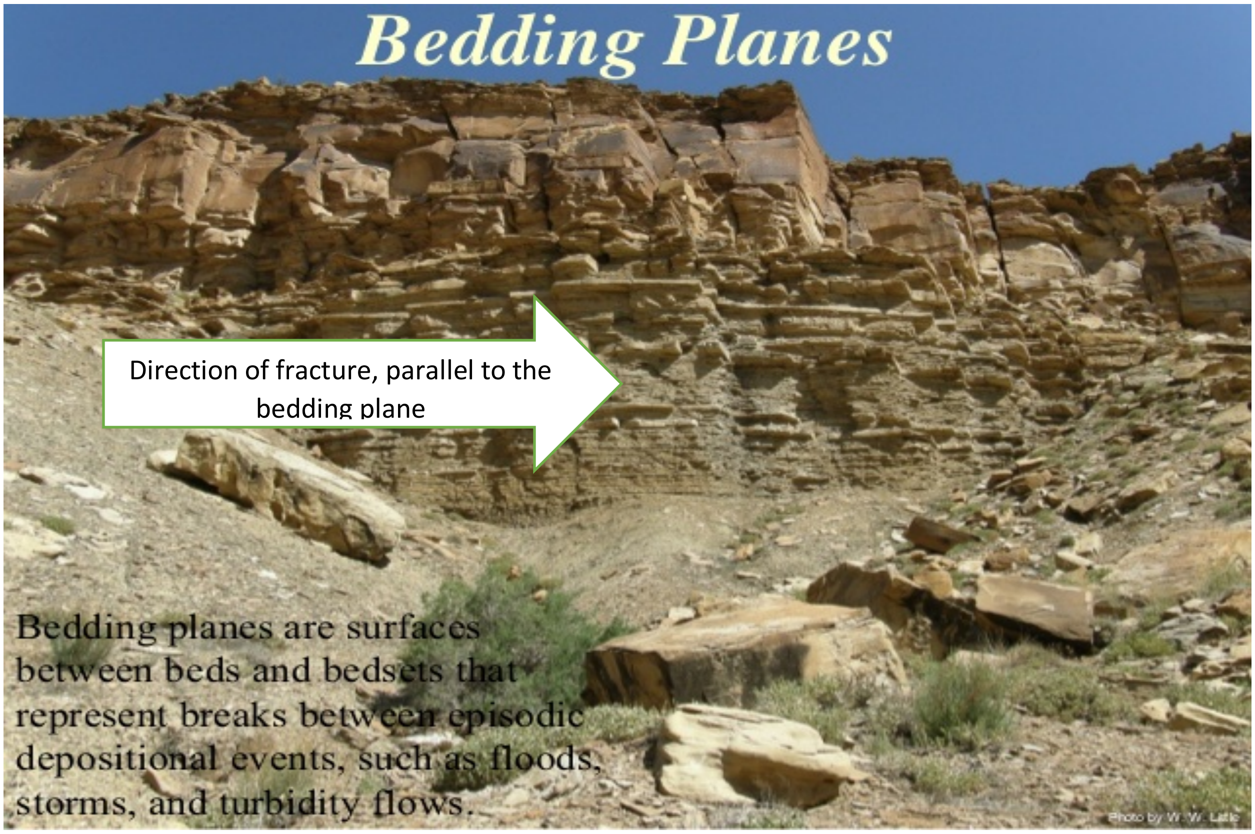



**Figure 21.** Bedding Plane Illustration (Slideshare.net ND).

The extent that a created fracture due to hydro-fracking will propagate is reasonably controlled by the upper confining zone of the sedimentary rock formation, inclusive of the volume, rate, and pressure of the fluid that is being pumped. The confining zone tends to limit the vertical growth of a fracture due to the fact that it tends to possess sufficient strength or elasticity to contain the pressure of the injected fluids as applied during the hydro-fracking process (Fracfocus 2010). This is of importance as the concern around groundwater contamination is centered on one fundamental question: Are the created fractures as a result of the hydro-fracking process contained within the target formation so that they do not contact the local aquifer (Fracfocus 2010)?

The Marcellus Shale is a new natural gas play and thus, the data available are not as comprehensive as in other natural gas plays in the contiguous United States, such as the Barnett Shale in Texas (Fracfocus 2010). The Barnett Shale research illustrates that hydraulic fractures as a result of hydro-fracking are better confined vertically (Fracfocus 2010). The data, as shown in Figure 22 on page 61 illustrates the huge distances separating the frack water from the nearest aquifers, at their closet points of approach. Thus, Figure 22 data demonstrates that hydraulic fractures, as a result of hydro-fracking processes, are not propagating into groundwater supplies, and therefore, can conceivably not contaminate them (Fracfocus 2010).

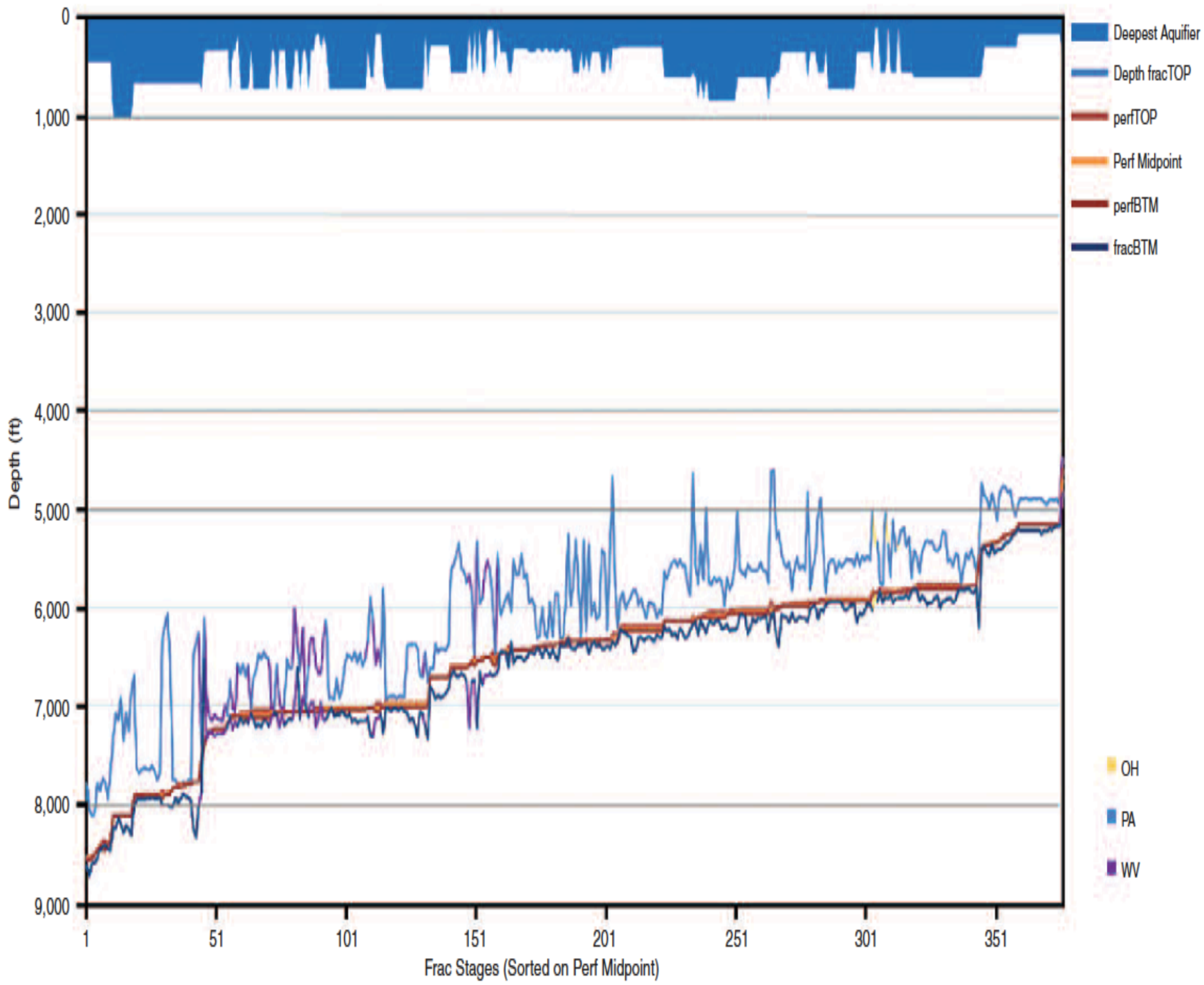



**Figure 22**. Marcellus Shale Mapped Frack Treatments/TVD (Foster, ND).

There are numerous chemicals used in the hydro-fracking process and each has a specific function. Of importance, all of the additives are used in every hydro-fracked well. However, the exact blend and proportions of additives will vary based on the site-specific depth, thickness and other characteristics of the target shale formation (Fracfocus 2010). As an example, hydrochloric acid is used to help dissolve minerals and initiate cracks in the rock (Fracfocus 2010). Table 1, as shown on page 62, lists a few of the chemicals and their function in the hydro-fracking process.

| Chemical Name | Chemical Purpose | Product Function |
|---|---|---|
| Glutaridehyde | Eliminates bacteria in the water | Biocide: kills any water-borne bacteria |
| Sodium Chloride | Product Stabilizer | Breaker: stabilizers the gel, and enables its delay and breakdown |
| Calcium Chloride | Product Stabilizer | Breaker: stabilizes the gel, and enables its delay and breakdown |
| Chlorine Chloride | Prevents clay from swelling | Clay Stabilizer: stabilizes the clay among the shale formation, and prevents the clay from swelling or shifting |
| Methanol | Winterizing agent | Corrosion: prevents the corrosion of the fluid injecting pipe |
| Formic acid | Prevents corrosion | Corrosion: prevents the corrosion of the fluid injection pipe |
| Hydrochloric Acid | Dissolves minerals | Acid: dissolves minerals and helps to induce cracks in rock |
| Polyacrylamide | Minimizes friction | Reducer: reduces the friction between the fluid and the pipe, and also between the fluid and its components |
| Guar gum | Thickens the water-sand suspension | Gelling Agent: causes gel formation such that sand particles are homogeneously suspended throughout |
| Citric Acid | Prevents metal oxide precipitation | Iron Control: prevents the metal oxides from precipitating |
| Ethylene Glycol | Product stabilizer | Non-Emulsifier: prevents the formation of emulsions in fluid |
| Acetic Acid | Adjusts the p-H | Acid/base control: maintains the p-H level at a level that is optimum for the other functions to occur |
| Sodium Polycarboxylate | Prevents scale deposits in pipe | Scale Inhibitor: prevents the formation and deposit of scales in the pipe and fissures |
| Ethanol | Product stabilizer | Surfactant: acts as detergent and serves to increase the viscosity of the fluid |

**Table 1**. Partial list of frackwater additives/chemicals (Fracfocus ND.; Patil, 2014):

One of the inherent problems with identifying the chemicals used in the hydro-fracking process is that some chemicals have multiple names. For example, Ethylene Glycol (Antifreeze) is also known as Ethylene alcohol (Fracfocus ND). This multiplicity of names makes a search for the chemical difficult and also imparts the impression that there are more chemicals being used than actually exist. However, a search using the Chemical Abstracts Service or CAS will provide the user with the correct chemical even if the name on the hydro-fracking record does not match (Fracfocus ND).

About 20 to 30 percent of the original water with the chemical additives utilized in the hydro-fracking (or fracking) process is obtained as flowback (Massaro 2012). The flowback (frackwater) is collected, typically held in retention ponds or pits located near the drilling site, and in some instances stored in above ground tanks for reuse. Figure 23, as shown on page 64, illustrates the water cycle which correlates to the hydro-fracking process, with concern for produced water (flowback) collection, handling, and disposal. The ultimate disposal and processing of the flowback water (frackwater) is environmentally problematic, representing a natural and human capital concern. As well, and coupled with natural and human capital, is the concern regarding flowback contamination of groundwater and soil substrate material.

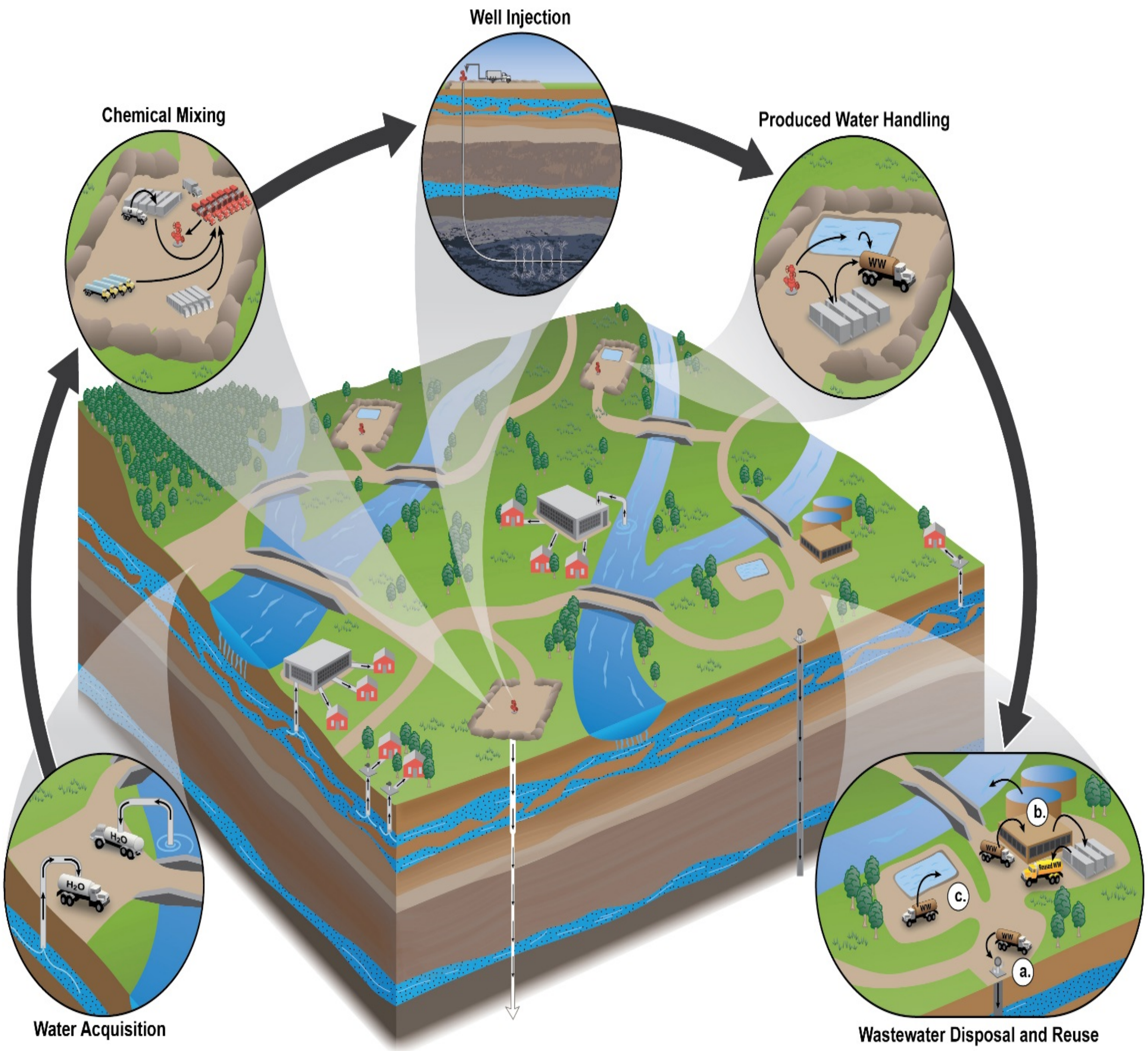



**Figure 23.** Water Cycle of Hydro-fracking (EPA 2016).

All attributes considered, the issues of hydro-fracking necessitate astute local community planning such as: consideration of increased traffic and transportation requirements, right of ways for gathering and collecting pipelines, water and sewer infrastructure capacity, access roads to well pad sites, education for landowners, private citizens, and public officials, public safety, lighting, noise, and the protection of sensitive environmental resources (Weaver 2011).

## 6.1. Water Usage

The water usage for the hydro-fracking process is intensive. The rate of water usage is higher in the hydro-fracking process than in any other energy initiative, such as steam-electric power plants (Els and Cuba 2013). This magnitude of water usage raises concern for water resource level sustainability for local communities. However, the amount of flowback seems to vary and can be reused. For example, one research study suggests that 0.5 million gallons is reused per well as a result of recycled flowback water (Veil 2010). While the flowback water is recyclable and reusable, concern exists as to its storage and the ultimate processing for safe discharge back into ecosystem waterways.

Groundwater recharge as a natural resource exists within the context of uncertainty as being dependent upon precipitation and climatic conditions. Extended periods of drought coupled with, climatic change will serve to potentially inhibit groundwater supplies. This concern is reasonably exacerbated by using groundwater supplies for the hydro-fracking process. During drought conditions water tends to leave groundwater storage as compared to entering it and groundwater levels will decline. If the water table drops below a stream bed for example, that streambed will be dry.

The water extracted for hydro-fracking purposes during drought conditions is problematic. Figure 24, as shown on page 66, illustrates the water cycle and the average annual hydrological budget in Pennsylvania. Clearly, the influence of climate change and drought, as well as the vast quantities of water extraction necessary for the purpose of hydro-fracking, will impact the hydrological budget. This illuminates the need to reuse flowback water for the purpose of hydro-fracking as an ongoing process.

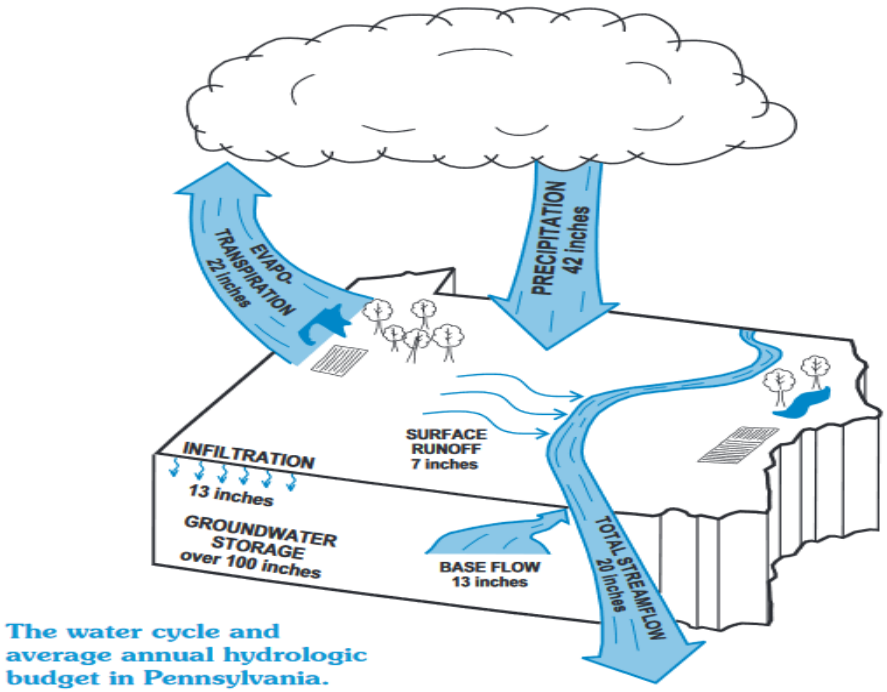



**Figure 24.** Hydrological Budget for Pennsylvania (Fleeger 1999).

In addition, it makes logical sense to reuse the flowback water to reduce the demand for water from local streams and rivers. Also, and of merit, is the value in treating the flowback water and its contaminants for ultimate discharge into local waterways as well. These aspects illuminate the necessity to provide flowback water treatment options that are proven to be successful, and which also solve water capacity shortfalls and meet all wastewater disposal requirements (Els and Cuba 2013). The storage of the flowback water in retention ponds, as was previously mentioned, is logistically strategic. The retention ponds are typically located in close proximity to the drilling site. Also, above-ground storage tanks are utilized in some instances.

In some cases, the natural gas drilling companies have either pre-treated the flowback water, which was stored in retention ponds, or blended the flowback with fresh water. The pretreatment process provided by a packaged plant is basically a flatbed trailer equipped with a treatment system that can be transported and used from site to site to treat the flowback water for reuse as necessary (Penn State 2011). While pretreatment has its advantages, several factors serve to complicate onsite treatment operations such as the variability of the flowback water chemistry over time post hydro-fracking, the variability in flowback water across the state, and the use of different amounts and types of chemical additives by different companies at different locations (Penn State 2011).

Inherent with flowback water is its high concentrations of Total Dissolved Solids or TDS. Total Dissolved Solids, or TDS, is a measure of the solids remaining in a water sample as filtered through a 1.2µm filter (BMU2.ND). Typically, the compounds and elements that remain after filtration for TDS are calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulfate, silicate and nitrate-n (BMU2.ND). Likewise, Total Suspended Solids or TSS, and also known as non-filterable residue, are those solids (minerals and organic material) that remain trapped on a 1.2 µm filter (BMU2.ND). Both TDS and TSS are of significance in consideration of treatment of the frackwater or flowback.

The Federal Safe Drinking Water Act (SDWA), as enforced by the Environmental Protection Agency (EPA), delineates TDS as a secondary maximum containment level which means that there is a recommended maximum level of .0667 ounces/gallon, but there is no requirement that public water systems meet this level (Penn State 2011). However, elevated levels of TDS may damage water treatment equipment at public water treatment facilities which also represents acute natural and human capital concerns for both short and long-term sustainability.

In addition, while the EPA at the Federal level enforces the SDWA, concern exists as to the ability of the Pennsylvania Department of Environmental Protection (PA DEP) to enforce safe drinking water standards. Federal officials have warned the PA DEP that it lacks the necessary resources for enforcement of the SDWA (Cusick 2017). Due to lack of staff and a 40 percent drop in budget, SDWA violations have doubled in a 2012 to 2017-time frame in Pennsylvania (Cusick 2017).

One of several disturbing aspects of the increase in violations and the lack of resources within the state to enforce the SDWA is that if Pennsylvania loses its primacy to enforce the SDWA, the state will lose $5.5 million dollars for its regulatory program and an additional $100 million of federal fund monies for water improvements (Cusick 2017). In addition, and correlated to hydro-fracking, the lack of resources to inspect and enforce the SDWA, as well as the potential for loss of fund monies, exacerbates the water quality issues that plague natural gas extraction in Pennsylvania.

Based upon a report released by the Government Accountability Office (GAO) in September 2012 the drilling for natural gas must comply with the requirements of federal environmental regulations which are applicable to natural gas extraction using hydro-fracking processes (Brown 2013). Specifically, the GAO report cites the federal environmental regulations that govern the development of natural gas, which include: The Safe Drinking Water Act (SDWA) (for disposal wells); Clean Water Act (CWA); Clean Air Act (CAA); Resources Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); Emergency Planning and Community Right-to-Know Act (EPCRA); Toxic Substances Control Act (TSCA); and Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) (Brown 2013).

## 6.2. Impact of water usage upon the Watershed: the relevance of the River Continuum Concept

There are six major watersheds in the state of Pennsylvania as Figure 25 on page 69 illustrates. The Susquehanna River and subsequently, the Susquehanna River Basin is a prime source of water withdrawal for the Marcellus Shale drilling effort. The Susquehanna River Basin Commission (SRBC), which governs water withdrawal from the basin, has indicated that “it has not found any impacts from Marcellus Shale gas drilling on the quality of water in streams that it has been monitoring” (Loewenstein 2015). However, the data collected is from a limited number of water quality monitoring stations and is not considered as a comprehensive study of the effects of natural gas drilling and the impacts of hydro-fracking on the quality of water in the Susquehanna River Basin (Loewenstein 2015).

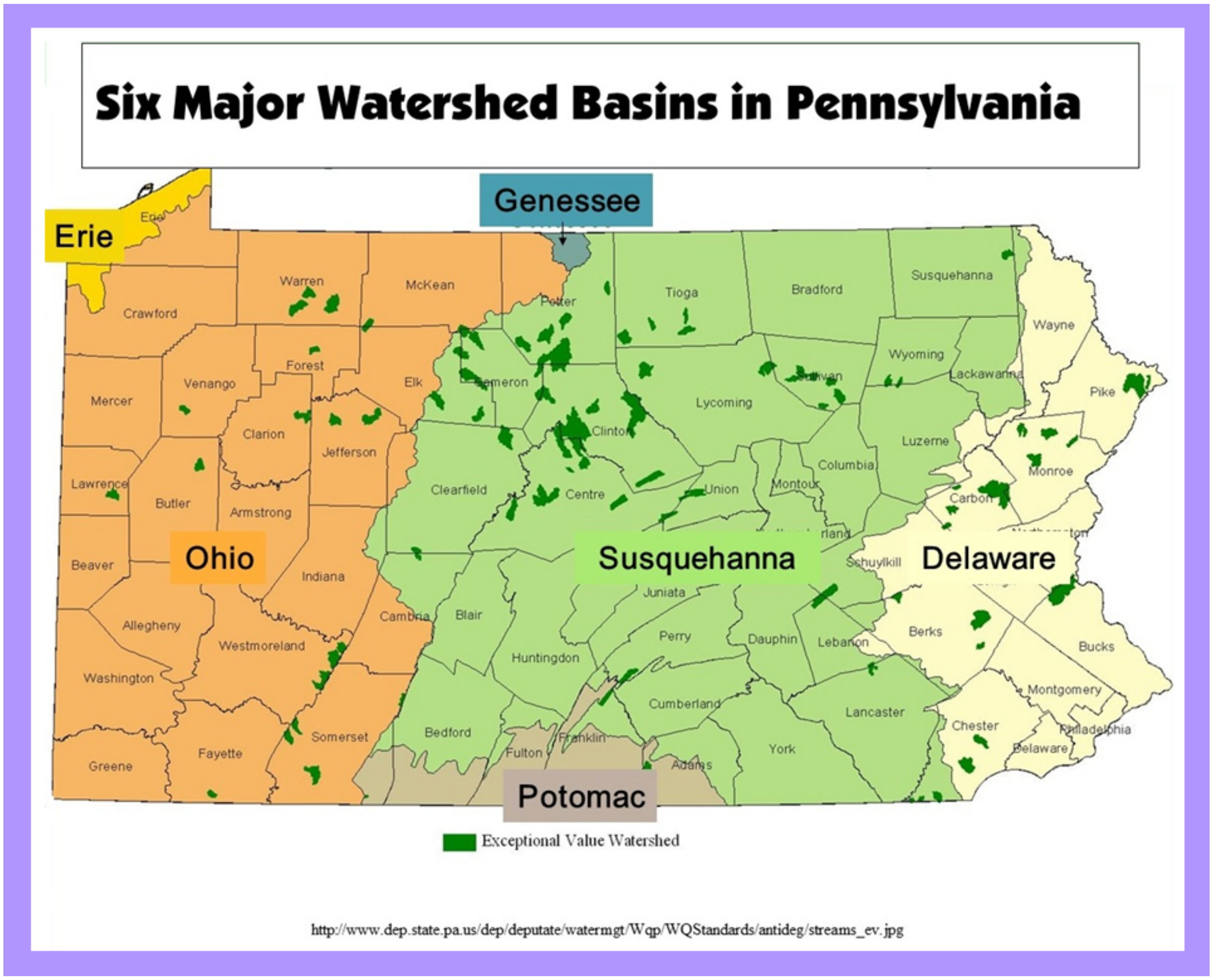



**Figure 25.** Six Major Watersheds in Pennsylvania (Elk County 2016).

Because of the large volume of water withdrawal used in the hydro-fracking process within the basin, the SRBC plays an important role in regulating water withdrawals and consumptive water uses. In addition, more than 72% of the Susquehanna River Basin is underlain by the Marcellus Shale, which is indicative of the basin's importance in the shale gas drilling effort (SRBC ND). The SRBC's review of any proposed natural gas drilling project within the basin entails an evaluation of whether a project would cause unfavorable impacts to the water resources of the basin. Significant water withdrawals may impact other water uses, fish, wildlife, or other living resources or their habitat, recreation and stream flows (SRBC. ND).

The SRBC, for every water withdrawal from the basin, conducts an environmental screening process that thoroughly examines the designated use of the stream, wild trout status, impairment, presence of rare and endangered species, and surrounding wetlands (SRBC ND). In certain instances, and stream specific, the SRBC engages in an aquatic survey to adequately assess the condition of the aquatic community within the stream's ecosystem (SRBC ND). Regarding impacts, the SRBC places protective conditions upon water withdrawals which are known as passby flows. The passby flows designate a prescribed quantity of stream flow that must be allowed to pass a specific point downstream from a designated water supply intake, at any time that a water withdrawal is occurring (SRBC ND). The intent of the passby flows is to safeguard streams during low flow conditions.

Of concern is the potential long-term impact of hydro-fracking upon the Susquehanna River Basin. The major issue being how rivers and streams function and how human activities influence those functional river processes. In an independent study by Wilkes University of Pennsylvania, the conclusion drawn is that depending on where and how it's done, the hydro-fracking process relative to natural gas drilling does have the potential to impact Pennsylvania's waterways (Nichols 2015).

This suggests the significance of the river continuum concept. The river continuum concept was developed from research studies on stable, well-balanced streams in north-temperate, forested watersheds (Johnson et al. 1995). The river continuum infers that forested river systems have a longitudinal structure that results from the inclination of physical forces that change predictably along the entire length of the river. These physical forces produce a continuum of morphological and hydrological features from the headwater location to the mouth of the river (Johnson et al. 1995). Figure 26, as shown on page 72, illustrates the river continuum concept and Figure 27, on page 73, shows the magnitude of the Susquehanna River and its basin. The postulate being the applicability of the river continuum concept to the Susquehanna River Basin and the significance of hydro-fracking.

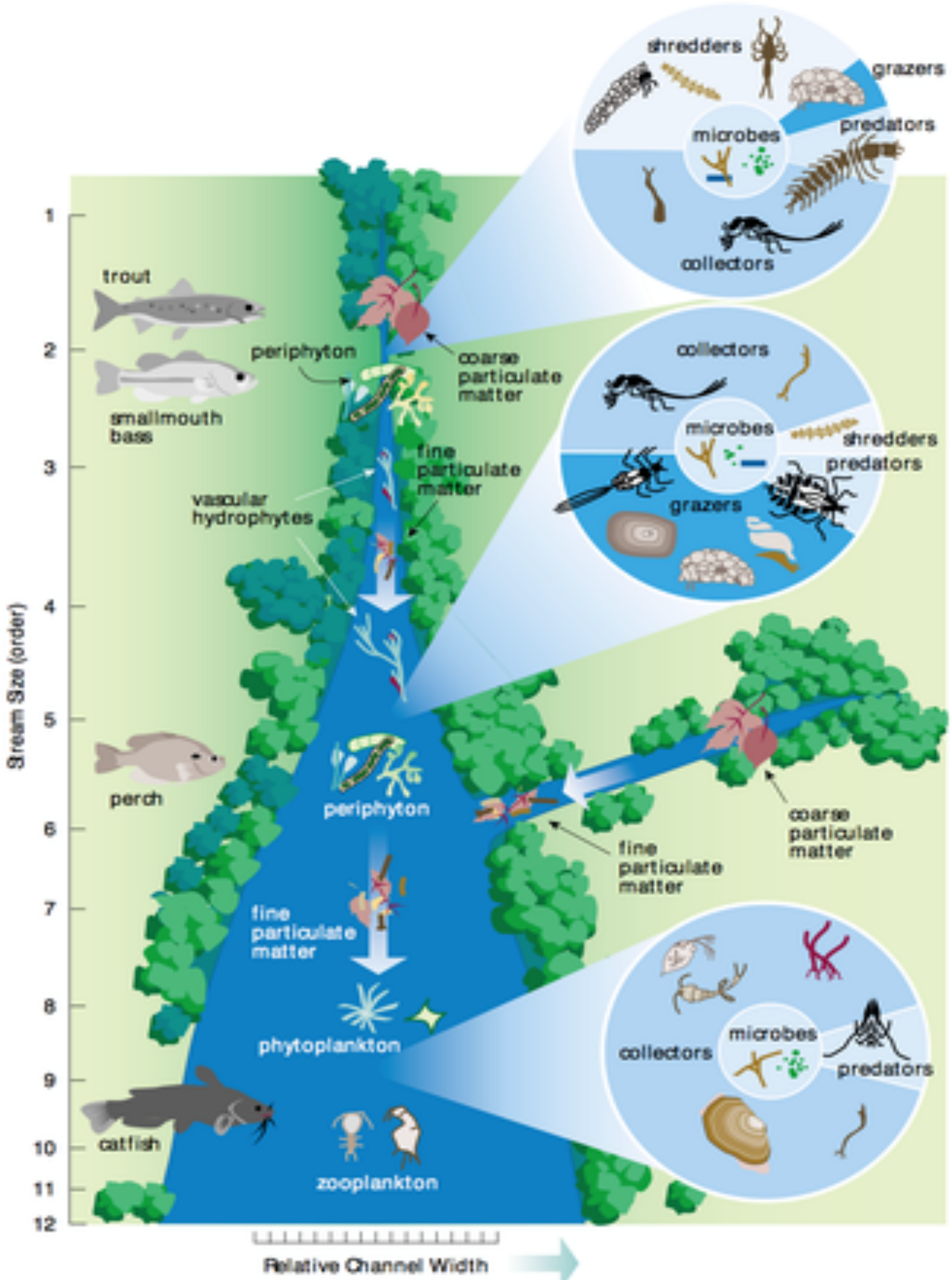



**Figure 26.** The River Continuum Concept (Stroud, ND).

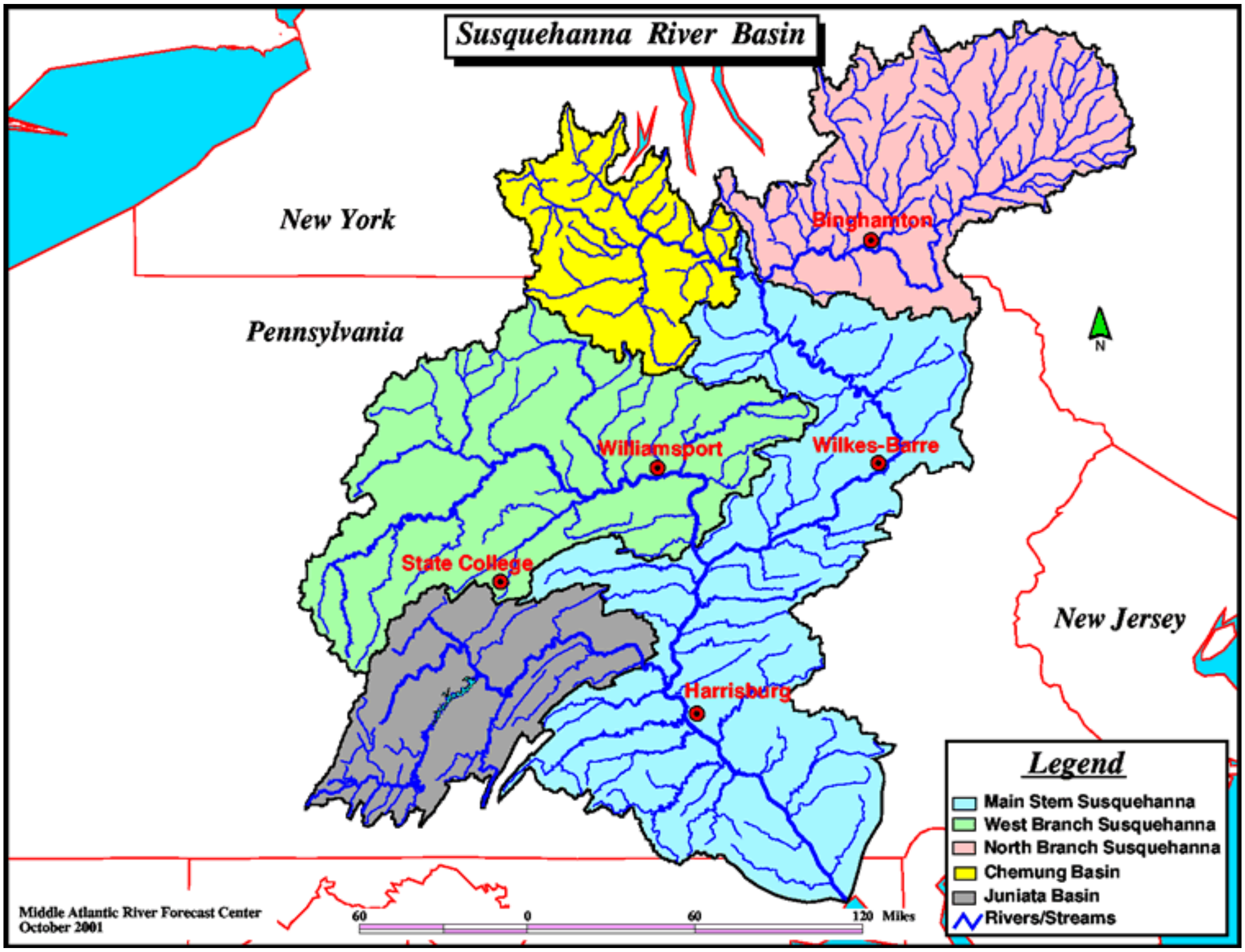



**Figure 27.** Susquehanna River Basin Map (Weather.gov. ND).

Human activity can alter the physical forces acting upon river/stream systems. In addition, high short-term variability may cause large variations in species abundance over time or might reduce species-ecology diversity. The use of hydro-fracking in the Marcellus Shale and its influence on terrestrial and aquatic ecology is not well understood (Grant et al 2016). Current research efforts have shown the potential for aquifer contamination and forest fragmentation.

In addition, surface waters can be possibly impacted by hydro-fracking through changes in aquatic ecosystems. These potential impacts to aquatic ecosystems are disconcerting, because changes in stream physio-chemistry, microbial communities, and soluble metal concentrations can cause cascading changes in aquatic trophic structure within riverine ecosystems (Grant et al. 2016). The river continuum concept becomes of significance as a starting point for understanding the impact of hydro-fracking upon these river systems in the Marcellus Shale of Pennsylvania. Recent research studies have revealed that elevated methyl mercury (MeHg) levels have been detected at the base of the food web for streams where hydro-fracking had occurred within their watershed (Grant et al. 2016).

Changes in the trophic structure and biomagnification rates are typically assessed by comparing the trophic position of specific organisms, the length of the food chains, and biodiversity measurement (Grant et al. 2016). The knowledge of food sources can assist in the understanding of the differences in bioaccumulation of contaminants, due to the aspect that terrestrial derived food sources often contain lower concentrations of contaminants such as mercury (Grant et al. 2016). Thus, relating trophic structure changes and the physiochemical characteristics of the stream enables the identification of factors controlling mercury levels within organisms. The observed perturbations, and with correlation to hydro-fracking, changing stream physiochemical conditions may affect the biomagnification of contaminants such as mercury, as well as aquatic biodiversity.

Thus, mercury accumulation is of great concern due to the ability of the element to persist, transform to methyl mercury, biomagnify, and have neurotoxic effects on organisms (Grant et al. 2015). Mercury can occur in ecosystems as a result of both natural and human induced processes, hydro-fracking being of concern. Hydro-fracking and flowback fluids have been shown to contain both organic and inorganic toxic substances, hydrochloric acid as an example and even mercury depending on the hydro-fracking chemicals utilized. While the direct input of mercury from hydro-fracking exists, changes in water quality in streams, such as the lowering of stream acidity makes mercury more soluble, which in turn increases bioaccumulation in macroinvertebrates and fish (Grant et al. 2015).

The research study found that biodiversity was most impacted at streams with documented frackwater fluid spills (Grant et al. 2016). Also, and of importance to riverine biodiversity, is that the apparent mismanagement of flowback water has been suggested as a significant risk and threat to surface water resources. The flowback fluids have the propensity to reach localized streams through leaking wastewater hoses, impoundment overflow, and lateral seepage and blowouts, as well as by backflow into the wellhead. Flowback water that is discharged into streams can directly impact stream physio-chemistry, as well as decrease aquatic biodiversity (Grant et al. 2016). Figure 28, as shown on page 76, provides a vivid example of the ability of flowback water to degrade the stream ecosystem. The picture in Figure 28 of dead fish is presumably due to illegally dumping flowback water into Dunkard Creek. The creek is a tributary of the Monongahela River as located in western Pennsylvania.

**Figure 28**. Fish Kill at Dunkard Creek (Hopey 2009).

These attributes indicate the need for ongoing research studies into the impact of hydro-fracking upon riverine ecosystems and the correlation to the river continuum concept. Thus, future efforts toward partitioning effects of land disturbance from infrastructure (well pads, pipelines, roads), hydro-fracking activities inclusive of spills, are necessary to establish pathways of contamination toward development of best management practices which serve to guarantee ecologically sound extraction of natural gas (Grant et al 2016).

## 6.3. The Groundwater Contamination Issue: spills, retention ponds, recycling

The use of hydro-fracking in the Marcellus Shale is a costly enterprise yet enables more productive wells than conventional drilling techniques. While the hydro-fracking process as utilized for the extraction of shale gas has created new economic opportunities for Pennsylvania and surrounding states, while in some instances it has also caused environmental issues, including both permitted and unintentional discharges of hydro-fracking related contamination into surface waters as well as causes in methane migration into water supplies (Brantley et al. 2014).

The Pennsylvania Department of Environmental Protection (PA DEP) is the primary regulator of natural gas in Pennsylvania. In a 2008 to 2012 time-frame, the PA DEP received roughly 1000 complaints about possible impacts on water supplies presumably due to hydro-fracking and natural gas extraction processes (Brantley et al. 2014). However, it is difficult to accurately determine whether deeply-emplaced hydro-fracking fluids have penetrated into an aquifer. For example, the detection of organic compounds such as toluene as used at low concentrations in hydro-fracking fluids may be difficult to detect where diluted into natural solutions that already contain natural organic compounds (Brantley et al. 2014).

If these hydro-fracking fluids were to migrate upward to contaminate shallow groundwater, they would most likely be accompanied by brine from the subsurface. This means that, instead of organic components, the most likely mode of detection of hydro-fracking fluids would be by analysis of inorganic components (Brantley et al. 2014). However, this detection is confounded by the fact that Pennsylvania's groundwater is already contaminated with natural brines that have migrated upward over geological time (Brantley et al. 2014).

Casing leaks, cementation problems and well construction problems are an ongoing concern using hydro-fracking. From a time period of 2005 to 2013 the PA DEP records indicate that 219 out of 6,466 wells received Notices of Violation for well construction problems, including casing or cementing issues (Brantley et al. 2014). This rate of well construction problems (3.4 %) lies within the range (1-5%) of newly constructed shale gas wells that are estimated to require workover for the surface string to safely pass pressure testing requirements. In contrast to this relatively high rate of natural gas well issues, between 2005 and March 2013 only sixteen wells received Notices of Violation for methane migration into groundwater. Of note, all sixteen wells where located in the northern Pennsylvania Marcellus Shale region (Brantley et al. 2014).

Many of these methane migration issues have been related to improper design and construction of wells for the local geological formation. In addition, a variety of mechanisms can contribute to leaks along the casing which can propagate contamination of water resources by methane migration. However, methane in Pennsylvania naturally occurs in groundwater due to both high-temperature maturation of organic matter at depth and low-temperature bacterial processes (Brantley et al. 2014).

The issue with methane migration into well water is that this methane has a low solubility (.00347 ounces/gallon at 1 atmosphere and 20 degrees Celsius) and enters the water as a solute, where it generally degasses (Brantley et al. 2014). Methane is not regulated as a health hazard in the United States. In addition, high methane levels are problematic due to the potential for an explosion (Brantley et al. 2014). Of relevance is the fact that methane explosions were reported in Pennsylvania long before Marcellus gas drilling (Brantley et al. 2014). Thus, much discussion continues as to whether methane gas migration into water wells is caused by drilling or by natural processes. The average concentration for methane gas samples as obtained by research efforts "are similar to values from Pennsylvania and West Virginia groundwater sampled by the U.S. Geological survey before Marcellus hydro-fracking began "(Brantley et al. 2014).

Pollution events from the Marcellus Shale hydro-fracking effort have included contamination from flowback (frackwater returned to the surface after drilling) water, fuels, or drilling materials

(Brantley et al. 2014). Of 161 pollution events, as reported from 2008 to 2012 by the PA DEP for example, 56% or 90 cases reported natural gas contamination, 14% or 23 cases reported brine contamination, 14 % or 23 cases reported contamination without brine, 4 % or 6 cases reported contamination by sediments, turbidity, and/or drill cuttings, and 12% or 19 cases reported no information about the cause of the pollution (Brantley et al. 2014). These various pollution events have resulted in localized environmental degradation that ultimately requires remediation and monitoring. Table 2, below, illustrates the magnitude of pollution events, spills, that have occurred in the Lycoming County area from 2010 through 2012.

| **Date** | **Location** | **Type of Spill** | **Quantity of Spill** |
|---|---|---|---|
| March 2010 | Pine Creek | Airfoam | 180 gallons |
| August 2010 | Big Run | Hydrostatic test water | 25,200 gallons |
| November 2010 | Tributary of Sugar Run | Flowback | Approx. 57,373 gallons |
| January 2012 | Pine Creek | Brine | 8,200 gallons |
| October 2012 | Tributary of Slack Run | Sediment | Unknown |
| November 2012 | Muncy Creek | Hydrostatic test water | 232,604 gallons |
| December 2012 | Brion Creek | Frackwater | 4,275 gallons |

**Table 2.** Examples of pollution events, spills, in Lycoming County (Brantley et al. 2014)

In addition, the methodology of storing the flowback water in retention ponds for reuse is problematic due to retention pond construction problems or retention pond liner failure (Brantley et al. 2014). Retention ponds can be rather expensive and time-consuming to construct however, and as David Yoxtheimer, a hydrogeologist with Penn State's Marcellus Center for Outreach and Research states, "they are simply prone to leak" (Legere 2015). The issue of retention pond leakage was brought into perspective when the natural gas extraction company, Range Resources, was cited in September 2014 for violations at six of its retention ponds (Gillooly 2014). The company was ultimately fined $4.15 million dollars by the PA DEP and instructed to close five of the retention ponds. Figure 29, below, illustrates a typical retention pond (impoundment) with liner.


**Figure 29.** Frackwater Retention Pond (Bomgardner 2012)

The most useful evidence for spill incidents links the contaminants directly to the source with a relatively high degree of certainty (Llewellyn et al. 2015). To evaluate impacts, a multiple lines of evidence approach is required which encompasses (i) time series analysis of natural gas as well as organic and inorganic compound concentrations, (ii) comparison of natural gas isotopic compositions between natural gas well annual gas and groundwater, (iii) assessments of the natural gas well construction itself, (iv) chronology of events, (v) hydrogeologic characterization, and (vi) existing geospatial relationships (Llewellyn et al. 2015).

Considering the multiple lines approach, investigative research has concluded that there is no substantiation that upward flowing fluids along fractures from the target shale formation is the source of contaminants but rather fluids flowing vertically along natural gas well boreholes and through intersecting shallow to intermediate flow paths via bedrock fractures are subject of concern. Flow along such pathways is most likely when hydro-fracking fluids are driven by high pressure such as exhibited during the hydro-fracking process itself (Llewellyn et al. 2015).

The number of flowback spills in Pennsylvania reported per year has increased since 2008 (Brantley et al. 2014). However, the probability of large spill events is low. For example, 32 large spills have been reported for more than 4,000 completed natural gas wells in the Pennsylvania Marcellus Shale (Brantley et al. 2014). Concern exists however regarding the untimely discharge of flowback water as the most concentrated constituents are sodium and chloride (Brantley et al. 2014).

Specifically, the concentrations from natural gas extraction operations have been associated with increased stream chloride ($Cl^-$) levels (Olmstead et al. 2013). Shale gas development tends to generate large quantities of flowback with high $Cl^-$ (Olmstead et al. 2013). Thus, elevated levels or fluctuating levels of $Cl^-$ can directly damage aquatic ecosystems. Research studies have concluded that municipal wastewater treatment facilities that have attempted to process flowback water have inadvertently released high concentrations of $Cl^-$ into local waterways (Olmstead et al. 2013).

At the onset of the Marcellus Shale municipal wastewater treatment facilities attempted to process the flowback fluids, the result of which was very unsuccessful. The processed water from the municipal wastewater treatment facilities was only partially treated prior to discharge into Pennsylvania streams. Concern about impacts to surface waters led the state to discourage this disposal practice (Brantley et al. 2014). Based on PA DEP records the natural gas drilling companies in the Pennsylvania Marcellus Shale now recycle 87 % of the flowback water, as of 2012 (Brantley et al. 2014).

## Chapter 7: Frackwater Treatment Processes

The disposal of frackwater (flowback water) through municipal wastewater treatment facilities can lead to elevated pollution levels in streams and rivers because these facilities are typically incapable of processing the high concentration of salts contained in the frackwater. The wastewater disposal risks are diminutive compared to the other water risks, although a rare, but serious retention pond failure could precipitate a very large contaminated water discharge to local waters (SBU 2012).

In its basic composition the frack fluid used for the hydro-fracking process, is a brine water mixture which possesses all the characteristics necessary to facilitate effective fracking. This includes easy preparation, rapid hydration, low fluid loss, good proppant transport capacity, low pipe friction, and effective recovery. Unlike freshwater, brine water does not restrict oil flow because of osmotic imbalance that results in clay swelling. Simply put, brine water is good for the hydro-fracking process (Gruber 2017).

In addition, frack fluids are blended to a level that is viscous enough to effectively transport the proppant, yet slick enough to permeate the micro-fissures that exist in the sedimentary shale rock formation (Gruber 2017). Thus, and with regards to the flow of frack fluid within the shale rock formation, the object is to reduce friction as a significant amount of total suspended solids in the fluid will create unwanted friction. The total suspended solids being comprised of gelling agents and friction reducers. Research infers that frackwater (flowback water) reuse is predicated upon removal of the total suspended solids contained in the frackwater, which minimizes the use of freshwater.

The flowback water contains gases such as carbon dioxide, hydrogen sulfide, nitrogen and helium; as well as naturally-occurring brine, trace elements of mercury, arsenic and lead, naturally occurring radioactive material (radon, thorium, uranium); and volatile organic compounds, such as benzene, that easily vaporize into air (Waterworld 2017). Herein lay the challenges as well as opportunities for water treatment companies and facilities to safely and adequately process the flowback water for reuse.

Several facilities now exist within the Pennsylvania Marcellus Shale, on a small scale, to process the frackwater. The process may be a fixed type facility or a mobile style unit. One typical mobile unit is capable of processing 0.864 mgd with typical total suspended solid removal rates above 99% (mgd= million gallons per day, Gruber 2017). Conversely, several fixed (in-situ) processing facilities have been constructed which process the flowback water whereby bag filtration is used to remove the high concentrations of total dissolved solids. For example, a typical in-situ facility is capable of processing 0.420 mgd of flowback water for ultimate reuse (mgd = million gallons per day, EurekaResources 2017). Figure 30, page 84, provides an illustration of the mobile style unit in comparison to a fixed facility for flowback water treatment.

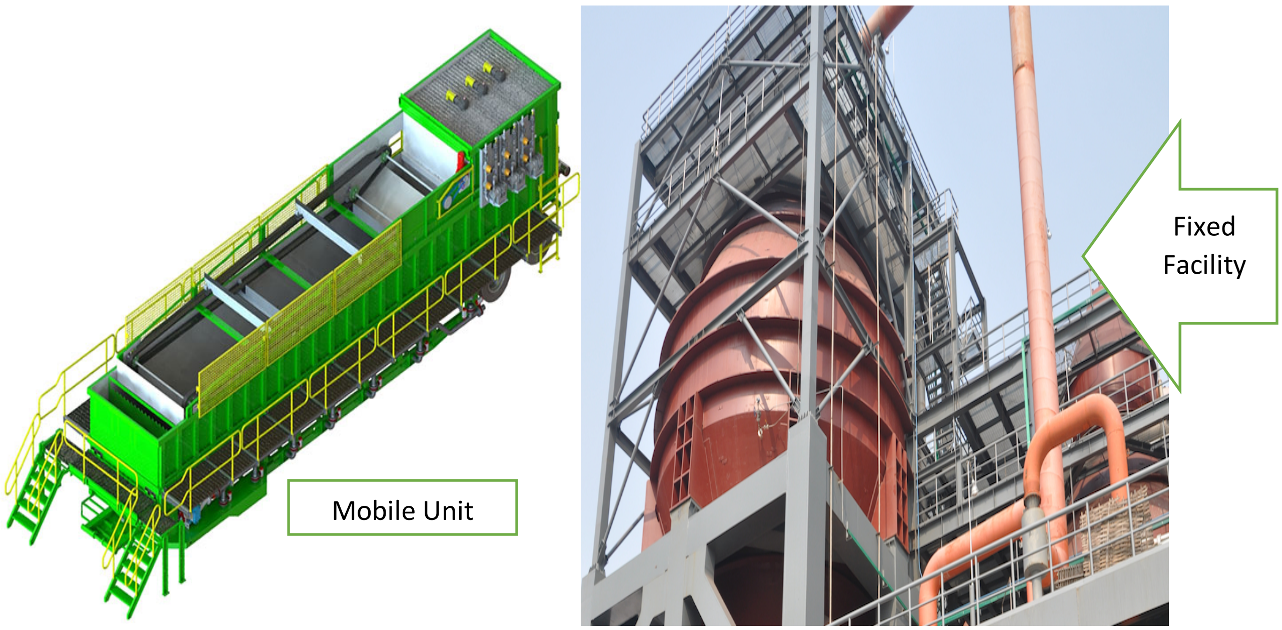



**Figure 30**. Mobile Style Frackwater Treatment Unit compared to a Fixed Facility (Ecologix 2017; EurekaResources 2017).

The mobile style unit removes the total suspended solids from the flowback water while the fixed facility removes the total dissolved solids. The difference between the two processes being that on-site processing removes the total suspended solids and enables quick reuse of the flowback water when mixed with fresh water (Waterworld 2017). In comparison, the fixed facility serves to remove the total suspended solids, which must be reduced to .0667 ounces per gallon to meet EPA water quality standards (Waterworld 2017).

The removal of total dissolved solids entails a five-step process. The first step encompasses the oxidation of chlorine dioxide, which breaks oil/grease emulsions. In essence, this process destroys friction reducers and other chemical additives; and essentially kills bacteria. The second step is dissolved air flotation which floats oil, grease and total suspended solids to the top of the process chamber. Liquid-phase activated carbon, as integral to the third and fourth steps, then removes most hydrocarbons and other organics, before chemical precipitation ultimately removes any scale-forming compounds. Finally, a conventional sand filtration process removes the total suspended solids (Waterworld 2017).

The total dissolved solid removal process is energy intensive and can entail either thermal distillation or membrane filtration (Waterworld 2017). The most common method to remove total dissolved solids is thermal distillation. The first step is vapor recompression-evaporation in which the flowback water is boiled to produce steam, while all of the dissolved solids remain in the concentrate (Waterworld 2017). The resulting steam is then condensed into pure water. Once the thermal distillation is complete the residual product, brine, is treated through crystallization (Waterworld 2017). The final product being a salt waste.

## 7.1. Alternative to processing frackwater, deep well injection

Of course, the easiest approach is to simply reuse the flowback water without any treatment however, continued reuse of flowback water will ultimately lead to problems as the high level of contaminants may plug the natural gas well with residual chemicals, precipitates or shale fines (Waterworld 2017). Another option is deep well injection but is fraught with controversy as well. Deep injection wells are also termed brine disposal wells and are officially known as class II underground injection wells. They can take any fluid related to natural gas drilling, including waste frackwater (Stateimpact 2017). In Pennsylvania, deep injection wells are regulated by the Environmental Protection Agency through the Underground Injection Control Program (Stateimpact 2017). Figure 31, as shown on page 86, provides an illustration of deep well injection.

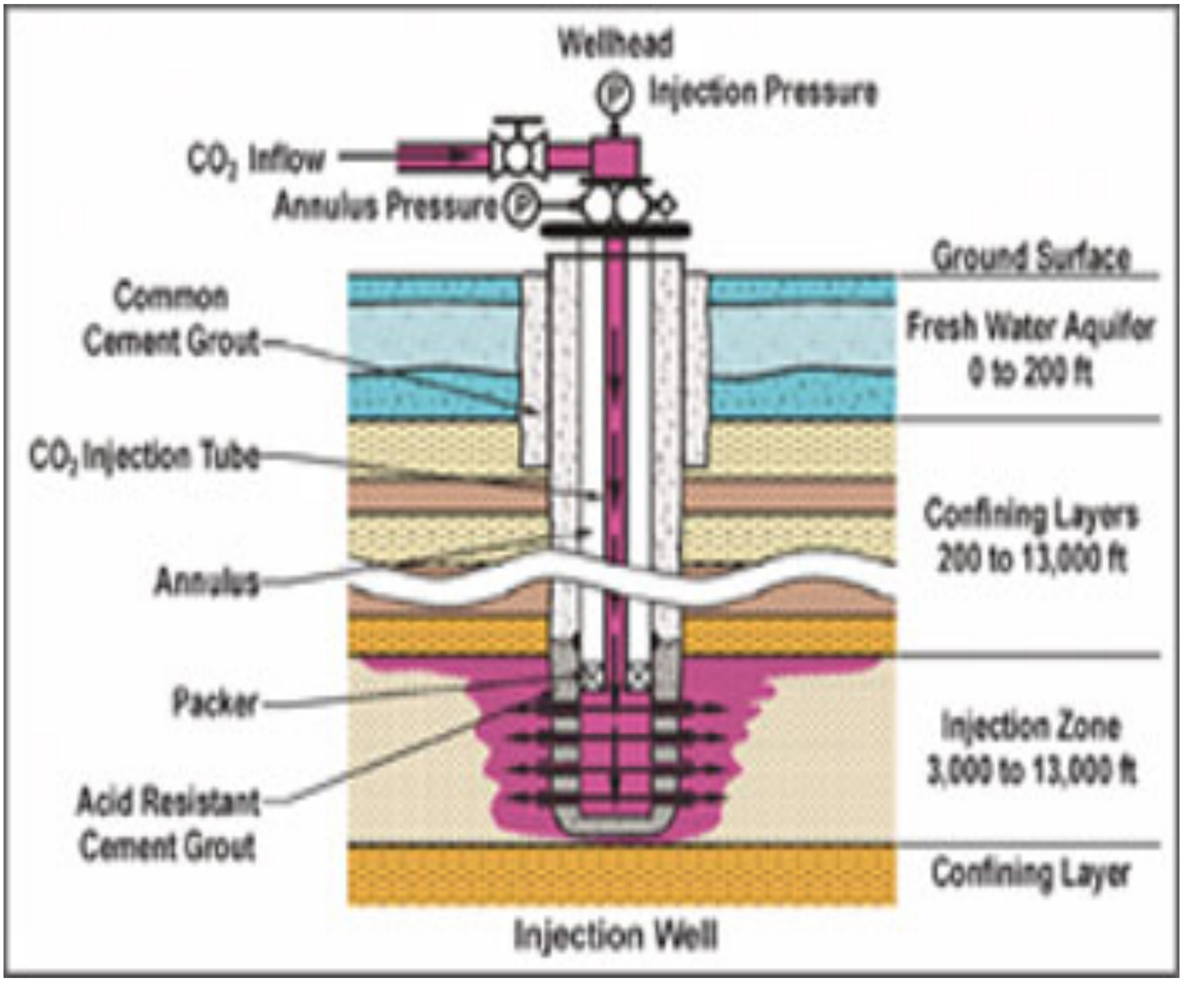



**Figure 31.** Deep Well Injection Diagram (Upstream 2011).

The primary concern with deep injection wells is leakage. Investigative research from across the United States has shown that wells drilled to bury flowback waste deep beneath the ground have repeatedly leaked, sending dangerous chemicals and waste propagating to the surface or, on occasion, seeping into shallow aquifers (Lustgarten 2012). Deep injection wells are subject to casing failures inclusive of sweet corrosion or carbon dioxide corrosion, sour corrosion or hydrogen sulfide corrosion, oxygen, galvanic, and microbiological induced corrosion (Green & Bertetti 2014).

These types of wells are also subject to failure due to formation damage during drilling, incomplete cementing, non-adequate drilling mud, cement shrinkage, and contamination of the cement (Green & Bertetti 2014). In essence, injection of flowback water into this type of well is not only controversial but risky.

## Chapter 8: Pipelines and Compressor Stations

Unquestionably, the Marcellus Shale “has the potential to alter the landscape of the global energy market” (Phillips 2015). However, a shortage of pipelines to get the natural gas from the well head to the consumer exists. The need for pipelines includes an estimated 4,000 miles of new interstate pipelines, which is in addition to the existing 6,800 miles of pipelines (Phillips 2015). Research indicates that the Marcellus Shale in Pennsylvania produces 19 billion cubic feet per day based on 2015 data (Phillips 2015). By 2020 that figure could be as high as 30 billion cubic feet per day which is a 1400 percent increase, and that massive increase is too much for the current pipeline system to handle (Phillips 2015).

Figure 32, as shown on page 88, illuminates one of the many proposed pipelines which are scheduled for construction as a result of the Marcellus Shale. This particular natural gas pipeline (as shown in red) originates in the northern Pennsylvania Marcellus Shale region and will ultimately connect to multiple natural gas distribution systems including a natural gas liquification-vaporization-storage facility located in the southeastern portion of the state (Pottsmerccommunityresources. 2012). The pipeline’s construction in this case is contingent upon many end users.

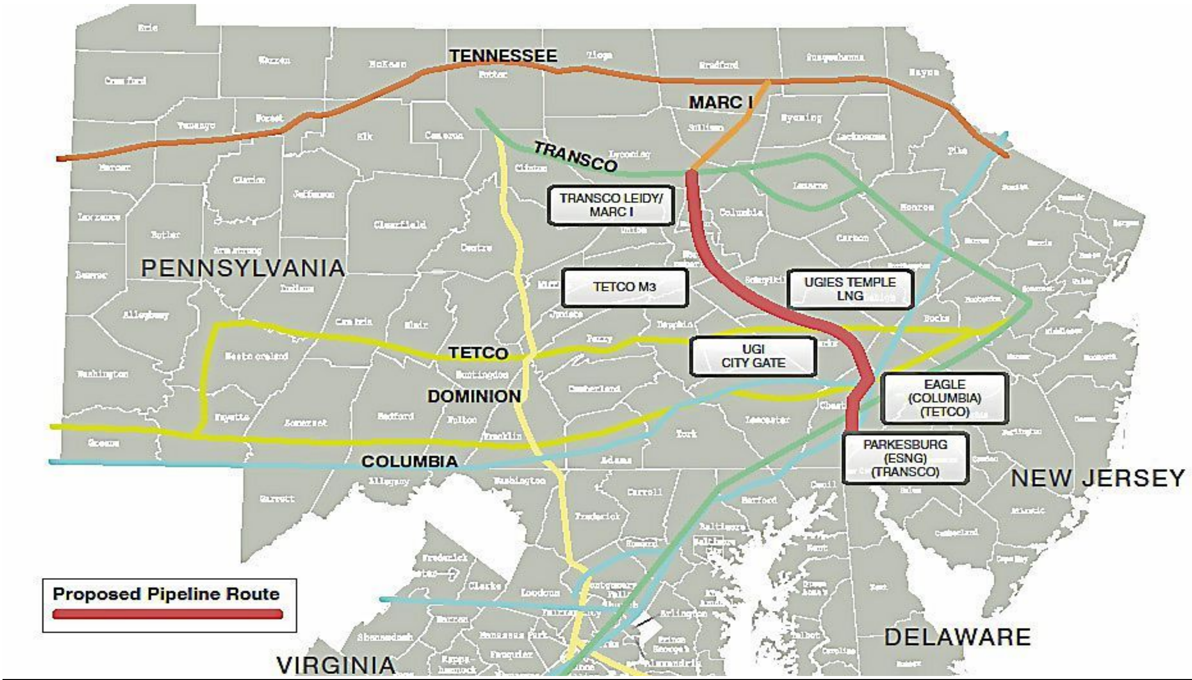



**Figure 32.** Map of Natural Gas Pipeline Construction in the Marcellus Shale (Pottsmerccommunityresources. 2012).

The need for natural gas pipelines is the result of the natural gas extraction process, or the positive feedback from hydro-fracking; more begets more. The new pipeline construction will provide economic benefit to those in need of jobs, as well as the companies that do the pipeline construction. But from a community impact perspective, residents and politicians worry about environmental degradation, and proclaim that the current regulatory structure needs to be revised and updated to meet current trends and needs (Paynter 2015). The issue is confounded by the fact that "Pennsylvania does not have one regulatory authority that oversees intrastate pipelines" (Paynter 2015).

To construct a natural gas pipeline a right of way must be secured from both private and/or public landowners as necessary. The natural gas companies pay for those rights of way as well as obtain the proper permits. However, obtaining the proper permits is problematic, the Federal

Energy Regulatory Commission (FERC) must approve the interstate pipeline and the Pennsylvania Public Utilities Commission must approve any pipelines that directly serve consumers. In the case of Marcellus Shale pipelines, few of these natural gas pipelines fall in a well-ordered manner into either of those categories (Paynter 2015).

If a natural gas pipeline traverses a wetland or stream/river permits are necessary from the Pennsylvania Department of Environmental Protection (PA DEP). In addition, if the pipeline crosses through areas with endangered species or rare species, the PA DEP has oversight. Also, local municipalities might have pipeline construction regulations as well. In essence, the pipeline boom, as a result of the natural gas boom in Pennsylvania, requires astute planning and a best practice approach to avoid environmental degradation and possible impacts to local communities. Despite these permitting and planning hurdles, the need for natural gas pipelines in the region and more specifically, the northeastern United State, has been illuminated in a report generated by the United States Chamber of Commerce, inferring that if no new natural gas pipelines were constructed, it could potentially cost the region well over 78,000 jobs and $7.6 billion in GDP by the end of year 2020 (Cusick 2017).

## 8.1. Compressor stations

Compressor stations represent another environmental concern and a side-effect of pipeline construction. As the number of natural gas wells increase, so too do the number of pipelines necessary to move the gas and likewise, the number of compressor stations. The fundamental purpose of the compressor station is to push the gas along the pipeline until the next pipeline connects to a larger pipeline (MDN 2012). From a basic design perspective, as natural gas moves through a pipeline, distance, friction, and elevation differences slow the movement or flow of the gas, and subsequently reduce the pressure within the pipeline. Compressor stations are placed strategically within the pipeline network to help maintain the pressure and flow of gas (PSU 2015).

From an environmental degradation perspective, and of concern, is the fact that significant soil disturbance and compaction often occurs during construction of a typical compressor station site (PSU 2015). This can result in the potential for reduced crop yields on agricultural type soils and reduced tree-vegetation growth in forest soil areas for several years (PSU 2015). Thus, compressor stations and their construction can be considered as the next battleground for those opposed to the natural gas extraction process inclusive of landowners (MDN 2012). The problem is exacerbated by the fact that local communities may have little say about where a compressor station site is located (TME 2009). In some cases, the compressor stations are being located beyond the town boundaries, which also means that they are out of the town's jurisdiction of governance (TME 2009). Which effectually means that local governance has no control over where the compressor stations are located.

## Chapter 9: Threats to Forest Area and Wildlife

The Pennsylvania Wilds (part of the northern Appalachian Mountains) consists of more than 6 million acres of unspoiled forest in northern Pennsylvania (Pennell 2009). The area has been known for its remnants of virgin forest and abundant wildlife. However, and since the inception of the Marcellus Shale, this area has been proliferated with new roads being cut into the forest. Those new roads carrying tank trucks and men and equipment to remote destinations. This increase in infrastructure and traffic is somewhat reminiscent of the heyday of heavy timbering and logging that occurred within the northern Pennsylvania forests (Pennell 2009).

The continued fragmentation of ecologically important core forests within the northern Pennsylvania/Appalachian region by pipeline, compressor stations, and infrastructure construction-is conceivably the major threat posed by shale gas development (Mulhollem 2017). Expansive tracts of this northern Pennsylvania forest area provide critical habitat for some species of forest dependent wildlife. Thus, the fragmentation of these forest areas due to natural gas well pad construction and pipelines for example will have varying impacts upon the wildlife. For example, the construction of new pipelines may serve as a benefit for deer, bear, and nest predators such as fox and raccoons, being utilized as travel corridors (Pacchioli 2013). Figure 33, as shown below, illustrates a natural gas pipeline construction site and the significance of forest fragmentation as well as the potential for a travel corridor to exist for wildlife.


**Figure 33.** Natural Gas Pipeline, Potential Travel Corridor for Wildlife (NAOGP 2016).

Habitat fragmentation as a result of the Marcellus Shale drilling effort is serving to disrupt and degrade the forest-ecosystem. Research findings indicate that current trends of land-use change resulting from shale-gas development suggest that the greatest loss of core forest will occur when natural gas well pads are located the farthest from pre-existing pipelines, which will necessitate new pipelines and infrastructure to be built (Mulhollem 2017). Figure 34, below, illustrates natural gas extraction in a Pennsylvania forest area.

**Figure 34**. Picture of Natural Gas Drill Rig in a Forest Area of Pennsylvania (Detrow 2012).

In addition, research studies suggest that to reduce future forest fragmentation, new natural gas pads should be strategically placed near pre-existing pipelines, and methods to consolidate pipelines with other infrastructure should be utilized (Mulhollem 2017). Also, of concern is the aspect of shale-gas development taking place on public land versus private land. Currently, nearly three fourths of all shale-gas development are located on private land. However, the number of natural gas wells drilled per pad is lower on private property compared to public land. As a result, loss of core Pennsylvania forest is more than double on private land than public land, which likely is the result of better management practices implemented on public land (Mulhollem 2017).

Of relevance, Lycoming County ranks fifth in the state of Pennsylvania for active natural gas well drilling with 925 wells or a well pad density ratio of 22 pads per 100 square miles, as of April 2016 (Mulhollem 2017). In addition, Lycoming County and its forest area since 2010 has sustained a 4 percent loss of core forest in six years due to shale-gas well pad development, with habitat fragmentation being of significance (Mulhollem 2017).

The shale-gas development fragmentation might provide habitat for early successional species. Early successional alluding to a mix of species which form the earliest successional stage, sometimes referred to as the pioneer plant community (Perry et al. 2008). This stage of species succession is dependent upon multiple factors including (1) what plants comprise the species pool, (2) the type, severity, and timing of the fragment or disturbance, (3) the abiotic environmental conditions such as water availability, microclimate, and nutrient availability, and (4) the biotic environment such as direct and indirect interactions among species (Perry et al. 2008). However, this will not occur until natural gas construction sites (natural gas well pads and pipeline areas for example) are properly restored (Pacchioli 2013). Figure 35, as shown on page 94, illustrates the progression from early successional to old growth or climax forest habitat.

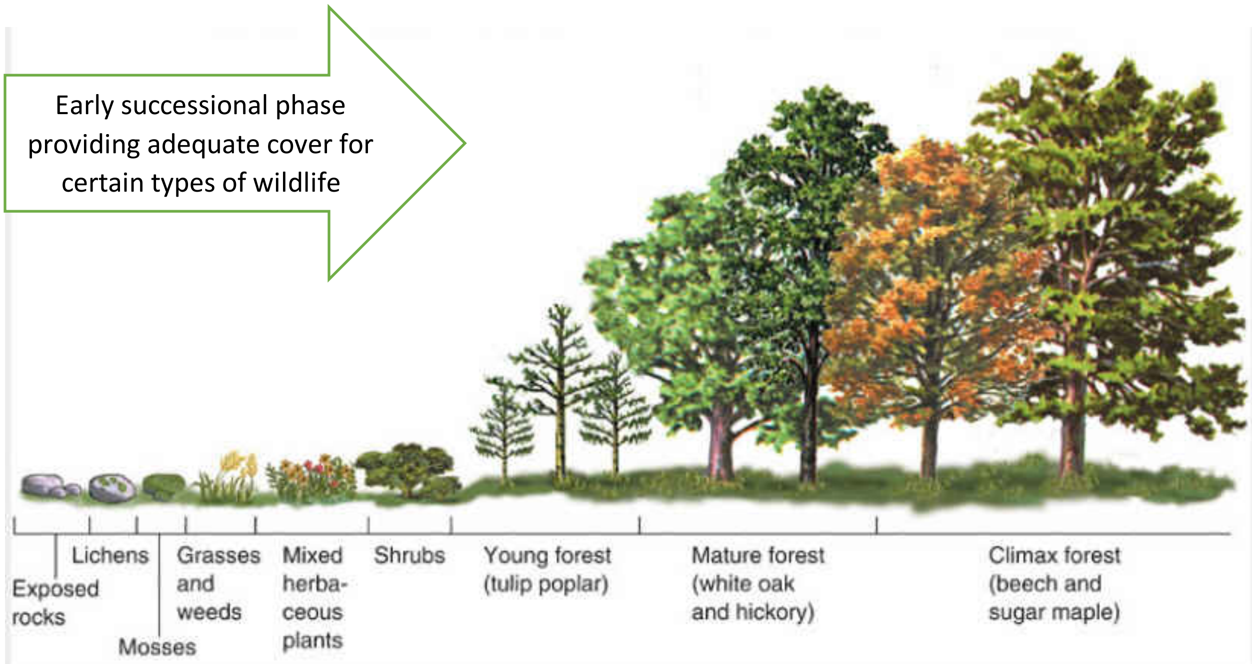



**Figure 35**. Early Successional to Old Growth Forest Habitat Progression (Reforestation.me ND).

In addition, Pennsylvania is critically important for numerous species of migratory neo-tropical birds coming from Central and South America that depend on large tracts of Pennsylvania forest and waterways/ponds/lakes for breeding (Pacchioli 2013). Thus, the impact of the Marcellus Shale upon the wildlife, and migratory wildlife species, of Pennsylvania has the potential for detrimental lasting effects and is of concern. For example, the fragmentation of habitat caused by the Marcellus Shale natural gas extraction effort may ultimately alter wildlife patterns and behavior from nesting to migration, as a lot of the wildlife depend on that habitat for breeding purposes. Of significance is the fact that communities of animals and microbes respond to successional changes of plant communities differently. Some species of birds tend to nest preferentially in early successional conditions (Perry et al. 2008). The fragmentation of habitat caused by the Marcellus Shale natural gas extraction effort may ultimately alter wildlife patterns and behavior from nesting to migration.

## 9.1. Other Forest Impacts due to Shale Gas Development

Forest fragmentation from shale-gas development potentially changes forest tree composition. Of special concern for Pennsylvania is the oak tree species-plant community. Oak trees are an important tree species with significant wood structural properties as well as an important source of mast for wildlife. In essence, as forest fragmentation continues and the effects of anthropogenic climate change magnify, the oak tree will decline to possibly a state of nonexistence within Pennsylvania. Inherently, the issue becomes one of propagating oak seedlings amongst the old growth oak trees that do exist in the face of a decline in core forest due to the Marcellus Shale natural gas development in Pennsylvania.

Research indicates that the forest trend for the mid-Atlantic states, inclusive of Pennsylvania, is one of uncertainty. While an understanding of the forest system is known as well as the drivers and stressors, caution and concern exists as the "impacts are non-linear with multiple interactions" (McWilliams 2010). Studies have revealed that there are fewer oaks and more maple tree species in Pennsylvania and the stand size structure is increasing. These factors equate to a general consensus that tree growth overall is slowing, mortality is increasing, and regeneration is lacking (McWilliams 2010). Again, in the face of forest fragmentation these issues become exacerbated.

Woodland regeneration and specifically oak regeneration is conducive in the eastern United States (Pennsylvania) as a result of suitable soil and climate regimes. While open-structured oak woodlands were at one time prominent in the eastern United States and Pennsylvania, their relative distribution changed over time as a result of climate change, and human populations and cultural influences (Dey et al 2016). Today the oak forest of Pennsylvania is in rapid decline, despite the Marcellus Shale, and the restoration of these valuable tree species requires active management practices.

Pennsylvania has a Koppen Climate Classification of *Dfb* which implies a warm summer continental climate (Weatherbase.com. ND). However, for the past 100-years annual temperatures in Pennsylvania have increased by around 0.5 degrees Fahrenheit (UCS 2008). In addition, annual rainfall has increased in all but the central southern portions of the state. Most noticeably winters have warmed significantly and, in most city-locations, the number of extremely hot (over 90 degrees F) summer days has increased dramatically since a 1970-time frame (UCS 2008). This apparent trend in warming is projected to continue through 2099 based upon the assumption that heat trapping emissions will remain at a high concentration (UCS 2008).

Winter temperatures are expected to rise about 8 degrees Fahrenheit above the historic levels and summer temperatures are projected to increase by 11 degrees Fahrenheit (UCS 2008). While these increases are based upon high emission concentrations in the atmosphere, under a lower level of emissions concentration the changes are projected to be about fifty percent less (UCS 2008). Considering a higher emission scenario, due in part because long-lived trees may persist for many decades in declining climatic conditions, it remains highly uncertain what Pennsylvania's forests will look like toward the end of this century (UCS 2008).

However, some magnitude of change is certain at the landscape level with quite rather significant change expected in a higher anthropogenic driven emissions future (UCS 2008). Disturbances, whether human induced (such as the Marcellus Shale) or natural, will shape forest ecosystems by influencing the forest composition and structure. This postulate suggestive that forest fragmentation due to the shale-gas development in Pennsylvania complicates forest best management practices, as well as regeneration of the oak tree species in the state.

In addition, the fragmentation and deforestation effect of shale-gas development has the potential to influence evapotranspiration. This infers that a portion of the precipitation that falls upon land surfaces infiltrates the soil and is taken up by plants and vegetation through their root system. Plants in turn release water, as water vapor, back into the atmosphere through the stomata. Because of the inherent difficulty to accurately distinguish between the amount of water that evaporates from that which is transpired by plants, the term evapotranspiration is often used to best describe the combined process (Lutgens & Tarbuck 2013).

The result of evapotranspiration, which is atmospheric moisture, is moved by the circulation of winds across the Earth's continents and oceans (Ellison et al. 2017). In this context, evapotranspiration is very much a transboundary phenomenon and as such, represents a linkage with the spatial extent of vegetation cover and forests. Deforestation and loss of core forest, as in the case of Pennsylvania forest, has the potential to influence evapotranspiration, which likewise has a correlation with climate change. This premise infers the biotic pump theory which states that the atmospheric circulation that brings rainfall to continental interiors is driven as well as maintained by large and continuous forest areas beginning from continental coastlines (Ellison et al. 2017).

The biotic pump theory asserts that forests, by virtue of the process of condensation and transpiration, actively create low pressure regions that draw in moist air from the oceans, thereby generating prevailing winds which are capable of carrying moisture and sustaining rainfall within continental interiors (Ellison et al. 2017). Deforestation (loss of core forest area) as a result of natural gas well pad development, natural gas pipeline construction, and shale gas development would potentially serve to inhibit air flow patterns and reduce precipitation dependability. Climate science illuminates this concept as forest clearings are capable of generating convection-driven breeze in which moist air is driven out of the forest (Shell & Murdiyarso 2009). This suggests that forest loss will be associated with the loss of stabilizing feedbacks as well as the potential for increased climatic instability (Shell & Murdiyarso 2009).

The loss of forest and potential influence upon climatic conditions, not only regionally but globally, as a result of the shale gas development plausibly epitomizes the sustainability criteria. The sustainability criterion states that at a minimum, future generations should be left no worse off than current generations. In essence, allocations that impoverish future generations in order to enrich current generations are, according to the sustainability criterion, considered to be unfair (Tietenberg & Lewis 2016). Considering that Pennsylvania has incurred a 4 % forest loss due to natural gas extraction, the question that beckons is, have we as a society considered future sustainability in this endeavor? The state and transition model, Figure 36 as shown on page 99, illuminates the aspects of the need for remediation relative to long-term sustainability.

.

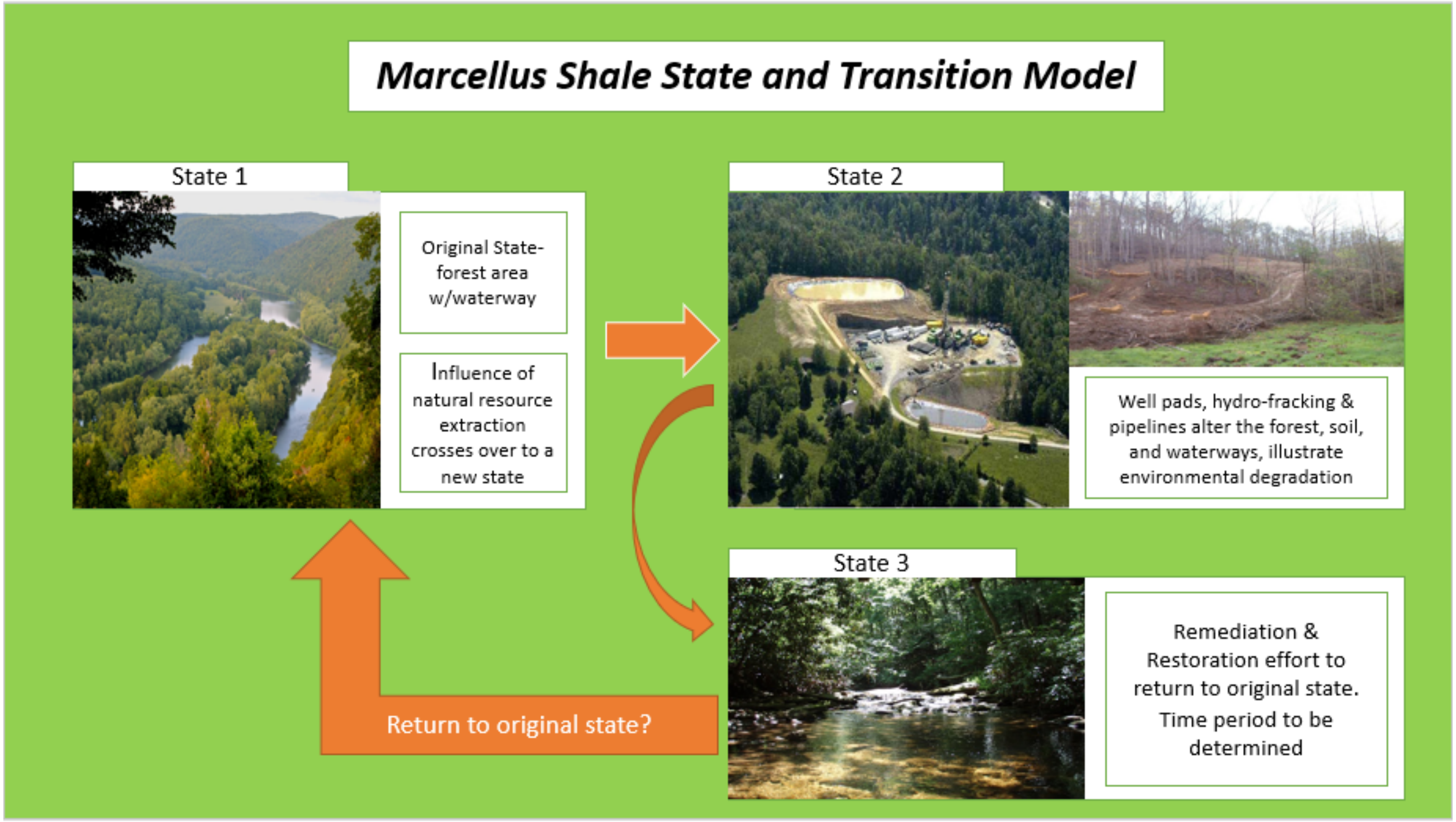



**Figure 36**. Marcellus Shale State and Transition Model

## Chapter 10: Groundwater Contamination Issues

In review of numerous possible water pollution and contamination scenarios in the Marcellus Shale, researchers suggest that the focus should be upon wastewater disposal (Rozell & Reaven. 2011). Research studies have concluded that even in a best-case scenario, an individual natural gas well would potentially release at least 52,834 gallons of contaminated fluids (Rozell & Reaven. 2011). The disposal of these large amounts of wastewater (flowback) presents inherent risks from salts and radioactive materials (Rozell & Reaven. 2011). The conclusion being that regulations and additional mandatory steps are necessary to reduce the potential for drinking water contamination within affected communities (Rozell & Reaven. 2011). Lawsuits have been filed in the states of Pennsylvania which claim that the drilling, storage, and containment process and procedure in the Marcellus Shale have caused contamination of groundwater and/or public water supply (Mullady et al. 2011). In individual actions which have been filed as of 2011, Marcellus Shale groundwater plaintiffs have argued a number of causes of action that are typically seen in environmental tort litigation (Mullady et al. 2011).

The groundwater plaintiffs have asserted a number of causes of action typically seen in environmental litigation such as: trespassing, private nuisance, violation of state statutes, negligence, strict liability for abnormally dangerous activity, and diminution of property value (Mullady et al. 2011). These types of claims represent a lawsuit model approach for class litigation in the Marcellus Shale.

The groundwater plaintiffs basically seek injunctive relief in the form of air, soil, groundwater and atmosphere monitoring for the presence of hazardous chemicals and compounds, as well as medical monitoring to determine the extent to which the natural gas extraction company's operations pose a health risk to the community (Mullady et al. 2011). The question being, do they have a valid case against the natural gas extraction companies?

There are four threshold requirements that must be met for authorization of class action lawsuits. Federal Rule of Civil Procedure 23, Rule 23 states: 1) a class be so innumerable that joinder of all members is unsuitable; 2) that there are questions of law or fact that exist which are common to the class; 3) that the claims and defenses of the representative parties are characteristic of the claims or defenses of the class; and 4) that the representative parties will fairly and creditably protect the interest of the class (Mullady et al. 2011). Unfortunately, it is highly unlikely that Marcellus Shale groundwater contamination plaintiffs can congruously meet these four threshold requirements (Mullady et al. 2011).

In some instances, litigation has resulted by families claiming that the drilling, storage, and containment process has caused groundwater contamination. Perhaps the most notable being 17 families in Dimock, Pennsylvania, as presented in the movie Gasland (Mullady et al. 2011). However, the counsel for Marcellus Shale groundwater plaintiffs have yet to attempt to aggregate groundwater contamination claims into a class action lawsuit (Mullady et al. 2011). In addition, and while class action lawsuits have their place in matters of litigation, conceivably that place is not within the context of groundwater contamination litigation relating to natural gas production activity (Mullady et al. 2011).

Marcellus Shale defendants-drilling companies have at their disposal a wide variety of facts to draw upon to highlight and emphasize the benefits that their extraction activities provide to the community, in which they are based. In addition, the courts have found that other more dangerous activities should be considered abnormally dangerous in view of their value and impact upon the community (Mullady et al. 2011). The plaintiff, as in the landowner who claims groundwater contamination, must provide scientific evidence that the defendant (drilling company) caused the landowner (plaintiff) to be exposed to a hazard through some form of tort conduct (Mullady et al. 2011).

This will be especially difficult as the plaintiff must reasonably demonstrate to the satisfaction of the court the existence of a potential pathway between the natural gas extraction company's operations and the landowner water well (Mullady et al. 2011). The ability to prove beyond reasonable doubt that this pathway exists and is a result of the Marcellus Shale drilling-operations efforts is no small task as, problems with natural gas propagation into water wells are not new, nor are they uniquely caused by Marcellus Shale natural gas extraction (Mullady et al. 2011).

## 10.1. Considering the need for Collaboration amongst Stakeholders

The drilling for natural gas in the Lycoming County region of the Marcellus Shale of Pennsylvania has been placed on hold in view of a glut of natural gas, the issues of dry natural gas versus wet natural gas (as found in western Pennsylvania and Ohio), and the lack of infrastructure piping. In the aftermath and after numerous environmental incidents, the natural gas industry in northern Pennsylvania, and specifically Lycoming County in this case is but a fleeting memory. Yet its mark has left an indelible footprint, once again, as an example of an extractive industry exploiting the community for obviously self-serving economic gain. Interestingly, assertions were made previously that the decade's long promises of Marcellus Shale boom growth would be a fallacy.

In hindsight, the forecasts for the longevity of the natural gas shale boom, including projections from energy companies as well as the Federal Energy Information Administration, are simply educated guesswork. Multiple indicators suggest that the boom might go bust sooner than was originally anticipated (Zeller 2015). In truth, the boom has ended and Lycoming County, Pennsylvania is perhaps no better off from an economic or social sustainability perspective. In fact, perhaps worse than before the Marcellus Shale drilling efforts arrived.

Since 2008, Pennsylvania has increased its environmental regulations over the Marcellus Shale exploration and development, which is justifiably the result of activist groups and appropriate statewide regulation. In 2008 the PA DEP implemented a mandatory water plan requirement for every drilling permit issued to a Marcellus Shale natural gas drilling company (DEP, 2013). By August 21, 2010 a new regulation was invoked that required drilling companies within the Marcellus Shale region to treat drilling water for compliance to the safe drinking water standard for Total Dissolved Solids (TDS).

The regulatory ruling of August 2010 was considered as a major step and milestone in attempting to reduce the uncertainty of Marcellus Shale wastewater treatment in the future by defining one important standard that treated wastewater must attain before discharge. Many industry experts strongly believe that the existence of a clear standard now will foster technological innovation in the field of Marcellus Shale wastewater treatment (Abdalla et al. 2016).

Additional legislation, and ultimately regulations imposed upon the Marcellus Shale extraction companies, entail natural gas drilling well setbacks from bodies of surface water. A general waste permit is now required for regulatory clarity of wastewater treatment facilities treating the Marcellus Shale wastewater for the purpose of reuse with zero liquid discharge to Pennsylvania waterways (DEP, 2013). It might be easy to conclude that Pennsylvania's government, the PA DEP, and activist groups have successfully mitigated the Marcellus Shale water issues.

The PennEnvironment Research and Policy Center identified a total of 3,355 violations of environmental laws by 64 different Marcellus Shale natural gas extraction companies between January 1, 2008 and December 31, 2011 (Staaf, 2012). Of these violations, the PennEnvironment Research and Policy Center has clearly delineated 2,392 violations that likely posed a direct threat to Pennsylvania's environment and were not reporting or paperwork violations. The greatest numbers of environmental violations were directly related to Marcellus Shale extraction company's failure to provide proper and coherent erosion and sedimentation plans (Staaf, 2012).

## 10.2. The role of governmental agencies and activist groups

The continual efforts and role of Pennsylvania's governmental agencies and community activist organizations, relative to the Marcellus Shale environmental issues, is plausibly a subject of debate. For example, the PA DEP has gained knowledge and thus implemented environmental regulations by conceivably a trial by error methodology over a time continuum. Inclusive of this environmental agency effort is the question of activist group unification of presentation. Central to this discussion is the postulate that cohesive and unified community activism and public involvement are integral to environmental policy decision making.

The need (or attempt) for a rigorous governmental oversight approach (involving community stakeholder activism) is perhaps exemplified by the Citizens Marcellus Shale Commission (CMSC) (State Impact, 2011). The CMSC was created as a reflexive reaction to Governor Corbett's Marcellus Shale Advisory Commission (Governor Corbett being the previous Governor of Pennsylvania from 2011 to 2015) (State Impact, 2011; Lewis 2016). However, the

CMSC is comprised of only eight activist groups in relationship to the numerous activist groups that currently exist within the Pennsylvania Marcellus region. Those activist groups that do comprise the CMSC are as follows: Clean Water Action, CLEAR Coalition, Housing Alliance of Pennsylvania, Keystone Progress, League of Women Voters, PennEnvironment, Pennsylvania Budget and Policy Center, and the Sierra Club Pennsylvania Chapter (Citizens Marcellus Shale Commission, 2011).

The CMSC is plausibly a rudimentary attempt to establish collaboration and cohesion for the purpose of sustainability which embraces human, natural, social, economic, and governance capital. This concept could hypothetically evolve into a Water Action Team (WAT) approach that engages potentially all necessary stakeholders: community, governing bodies, and the natural gas companies themselves. The suggestion of a WAT is representative of the characteristics that "consensus-based institutions play a major role in building trust, goodwill, and mutual understanding" (Weible & Sabatier, 2009).

Ferreyra and Beard (2006) describe the WAT concept within this context: "members in each service team worked collaboratively with the support of professional facilitators to develop common visions, strategies and action plans". The WAT would presumably breach the gaps and individuality of each activist group working in an independent nature to encompass a unified partnership, engaging all activist groups under one umbrella. The effort to achieve success of the WAT exists in a mutually agreed upon outcome evaluation, dependent upon evaluation indicators.

## 10.3. The Water Action Team Approach

McCool and Stankey (2001) state that "sustainability requires; (i) achieving a variety of social, economic, and environmental goals; (ii) more or less simultaneously while; (iii) providing options for the future; yet (iv) meeting the needs of the present". The frackwater disposal and treatment issue remains at large and will continue to be problematic when drilling resumes in the future in the northern Pennsylvania region of the Marcellus Shale. One disposal method utilized was injection of the frackwater into deep wells. However, this process resulted into periodic earthquakes. Treatment of the frackwater at municipal water treatment facilities has been banned. In addition, brine treatment technology has been utilized on a small scale however, many of these facilities have incurred fines for failing to meet Clean Water Act standards (Chameides 2013).

Regardless of the frackwater treatment technology utilized, the ultimate regulatory requirement infers water quality that is safe for the ecosystem-watershed and public use. Thus, and with respect to ecosystem functionality, the discharge of wastewater effluent to surface water has a detectable impact on water quality of the waterway (Warner et al. 2013). This aspect infers that the processing of frackwater requires technology that meets ecosystem needs as well as public use requirements. This is no small task realizing that the safe disposal of large volumes of frackwater associated with natural gas extraction is a major challenge because the waste fluids often contain high levels of salinity, toxic metals, and radioactivity (Warner et al. 2013).

In essence, the processing of frackwaste water embraces socio-ecological issues that are far reaching inclusive of: political, social capital, natural capital, human capital, and financial concerns. Thus, prioritizing those areas of natural and human capital that could be made more sustainable is mandatory. Figure 37 below illustrates the hierarchal importance and priority of water (natural capital) supply protection inclusive of: rivers, streams, well-water, irrigation water, and groundwater. For example, contamination of local water resources has an implication to well-water, soil-crop production, ecosystem degradation, and impact to wildlife.

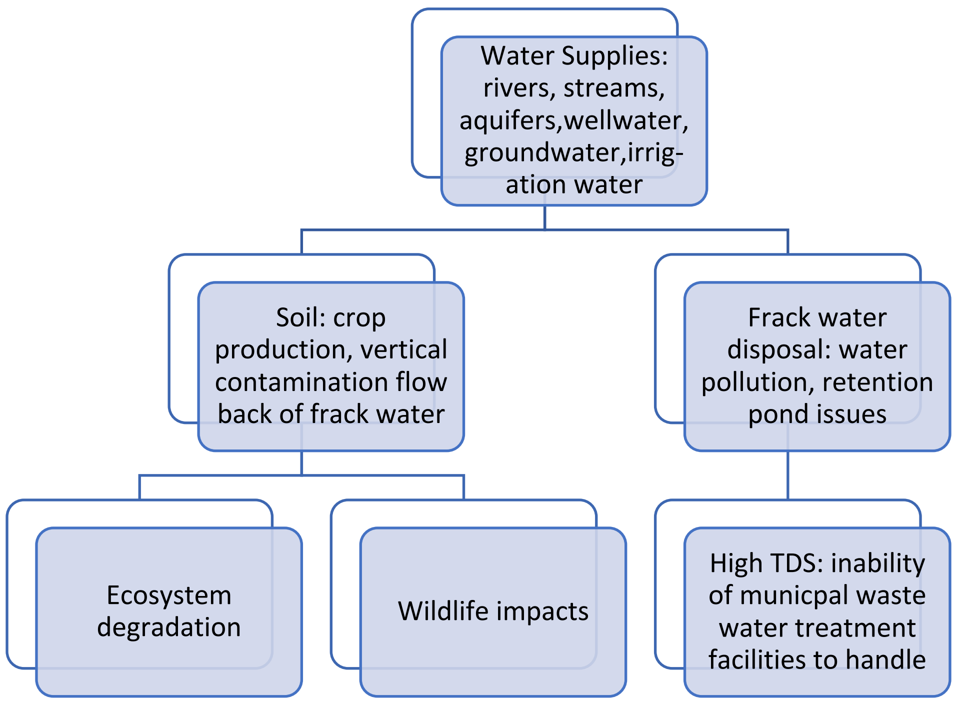



**Figure 37.** Natural Capital Priority Diagram (Bryant 2013)

Likewise, the inability to process the flowback (frackwater) represents potential water pollution problems. In similar fashion, water resource extraction for hydro-fracking (fracking) serves to deplete local water resources which are vital for human capital sustainability. In addition, the inability to process the frackwater at municipal disposal facilities implies that frack water stored in retention ponds is potentially problematic. This infers the potential for spillover due to flood issues, and retention pond liner tear, as well as the possibility for leaching into soil and groundwater.

Figure 38 below illuminates the prioritization of human capital whereby; community autonomy is perhaps central to human capital sustainability. Within this framing, political capital plays a key role in providing legislation to protect community autonomy.

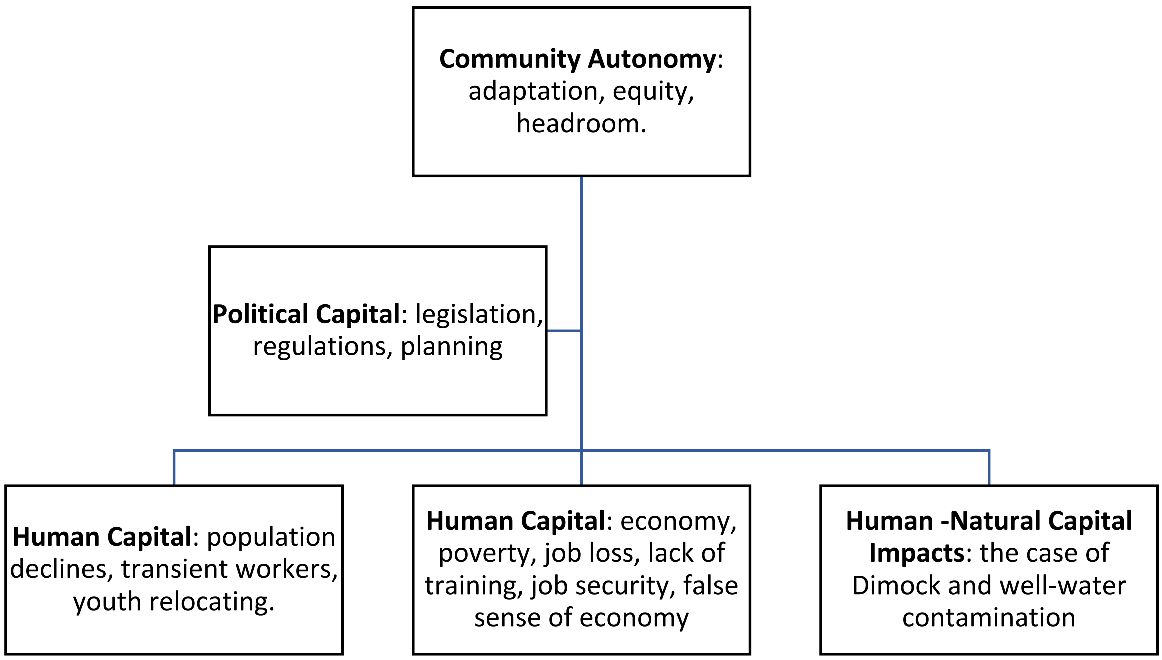



**Figure 38.** Human Capital Priority Diagram (Bomgardner 2012)

For example, the Federal Government's Energy Bill of 2005 and Pennsylvania State Act 13 served as political instruments to disrupt community autonomy. One of the many dubious provisions in the 2005 Energy Bill was the infamous Halliburton loophole, which was inserted at the dictate of then-Vice President Dick Cheney, a former chief executive of Halliburton. The loophole stripped the Environmental Protection Agency of its authority to regulate the hydro-fracking process (Nytimes.com. 2009).

The impacts to human capital illuminate population decline, poverty, loss of jobs, transient workers, a false sense of economy, and the impact of natural capital degradation upon human capital. The false sense of economy is illustrated by transient workers who took job opportunities away from the local community, resulting in eventual population decline and the community's youth moving away from the area. In general terms, the population of Lycoming County itself has been steadily declining (percent change, 2000 to 2015 is -3.2 %) since the inception of the Marcellus Shale (EPS 2017).

The problem has been exacerbated as a recent research study by the Keystone Research Center concluded: 91% of adults over the age of 20 are in need of an increase in the minimum wage (Keystone Research Center ND). The research study also stated, "when a significant number of jobs in Lycoming County don't pay enough for our neighbors to afford the basics-things like food, car repairs and eyeglasses-the local economy suffers. For many people in our community wages are so low that they are forced, even while working, to rely on the local food bank to help make ends meet. Policies that raise the wage and benefits floor can help restore spending on the basics and, in the process, boost the economy" (Keystone Research Center ND).

The conclusions of the Keystone Research Center provide an apt description of the poverty level of Lycoming County; conclusive of the aspect that the Marcellus Shale has failed miserably to mitigate low income in the region. The Economic Profile System reports that the average earnings per job in Lycoming County is $48,153 as compared to a U.S. benchmark of $58,985, coupled with a per capita income level of $41,706 for the county compared to the U.S. benchmark of $48,737; illustrative of the marginally low economic circumstances for the region (EPS 2017). Within this context is the realization that Lycoming County has been victimized with persistent poverty within a framework where the social well-being of a relatively large portion of the County is impoverished. This also brings into perspective the loss of effectiveness for the community-people to improve their well-being and population decline as the younger generation seeks to relocate to external areas of improved opportunity.

The interaction of natural capital and human capital, with relevance to governance as well as biotic and abiotic factors, is illustrated in Figure 39, on page 111. This figure serves to embrace the attributes of prioritizing the human and natural capital aspects: as outlined in Figures 37 and 38. In addition, Figure 39 illustrates key areas that require sustainability as well as the stakeholder-characters instrumental in plugging the gaps, thus creating community autonomy.

The left-hand side of Figure 39 encompasses the general population attributes, while the right-hand side delineates the governmental characters as well as the natural gas companies themselves. At the top of the diagram is the ultimate decision-making entity, the Governor's office of the state of Pennsylvania. The abiotic and biotic factors that comprise the issues of sustainability are shown in the center of the diagram. In addition, and not shown previously on any diagram is the presentation of the climatic variable to the sustainability issue.

Climate change is an important aspect of the Marcellus Shale frack water issue. For example, in fall 2011, Tropical Storm Lee inundated the northern Pennsylvania region, including Lycoming County, causing serious damage. While not only causing damage to areas within flood plains, the danger that exists from such events is retention pond overflow.

Figure 39, as a modified sustainability diagram, serves to outline and present the inherent environmental concern and human and natural capital aspects within the Marcellus Shale. In addition, the compelling aspect of activist group unification, the Water Action Team, has been represented as a plausible engaging force for propelling community autonomy and sustainability.

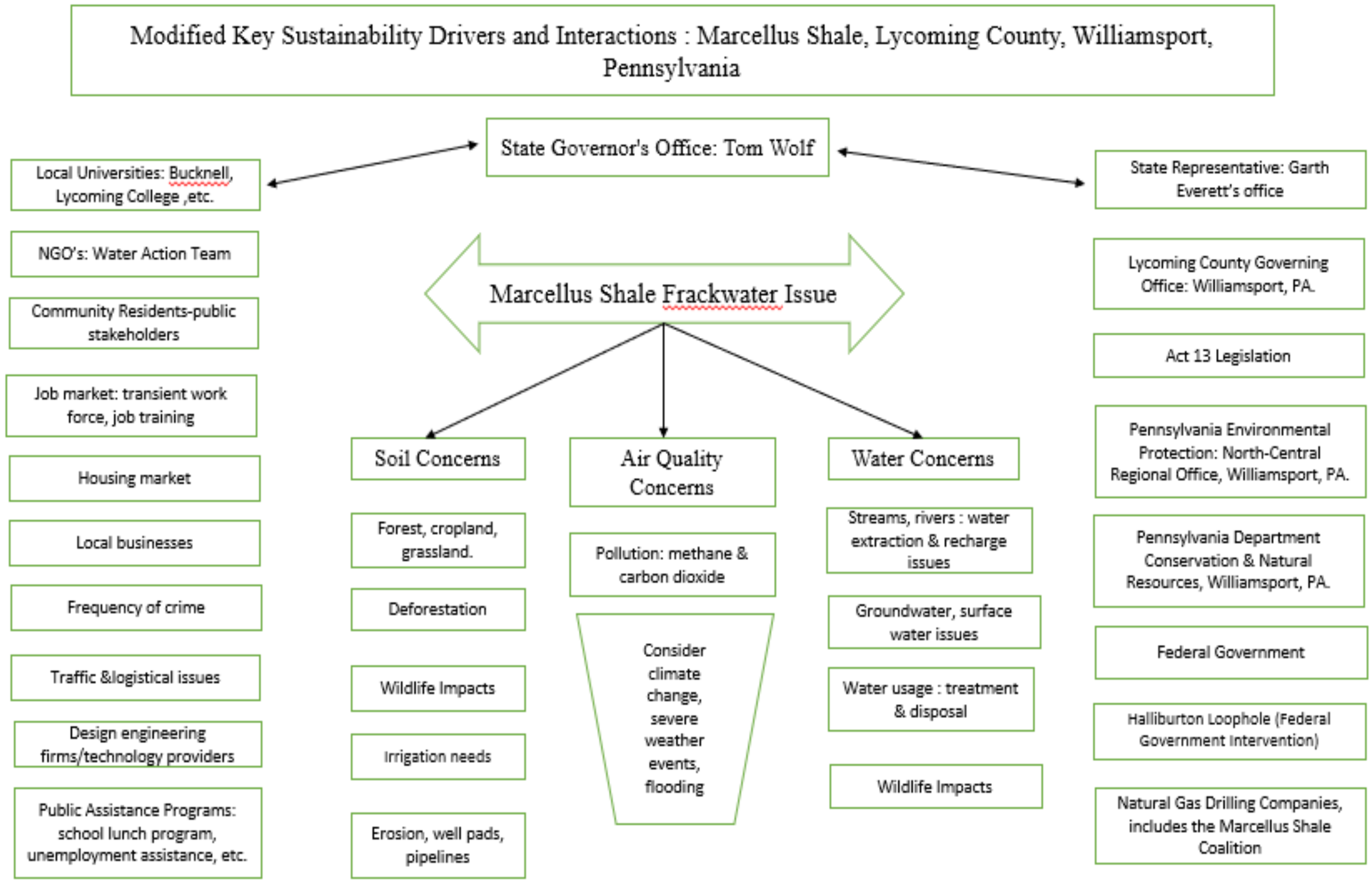



**Figure 39.** Modified Key Sustainability Drivers and Interactions

Figures 37, 38, and 39 provide a solid foundation for the formation of a situational mapping tool as shown in Figure 40, on page 113. Figure 40 illuminates the Water Action Team (WAT) concept and the various interactions between stakeholders within a situational mapping tool format. The effort to achieve success of the WAT exists in a mutually agreed upon outcome evaluation, dependent upon evaluation indicators. In this sense as well, the WAT is representative of a caucus for information exchange and social learning whose purpose is to engage all Marcellus Shale activist groups for a common and unified vision, goal, and outcome (Ferreyra & Beard, 2006).

The progress and success of the WAT will be dependent upon the participation of watershed residents, including businesses, farmers, rural residents, and local governance (Ferreyra & Beard, 2006). Invariably, a mechanism for quality control is necessary to ensure that WAT environmental initiatives and governmental legislation is monitored and ecology is in fact improving and meeting environmental standards.

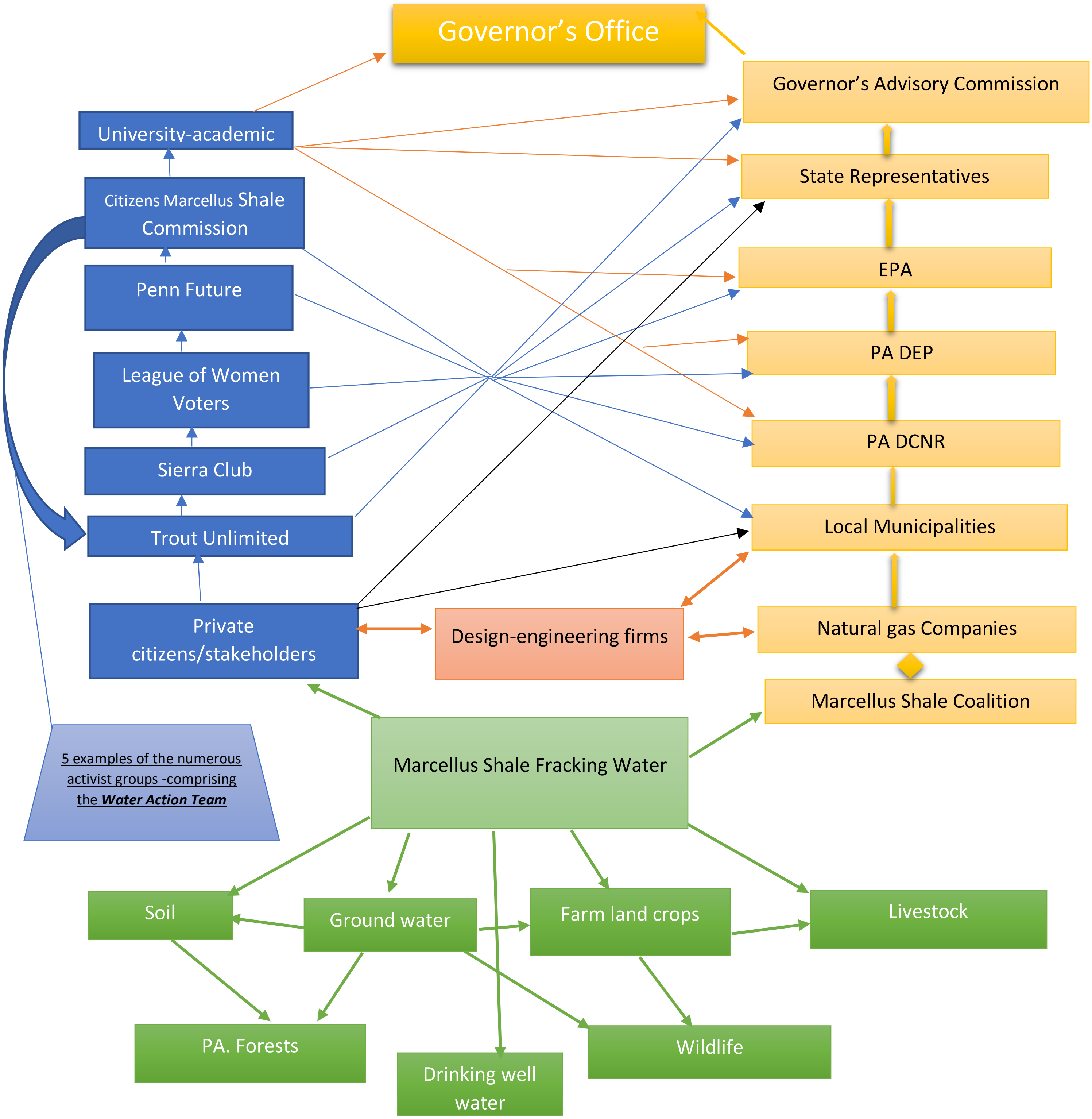



**Figure 40.** Situational Mapping Tool

Suggested indicators of inputs, outputs, actions, and outcomes relative to the WAT is illustrated on the flow chart, Figure 41, below. Specifically, Figure 41 illuminates a common vision which incorporates the diversity of the current independent acting activist groups as an essential input.

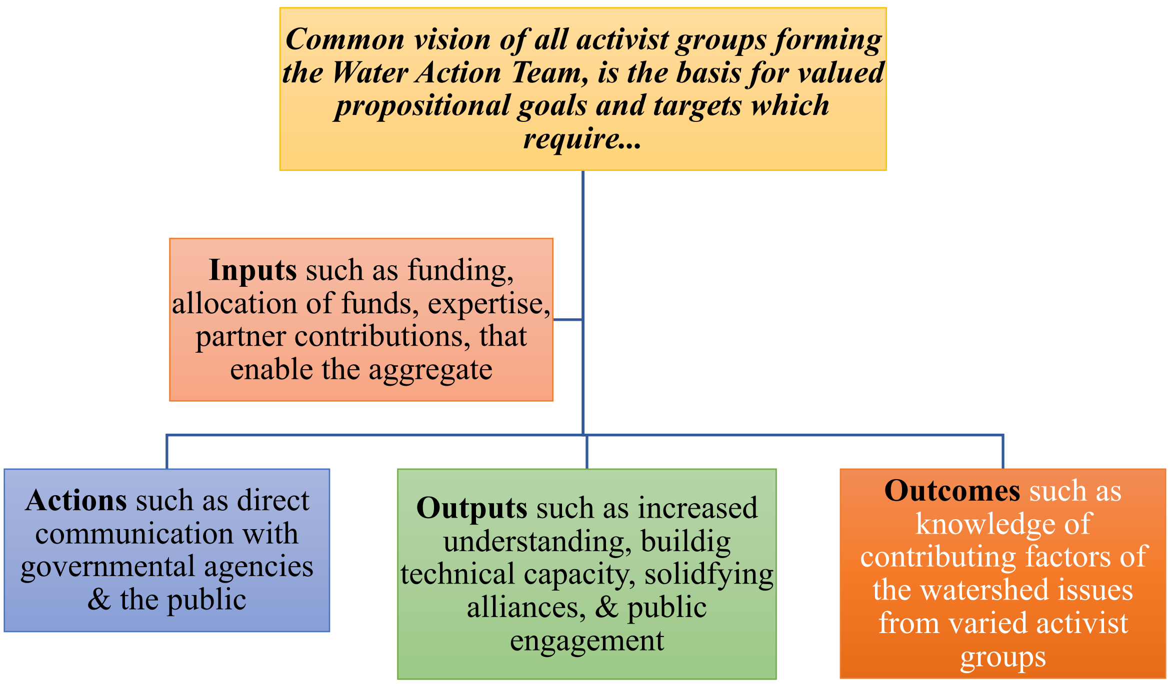



**Figure 41.** WAT Common Vision Flow Chart.

Considered as a starting point, this vision or mission statement will clearly identify the goals and objectives as well as outline the unified spirit of the WAT. The second input considers the valued propositional attributes of the WAT relative to the water issues at large within the Marcellus, thus answering the questions; (i) why do we need this approach? (ii) what are the values in the short and long term? and (iii) what does the WAT visionary statement mean to the community? Output indicators, as illustrated on the flow chart, identify the direct communication by WAT membership with governmental agencies and additional caveat of communication with the public.

## Chapter 11: Conclusions and the Future

Ronald Castille who served as Chief Justice of Pennsylvania's supreme court from 2008 to 2014 had decried the state's long history with coal and timber as lessons to be learned for a sustainable future, "Pennsylvania has a notable history of what appears, retrospectively, to have been a shortsighted exploitation of its bounteous environment, affecting its minerals, its water, its air, its flora and fauna and its people" (Stateimpact. ND; Ballotpedia, ND). Castille made these comments after Pennsylvania Act 13 was passed as legislation in 2012 (Stateimpact. ND). However, Act 13 has been appealed several times, and in September 2016, the State Supreme Court ultimately sided with activist groups that challenged the law (Stateimpact. ND).

While the battle in the state judiciary system continued over time, the plight of the residents of Lycoming County continue as well. In their struggle the community's low income, population, and social capital has declined perhaps proportionally. In the aftermath of the Marcellus Shale in Lycoming County, and after numerous environmental incidents (as Table 2 on page 77 illustrates), the natural gas industry is but a fleeting memory. Yet its mark has left an indelible footprint, once again, as an example of an extractive industry exploiting the community for obviously self-serving economic gain.

In essence, and prior to the drilling in the Lycoming County region of the Marcellus Shale for natural gas, a restructuring of environmental and economic policy was necessary. While Act 13 was perhaps an attempt to offer restructuring by giving the local level regulatory power over the drilling, Act 13 did not prevent drilling, as the community level governance was not allowed to ban the drilling-fracking effort. In addition, Act 13 was implemented not at the onset of the drilling effort but in due course of the effort. This decentralized legislation failed in many ways to improve the efficiency, equity, and management of not only the resource itself but the community at large.

In some respects, Lycoming County is reflective of a tenurial shell whereby the residents live in a bubble. The residents have been typically low income and have relied on the community as a form of decision-making and sustainability. In addition, and while having been a timber resource community in its past, Lycoming County perhaps welcomed the Marcellus Shale effort, believing that the community would thrive once again. Living in this shell of self-reliance it is easy to postulate that the community, being low income, was conditioned to the boom and bust philosophy of the extractive industry. This aspect might also be a contributing factor as to why the younger generation is moving away for more sustainable opportunities and the community population is in decline. Which in essence epitomizes the paradigm of the forest fig leaf concept, and management failure at multiple levels.

The WAT concept, as suggested here-in, to enable a cohesive framework for community autonomy and activism has merit. Needless to say, the frackwater issue is shrouded with potential human and natural capital impacts, being detrimental in a multiplicity of ways to the community. This aspect was illuminated and perhaps dramatized in the movie Gasland, which documented well water contamination in the village of Dimock, Pennsylvania. The documentary Frack Nation questioned the validity of the well-water contamination claim in Dimock (Frack Nation 2013). Interestingly, the federal government has returned for the first time in more than five years to investigate ongoing claims of well water contamination. The testing has resurrected an old debate about the groundwater in Dimock, whose plight was the focus of the Emmy Award-winning documentary Gasland (Rubinkan 2017).

While hydro-fracking will presumably resume in the near future in Lycoming County, viable technological solutions for frackwater processing are mandatory. This premise working in concert with human and socio-economic capital concerns. In addition, is the need for strong policy and regulations which are necessary to protect both community and environment. Succinctly stated, traditional wastewater treatment facilities are incapable of processing the high total dissolved solid content of frackwater. This aspect implies that frackwater processing technology must embrace not only the ability to process the frackwater for reuse in the natural gas drilling process but, also for ultimate discharge into streams and waterways.

Obviously, the treatment of frackwater for either reuse or discharge into waterways tends to minimize the need for retention ponds. This in turn reduces the risk of groundwater contamination as possibly a result of overflow or retention pond liner malfunction. Currently, a handful of advanced frackwater processing facilities exist in the greater Lycoming County area, of which either partial treatment is accomplished (the residual water then being reused for drilling) and then additional processing accomplished at a traditional wastewater treatment facility. The latter process capability then, enabling discharge into a local waterway (EurekaResources ND).

These frackwater processing facilities are small in size (and processing capability) in comparison to the more traditional (large scale) municipal waste treatment facilities. When considering the massive volume of water utilization for hydro-fracking (or fracking) a single natural gas well, reuse of frackwater is an absolute necessity. The issue being magnified in drought conditions and the continual water extraction from local stream-waterway sources. Thus, perhaps larger scale frackwater treatment facilities are required as a future regulatory, industry, and community well-being consideration.

The manifestation of such large-scale facilities would require significant electrical power, large scale evaporation and crystallization processes inclusive of land-use, logistical consideration, and funding. The latter aspect, funding, brings into question who pays for this large-scale endeavor such as the general public, federal or state government, or the natural gas drilling companies. In addition, a large scale frackwater processing facility would produce a significant volume of crystalized material which raises the question as to potential markets for this type of material.

## 11.1. The relevance of the forester's fig leaf paradigm to natural gas extraction

The frackwater issue (and its processing and regulatory framework) is plausibly at the loci of the issues which comprise the sustainability of natural-human-social-economic capital of the Marcellus Shale for Lycoming County, Pennsylvania. For today, the Pennsylvania Marcellus Shale frackwater issue certainly typifies the forester's fig leaf paradigm. That paradigm being the seemingly boom to bust cycles which are typical of oil and natural gas extraction and development (Haefele ND). Unquestionably, a significant level of uncertainty exists and "is exacerbated by an equally high level of concern about the consequences associated with mistakes" (Clark et al. 1999).

In a world of climate change, we are conceivably running out of options to mitigate the harm we cause to the ecosystem and ourselves. Sustainability within the Lycoming County Marcellus Shale region of Pennsylvania embraces the notion of meeting the socio-ecological needs of the present, without compromising the future. In addition, the extraction of natural gas must encompass environmental regulations that are administered in a non-discriminatory manner of governance, as unequal regulation conceivably results from the lack of scientific understanding and undemocratic decision making. Also, proper training and educational programs are vital to the well-being of the Lycoming County region for community autonomy with respect to natural resource extraction. These types of programs plausibly mitigating population decline relative to the youth departing the area.

Natural resource extraction and specifically natural gas extraction within Lycoming County has been a moving target since the onset. However, and while natural gas is integral to our nation's energy portfolio inclusive of its many uses, we cannot afford to sacrifice environmental injustice and environmental degradation due to the extraction effort. If we fail to solve the problems that we create in the natural gas extraction process we are perhaps doomed to repeat the boom to bust cycle of the fracker's figleaf paradigm again. And likewise, leave an edible footprint for future generations.

*The ultimate test of man's conscience may be his willingness to sacrifice something today for future generations whose words of thanks will not be heard.*

***– Gaylord Nelson, American politician and environmentalist***

## References


Abdalla C.W., J.R. Drohan, K.S. Blunk, and J. Edson. 2016. Marcellus Shale Wastewater Issues in Pennsylvania. Penn State Extension. From https://extension.psu.edu/water
Accessed 9/5/2017

Adger, W.N. 2003. "Social capital, collective action, and adaptation to climate change". *Economic Geography*. 79(4):387-404.

Akron Beacon Journal. 2012. Ohio has a new No. 1 Utica well in Belmont County. From https://www.ohio.com/akron/archive/ohio-has-a-new-no-1-utica-well-in-belmont-county
Accessed 12/19/2017

Arthur, D., B. Bohm, and M. Layne. 2008. Hydraulic Fracturing Considerations for Natural Gas Wells of the Marcellus Shale. All Consulting.

Associated Press. 2015. *Public land natural gas drilling leases once again banned in Pa.* WITF. From http://www.witf.org/news/2015/01/public-land-natural-gas-drilling-leases-once-again-banned-in-pa.php
Accessed 12/19/2017

Baker, J. 2015. Economic impact of oil and gas boom a positive for eastern Ohio. From http://www.timesreporter.com/article/20150424/NEWS/150429461

Accessed 12/28/2017

Ballotpedia. ND. Ronald Castille. From https://ballotpedia.org/Ronald_Castille
Accessed 12/16/2017

Barlow, K.E. 2014. *Marcellus Shale: Will the economic boom last.* University of Pittsburgh. Available from http://www.utimes.pitt.edu/?p=14234.
Accessed on 6/29/2017.

Barrett, K. 2010. Ignorance or Apathy? The Disconnect Between the Marcellus Shale Industry and Lycoming County Youth. Lycoming College: Sociology-Anthropology Department.

Bennear, L. 2011. Fracking Externalities and the Coase Theorem. From http://sites.nicholas.duke.edu/loribennear/2011/09/05/fracking-externalities-and-the-coase-theorem/
Accessed 11/19/2017

Bennett, S. 2014. Oil and Gas Development Fuels Local Business Boom in Eastern Ohio. From https://energyindepth.org/ohio/oil-gas-development-fuels-local-business-boom-eastern-ohio/

Accessed 12/29/2017

BMU2.ND. Residues: Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). From file:///C:/Users/chest/Downloads/BMU2_NPS_report3.pdf
Accessed 12/14/2017

Bomgardner, M.M. 2012. Treating Water from Hydraulic Fracturing. From https://cen.acs.org/articles/90/i42/Treating-Water-Hydraulic-Fracturing.html?h=-1297580797
Accessed 12/30/2017

Brantley, S.L., D. Yoxtheimer, S. Arjmand, P. Grieve, R. Vidic, J. Pollak, G.T. Llewellyn, J. Abad, and C. Simon. 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. *International Journal of Coal Geology*. 126:140-156

Brasier, K., and M, Filteau. 2010. Community Impacts of Marcellus Shale Development: Preliminary Research Findings. http://extension.psu.edu/natural-resources/natural-gas/news/2010/06/commimpactsresearchsum
Accessed 6/23/2017

Brockett, D. 2015. Natural Gas Liquids (NGL's). Power Point. Penn State Extension. From https://energizeohio.osu.edu/sites/energizeohio/files/imce/NGL%20Webinar3.19.15Final.pdf
Accessed 12/19/2017

Brown, K. 2013. Shale "Exempt" From Federal Laws? Um, Not Even Close. From https://energyindepth.org/national/shale-exempt-from-federal-laws-um-not-even-close/
Accessed 9/4/2017

Bryant, M. 2013. Aerial view of a Marcellus Shale well site near Waynesburg, Pa. AWRA. From https://acwi.gov/swrr/p&p_library/Nov20_2013/collin_20nov2013_swrr.pdf
Accessed 12/30/2017

Bugden, D., D. Evensen, and R. Stedman. 2017. A drill by any other name: Social representations, framing, and legacies of natural resource extraction in the fracking industry. *Energy Research & Social Science*. 29: 62-71.

Castelli, M. 2015. Fracking and the Rural Poor: Negative Externalities, Failing Remedies, and Federal Legislation. Indiana Journal of Law and Social Equality. Vol. 3. Iss. 2. Article 6.

Census.gov. 2017. *Quick Facts. Population of Lycoming County, Pennsylvania.* Available from http://www.census.gov/quickfacts/table/PST045215/42081

Accessed 6/8/2017

Cfact. ND. Chesapeake Energy Graphic. From http://www.cfact.org/tag/hydraulic-fracturing/
Accessed 9/3/2017

Chameides, B. 2013. *Fracking Water: It's Just So Hard to Clean*. Huffington Post. Available from http://www.huffingtonpost.com/bill-chameides/fracking-water-its-just-s_b_4045936.html Accessed 7/27/2017.

Chesapeake Energy. ND. Chesapeake Energy Marcellus Shale Development. From file:///C:/Users/chest/Downloads/Sheppard.pdf
Accessed 12/4/2017

Citizens Marcellus Shale Commission. 2011. "Marcellus Shale: A Citizens View". http://www.pennbpc.org/sites/pennbpc.org/files/CMSC-Final-Report.pdf

Accessed 8/18/2017

Clark, R.N., G. H. Stankey, P. J. Brown, J. A. Burchfield, R. W. Haynes and S. F. McCool. 1999. *Toward and Ecological Approach: Integrating Social, Economic, Cultural, Biological, and Physical Considerations.* 297-318.

Cusick, M. 2017. Northeast need more gas pipelines, says new report. From https://stateimpact.npr.org/pennsylvania/2017/04/25/northeast-needs-more-gas-pipelines-says-new-report/

Accessed 12/6/2017

Cusick, M. 2017. Pennsylvania lacks resources to enforce safe water standards, says EPA. From https://stateimpact.npr.org/pennsylvania/2017/02/01/pennsylvania-lacks-resources-to-enforce-safe-water-standards-says-epa/
Accessed 1/24/2018

DEP. 2007. *Factsheet: Landowners and Oil and Gas Leases in Pennsylvania.* Commonwealth of Pennsylvania - Department of Environmental Protection.

DEP. 2013.*" Marcellus Shale: Tough regulations, Greater Enforcement"*. 0130-FS-DEP4288. Fact Sheet.

Detrow, S. 2012. SRBC Suspends Water Withdrawal In 5 Counties. From https://stateimpact.npr.org/pennsylvania/2012/04/18/srbc-suspends-water-withdrawal-in-5-counties/
Accessed 9/4/2017

Dey, D.C., Schweitzer, C.J., Kabrick, J.M. 2016. Silviculture to Restore Oak Woodlands. Proceedings of the 18th biennial southern sylvicultural research conference. Rep. SRS-212. P 160-169.

Dillon, M. 2011. *Water Scarcity and Hydraulic Fracturing in Pennsylvania; Examining Pennsylvania Water law and Water Shortage Issues Presented by Natural Gas Operations in the Marcellus Shale.* Temple University. 84: 201-210.

Ecologix. 2017. Mobile Frack Water Unit. Integrated Treatment System for Frac water Management. ITS-1500. Ecologix Environmental Systems. From http://www.ecologixsystems.com/system-its.php

Accessed 12/24/2017

EIA. 2017. Marcellus Shale Play: Geology Review. U.S. Energy Information Administration. From https://www.eia.gov/maps/pdf/MarcellusPlayUpdate_Jan2017.pdf

Accessed 9/3/2017

EIA 2012. Today in Energy. From https://www.eia.gov/todayinenergy/detail.php?id=4790

Accessed 3/14/2018

Ellison, D., C.E. Morris, B., Locatelli, D. Shell, J. Cohen, D. Murdiyarso, V. Gutierrez, M. van Noordwijk, I.F. Creed, J. Pokorny, D. Garveau, D.V. Spracklen, A.B. Tobella, U. Iistedt, A.J. Teuling, S.G. Geebrehiwot, D.C. Sands, B Muys, B Verbist, E. Spriggay, Y. Sugandi, C.A. Sullivan. 2017. Trees, forests and water: Cool insights for a hot world. *Global Environmental Change.* 43:51-60

Elk County. 2016. Watersheds in Pennsylvania. From http://www.co.elk.pa.us/index.php/watersheds

Accessed 12/21/2017

Els, P. and J. R. Cuba. 2013. “Frack Water Treatment Challenge”. *Pollution Engineering.*

Engelder, T. 2017. Natural gas reservoir may hike U.S. output. From http://www3.geosc.psu.edu/%7Ejte2/

Accessed 12/8/2017

EPA 2016. Fracturing Water Cycle. From https://www.epa.gov/hfstudy/hydraulic-fracturing-water-cycle

Accessed 3/11/2018

EPS. 2017 *A Profile of Socioeconomic Measures: Lycoming County, Pennsylvania.* Economic Profile System. Available from https://headwaterseconomics.org/tools/economic-profile-system/about
Accessed on 6/10/2017

EurekaResources ND. Managing Wastewater in the Marcellus and Utica Shales. From https://www.bing.com/search?q=eureka+resources&form=EDGHPT&qs=AS&cvid=3133b313bf1b4d3fbe47b552521e9114&cc=US&setlang=en-US
Accessed 8/18/2017

EurekaResources. 2017. Wastewater pretreatment. From http://eureka-resources.com/facilities/process-technology/
Accessed 12/11/2017

Favede, G. 2014. Oil and Gas Boom Changing Belmont County. From http://oogeep.org/2014/02/oil-and-gas-boom-changing-belmont-county/
Accessed 12/28/2017

Ferreyra, C. and P. Beard. 2006." *Participatory Evaluation of Collaborative and Integrated Water Management: Insights from the Field"*.
http://www.tandfonline.com/doi/abs/10.1080/09640560601156532
Accessed 9/2/2017

Fershee, J.P. and S. A. Shay. 2015. Horizontal Drilling, Vertical Problems: Property Law Challenges from the Marcellus Shale Boom. The Marshall Law Review. 49 J. Marshall L. Rev. 413.

Fleeger, G.M. 1999. The Geology of Pennsylvania's Groundwater. Pennsylvania Geological Survey. Fourth Series. From
http://www.docs.dcnr.pa.gov/cs/groups/public/documents/document/dcnr_014598.pdf
Accessed 2/5/2018

Food & Water Watch. 2013. *The Social Costs of Fracking: A Pennsylvania Case Study*. Food & Water Watch. Available from http://www.foodandwaterwatch.or
Accessed on 6/7/2017

Fortmann, L.P., J Kusel, and S.K. Fairfax. 1989. *Community Stability: The Forester's Fig Leaf.* P: 44-50. Portland, OR. Timber Press.

Fortuna Energy, ND. *Chemical Descriptions for Marcellus Shale Wells-Fortuna Energy.* Available from. http://tompkinscountyny.gov/files2/emc/gasdrilling/Fortuna_000.pdf
Accessed 7/23/2017.

Foster, J. ND. Lecture 26. University of Texas. From
http://johnfoster.pge.utexas.edu/PGE334ResGeomechanics/slides/Lecture26.slides.html#/

Accessed 12/6/2017

Fracfocus. 2010. Hydraulic Fracturing: The Process. From:
http://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process
Accessed 12/3/2017

Fracfocus. ND. What Chemicals are Used. From http://fracfocus.org/chemicals-use/what-chemicals-are-used
Accessed 12/3/2017

Frack Nation, 2013. Frack Nation. From
https://www.amazon.com/dp/B00L8O89HS/ref=nav_custrec_signin?
Accessed 9/5/2017

Fracktracker 2017. Known Ethane Cracker Risks. From
https://www.fracktracker.org/2017/02/formula-disaster-ethane-cracker/
Accessed 3/16/2018

Fruedenberg, W.R.and R. Gramling. 1993. Natural Resources and Rural Property: A Closer Look. *Society of Natural Resources*. Vol. 7 P 5-22.

Gillooly, A. 2014. DEP Fines Range Resources $4.15 Million for Violating Environmental Regulations Consent Order: Agreement to Close 5 Washington County Impoundments. From https://marcellusmonitor.worldpress.com/tag/frack-ponds/

Accessed 3/14/2018

Grant, C.J., A.K. Lutz, A.D. Kulig, M.R. Stanton. 2016. Fracked ecology: Response of aquatic trophic structure and mercury biomagnification dynamics in the Marcellus Shale Formation. *Ecotoxicology.* 25:1739-1750

Grant, C.J., A.B. Weimer, N.K. Marks, E.S. Perow, J.M. Oster, K.M. Brubaker, R.V. Trexler, C.M. Solomon, R. Lamendella. 2015. Marcellus and Mercury: Assessing potential impacts of unconventional natural gas extraction on aquatic ecosystems in northwestern Pennsylvania. *Journal of Environmental Science and Health, Part A*. 50: 5,482-500.

Gruber, E. 2017. Recycling: Produced & Flowback Wastewater for Fracking. ECOLOGIX. From http://www.ecologixsystems.com/

Accessed 12/11/2017

Green, R.T. and F.P. Bertetti. 2014. Assessment of Depp-Well Injection of Liquid Wastes from Hydraulic Fracturing. Southwest Research Institute. From
file:///C:/Users/chest/Downloads/Assessment%20of%20Deep-Well%20Injection.pdf

Accessed 12/12/2017

Haefele, M. ND. Threats to Landscape and Lifestyle: The Not- So-
Hidden Costs to Communities of Oil and Gas Development. The Wilderness Society. From file:///C:/Users/chest/Desktop/Cost%20to%20Communities%20from%20Oil%20and%20Gas%20Development%20.pdf

Accessed 9/5/2017

Hammond, J. 2016. After the Boom: How the Marcellus Changed Life in Pennsylvania. The Daily Caller. From http://dailycaller.com/2016/07/11/after-the-boom-how-the-marcellus-shale-changed-life-in-pennsylvania/
Accessed 12/29/2017

Hanson, L, S. Habicht, and P. Faeth. 2016. Potential Environmental Impacts of Full-development of the Marcellus Shale in Pennsylvania. CAN Analysis & Solutions. Document Number: IRM-2016-U-013695

Hargreaves, S. 2011. Ohio set to see oil boom thanks to fracking. CNNMoney. From http://money.cnn.com/2011/12/20/news/economy/ohio_oil/index.htm

Accessed 12/29/2017

Hatzenbuhler, H. and T.J. Centner. 2012. Regulation of Water Pollution from hydraulic Fracturing in Horizontally-Drilled Wells in the Marcellus Shale Region, USA. *Water.* 4: 983-994

Homefacts.com. 2017. Unemployment for Belmont, County, Ohio. From https://www.homefacts.com/unemployment/Ohio/Belmont-County.html
Accessed 11/21/2017

Hopey, D. 2009. Toxins tied to fish kill may have hitchhike. Pittsburgh Post-Gazette. From http://www.post-gazette.com/news/environment/2009/10/04/Toxins-tied-to-fish-kill-may-have-hitchhiked/stories/200910040247

Accessed 3/18/2018

Howe, M. 2014. "Tight Gas, Tight Sands and Fracking Light". *Halifax Media Co-op.* Available from http://halifax.mediacoop.ca/story/tight-gas-tight-sands-and-fracking-light/31111
Accessed 6/9/2017

Jacobs, J.N. 2016. Tax Day: Marcellus Shale Impact Fee Benefits Local Communities. From https://energyindepth.org/marcellus/tax-day-marcellus-shale-impact-fee-benefits-local-communities/
Accessed 12/8/2017

Jacobson, M. and K. Kovach. 2007. How Important is Forestry in Lycoming County? http://extension.psu.edu/natural-resources/forests/finance/county-forest-economic-data/lycoming-county
Accessed on 7/ 2/ 2017.

Jaffe, A.M. and M.L. O'Sullivan. 2012. The Geopolitics of Natural Gas: Report of Scenarios Workshop of Harvard University's Belfer Center and Rice University's Baker Institute Energy Forum. Report, Belfer Center for Science and International Affairs. Harvard Kennedy School. From file:///C:/Users/chest/Downloads/Harvard_Rice_Study.pdf
Accessed 12/17/2017

Johnson, B.L., W. B. Richardson., T.J. Naimo. 1995. Past, Present, and Future Concepts in Large River Ecology. *Bioscience*. 3; 134-141

JUSC 2008. The Economic Impact of Marcellus Shale in Northeastern Pennsylvania. Joint Urban Studies Center. From http://www.institutepa.org/PDF/Marcellus/mtwhitepaper.pdf
Accessed 3/12/2018

Kelsey, T. W.  ND. Regional & Local Community Economic Impacts of Natural Gas Development. Penn State Cooperative Extension.

Keystone Research Center. ND Giving Lycoming County's Economy a Boost: The Impact of Raising the Pennsylvania Minimum Wage to $10.10 per Hour.
http://keystoneresearch.org/sites/default/files/KRC_Lycoming_1010.pdf
Accessed on 3/14/2018

King. H. 2017. Marcellus Shale-Appalachian Basin Natural Gas Play. From http://geology.com/articles/marcellus-shale-shtml
Accessed 12/9/2017

Legere, L. 2015. New Rules to Restrict Shale Wastewater Ponds Could Put Tank Manufacturers in Demand. From http://powersource.post-gazette.com/powersource/policy-powersorce/2015/03/17/New-rules-to-restrict-wastewater-ponds-could-put-tank-manufacturers-in-demand/stories/201503170012
Accessed 3/14/2018

Lewis, W. 2016.  Critiquing Pa. Gov. Tom Corbett's time in office. From http://www.wfmz.com/news/pennsylvania/critiquing-pa-gov-tom-corbetts-time-in-office-1/20594096
Accessed 12/15/2017

Llewellyn, G.T., F. Dorman, J.L. Westland, P. Grieve, T. Sowers, E. Humston-Fulmer, and S.L. Brantley. 2015. Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *PNAS.* 20: 6325-6330.

Loewenstein, J. 2015. Susquehanna River Basin Commission's study finds no impacts on streams from Marcellus Shale drilling. From http://marcellus.com/news/id/127589/susquehanna-river-basin-commissions-study-finds-no-impacts-on-streams-from-marcellus-shale-drilling/
Accessed 12/22/2017

Lutgens, F.K. and E.J. Tarbuck.2013. The Atmosphere: An Introduction to Meteorology. 12th edition. Pearson. New York

Lustgarten, A. 2012. Injection Wells: The Poison Beneath Us. From
https://www.propublica.org/article/injection-wells-the-poison-beneath-us
Accessed 12/12/2017

Mason, C.F., L.A. Mushlenbachs, and S.M. Olmstead. 2015. The Economics of Shale Gas Development. Resources for the Future. RFF DP 14-42-REV.

Massaro, J. 2012. The Mysterious Case of The Flowback Fluid. From
https://energyindepth.org/marcellus/the-mysterious-case-of-the-flowback-fluid/

Accessed 9/3/2017

McCool, S.F., and G. Stankey. 2001. "Representing the future (Links to an external site.)Links to an external site.: a framework for evaluating the utility of indicators in the search for sustainable forest management." In *Criteria and indicators for sustainable forest management*, edited by R.J. Raison, A.G. Brown, and D.W. Flinn, 93-105. Wallingford, UK; New York: CABI Publishing, in association with the International Union of Forestry Research Organizations [IUFRO]. 462 p.

McWilliams. W.H. 2010. Forest Trends in the Mid-Atlantic States: Prospective Impacts due to Climate Change. Research Forest, USDA Forest Service. Northern Research Station.

MDN. 2012. The Next Battleground for Shale Drilling: Compressor Plants. Marcellus Drilling News. From https://marcellusdrilling.com/2012/06/the-next-battleground-for-shale-drilling-compressor-plants/

Accessed 12/8/2017

MDN 2015. Bentek: August NatGas Production Nearly as High as July Record. Marcellus Drilling News. From https://marcellusdrilling.com/2015/09/bentek-august-natgas-production-nearly-as-high-as-july-record/
Accessed 3/20/2018

Meng, O. 2015. Spatial analysis of environmental and population at risk of natural gas fracking in the state of Pennsylvania, USA. *Science of Total Environment.* 515-516:198-206

Moss, R. and S. Schneider. 1996. Session Synthesis Essay: Characterizing and Communicating Scientific Uncertainty: Building on the IPCC Second Assessment. AGCI Session II: Characterizing and Communicating Scientific Uncertainty.

Muehlenbachs, L., E. Spiller and C. Timmins. 2015. *The Housing Market Impacts of Shale Gas Development*. Resources for the Future. Washington DC. RFF DP 13-39-REV2.

Mulhollen, J. 2017. Shale gas threat to forests can be eased by consolidating infrastructure. Penn State University. From http://news.psu.edu/story/463088/2017/04/19/research/shale-gas-threat-forests-can-be-eased-consolidating-infrastructure

Accessed 12/12/2017

Mullady, R.G., S.J. Doyle, C.A. Fitzpatrick and A.M. Guarino. 2011. Marcellus Shale Groundwater Contamination Claims: A Case Against Class Action Treatment and Assorted Theories of Liability. Blank Rome LLP.From http://www.ettdefenseinsight.com/wp-content/uploads/2014/06/blank.pdf
Accessed 12/14/2017

Murtazashvili, I. 2016. "Origins and Consequences of State-Level Variation in Shale Regulation: The Cases of Pennsylvania and New York" in William E. Hefley and Yongsheng Wang, eds., Economics of Unconventional Shale Gas Development: Case Studies and Impacts, 2016.

Myers, T. 2012. Potential Contaminate Pathways from Hydraulic Fractured Shale to Aquifers. NGWA.org. Ground Water.

Naeoff, J. 2017. Seriously, Pennsylvania Pass a Severance Tax Already. From http://www.philly.com/philly/business/seriously-pennsylvania-pass-a-severance-tax-already-20170818.html
Accessed on 9/1/2017

NAOGP 2016. 2016 U.S. Natural Gas Pipeline Report: Marcellus, Utica Drive Market. From http://napipelines.com/2016-u-s-gas-pipeline-report/
Accessed 3/16/2018

NASDAQ. 2017. Chesapeake Energy Corporation Common Stock Historical Stock Prices
From http://www.nasdaq.com/symbol/chk/historical
Accessed 11/17/2017

Natgas. 2013. Uses in Industry. From http://naturalgas.org/overview/uses-industrail/
Accessed 12/1/2017

Nichols, D. 2015. Marcellus Shale Drilling, Fracking, & Pipelines can Impact Rivers, Streams, Wetlands. From http://www.frackcheckwy.net/2015/11/17/marcellus-shale-drilling-fracking:pipelines-can-impact-rivers-streams-wetlands/
Accessed 12/29/2017

Nolon, J.R. and S.E. Gavin. 2013. Hydrofracking: State Preemption, Local Power, and Cooperative Governance. Case Western Reserve Law Review. Volume 63. Issue 4.

Nytimes.com. 2009. The Halliburton Loophole. From
http://www.nytimes.com/2009/11/03/opinion/03tue3.html
Accessed 9/5/2017

Olmstead, S.M., L.A. Muehlenbachs, J-S Shih, Z Chu, and A.J. Krupnick. 2013. Shale gas development impacts on surface water quality in Pennsylvania. *PNAS* 13: 4962-4967

PA Budget and Policy Center. 2013. Pa's Marcellus Impact Fee Comes Up Short. From
https://www.pennbpc.org/pa-marcellus-impact-fee-comes-short
Accessed 12/8/2017

PA BULLETIN. 2011. Notices" Public Hearing and Meeting. [41 Pa.B. 4070] From
http://www.pabulletin.com/secure/data/vol41/41-30/1262.html
Accessed 9/4/2017

Pacchioli, D. 2013. Grad researcher studies impacts of Marcellus Shale development on wildlife. From http://news.psu.edu/story/282350/2013/07/22/research/grad-researcher-studies-impacts-marcellus-shale-development

Accessed 12/12/2017

Page, S. 2015. A $600-Million Fracking Company Just Sued This Tiny Ohio Town for Its Water. From
https://thinkprogress.org/a-600-million-fracking-company-just-sued-this-tiny-ohio-town-for-its-water-3a776651f59f/
Accessed 11/20/2017

PA Vistornetwork. ND. Lycoming County. http://pavisitorsnetwork.com/lycoming/
Accessed on 7/ 1/2017.

Patil, K.B.2014. Chemicals Used in Fracking and Their Purpose. From
https://www.buzzle.com/articles/chemicals-used-in-fracking-and-their-purpose.html
Accessed 3/15/2018

Paynter, K. 2015. Your Guide to Pipelines. From
https://stateimpact.npr.org/pennnsylvania/tag/pipelines/
Accessed 12/6/2017

Peluso, N.L. 1992. Structures of access control, repertories of resistance. Ch. 1 in *Rich Forests, Poor People: Resource Control and Resistance in Java.* Berkeley, CA: University of California Press.

Pennell, R. 2009. Marcellus shale drilling is biggest threat to Pennsylvania wilds. From
http://www.pennlive.com/editorials/index.ssf/2009/11/marcellus_shale_drilling_is_bi.html
Accessed 12/26/2017

Penn State. 2011. “Marcellus Shale Wastewater Issues in Pennsylvania-Current and Emerging Treatment and Disposal Technologies”. Penn State Extension: College of Agricultural Sciences.1-9.

Penn State. 2014. Explore Shale. From http://exploreshale.org/#
Accessed 9/5/2017

Perez, J. 2018 Vertical and Horizontal Drilling. From https://www.geoart.com/schematic-industries/horizontal-drilling/
Accessed 3/12/2018

Perry, D.A., Oren, R., Hart, S.C. 2008. Forest Ecosystems. 2nd edition. The Johns Hopkins University Press. Baltimore.

Phelan, A and S. Jacobs. 2016. Facing the true cost of fracking: social externalities and the role of integrated valuation. *Ecosystem Services.* 22: 348-358.

Phillips, A. 2014. The US Shale Boom: Geopolitical Ramifications of a Changing Energy Market. Harvard International Review. Global Notebook. From http://hir.harvard.edu/article/?a=5757
Accessed 12/16/2017

Phillips, S. 2011. Burning Question: What would life be like without the Halliburton Loophole? https://stateimpact.npr.org/pennsylvania/2011/12/05/burning-question-what-would-life-be-like-without-the-halliburton-loophole/
Accessed on 8/3/2017

Phillips, S. 2011.*Citizen's Marcellus Shale Commission wants to slow down Drilling.* From https://stateimpact.npr.org/pennsylvania/2011/10/24/citizens-marcellus-shale-commission-wants-to-slow-down-drilling/

Accessed 7/1/2017

Phillips, S. 2012. Pampers Plant a Model of Sustainability. From https://stateimpact.npr.org/pennsylvania/2012/10/25/pampers-plant-a-model-of-sustainability/
Accessed 10/31/2017

Phillips, S. 2015. Pipelines: The new battleground over fracking. From https://stateimpact.npr.org/pennsylvania/2015/04/02/pipelines-the-new-battleground-over-fracking/

Accessed 12/6/2017

Places.findthehome.com. 2017. *Lycoming County-PA*. Available from http://places.findthehome.com/l/78990/Lycoming-County-PA Accessed on 6/10//2017

Population.us. 2017. *Population of Williamsport*. Available from http://population.us/pa/williamsport/
Accessed on 6/11/2017

Pottsmerccommunityresources. 2012. Pipeline plans for Warwick Township. From http://pottsmerccommunityresources.blogspot.com/2012/12/pipeline-plans-for
Accessed 12/29/2017

Pressconnects.com 2015. Promise of Fracking Lessons Pennsylvania. http://.pressconnects.com/story/news/local/fracking/2015/11/23/promise-fracking-lessons-pennsylvania/76052604
Accessed on 6/25/2017

PRI 2011. Jointing and Fracturing in the Marcellus Shale. Paleontological Research Institution. Issue Number 5,

PSU. 1986. Soil Survey Lycoming County. Penn State University.

PSU. 2015. Understanding Natural Gas Compressor Stations. Marcellus Shale Education Fact Sheet. From file:///C:/Users/chest/Downloads/understanding-natural-gas-compressor-stations.pdf
Accessed 12/8/2017

Queens University 2014. Thrust Fault Picture. From http://minewiki.engineering.queensu.ca/mediawiki/index.php/The_geological_model
Accessed 3/14/2018

Rabe, B.G. and R.L. Hampton. 2015. Taxing Fracking: The Politics of State Severance Taxes in the Shale Era. *Review of Policy Research.* 4: 389-412.

Rahm, B.G. and S.J. Riha. 2012. Toward strategic management of shale gas development: Regional, collective impacts on water resources. *Environmental Science & Policy.* 17: 12-23.

Reforestation.me ND. Picture of Succession. From https://reforestation.me/improved-fallows-succession/
Accessed 3/14/2018

Riley, A. 2012. The Shale Revolution's Shifting Geopolitics. From http://www.nytimes.com/2012/12/26/opinion/global/the-shale-revolutions-shifting-geopolitics.html
Accessed 12/16/2017

Rittel, H.W.J and M.M. Webber. 1973. Dilemmas in a General Theory of Planning. *Policy Science.* 4:155-169.

Rozell, D.J. and S.J. Reaven. 2011. Water Pollution Risk Associated with Natural Gas Extraction from the Marcellus Shale. Science Daily. From www.sciencedaily.com/releases/2012/08/120806093929.htm
Accessed 12/14/2017

Rubinkan, M. 2017. In 'Gasland' community, new tests revive old drilling debate. From http://m.startribune.com/in-gasland-community-new-tests-revive-old-drilling-debate/442538933/?section=nation
Accessed 9/6/2017

SBU. 2012. Substantial water pollution risks from hydraulic fracturing: research. Stony Brook University. From https://phys.org/news/2012-08-substainial-pollution-hydraulic-fracturing.html Accessed 12/11/2017.

Schafft, K.A. and C. Biddle. 2015. Opportunity, Ambivalence, and Youth Perspectives on Community Change in Pennsylvania's Marcellus Shale Region. *Human Organization.* 1: 74-85

Shalestuff.com. ND. The Process of Fracking. From
http://shalestuff.com/education/fracking/fracking
Accessed 9/4/2017

Schlegel, J., R.A. Powell, J.D. Ubersax, J.P. Mileer, K.C. Meacham, and Z.R. Brecheisen. 2017. Pennsylvania Supreme Court Resolves Marcellus Shale Ownership and Lease Uncertainty by Reaffirming Longtime Dunham Rule. Mondaq Business Briefing 2 May 2013. *Business Insights: Global. Web.* From
http://bi.galegroup.com.ezproxy.proxy.library.oregonstate.edu/global/article/GALE|A328414823/18a4e3d2614ffdceb3aec850cff2a392?u=s8405248
Accessed 12/5/2017

SEC 2014. Hydraulic Fracturing. From http://www.sanchenergycorp.com/media-center-2/industry-library/hydraulic-fracturing/
Accessed 3/16/2018

Shell, D. and D. Murdiyarso. 2009. How Forests Attract Rain: An Examination of a New Hypothesis. *BioScience.* 4: 341-347

Sites.psu.edu ND. Background. What is the Marcellus Shale? From
http://sites.psu.edu/marcellus/marcellus-shale-background/
Accessed 3/18/2018

Slideshare.net ND. Sequence Stratigraphy Principles. From
https://www.slideshare.net/wwlittle/sequence-stratigraphy-principles
Accessed 3/11/2018

Smit, B. and J. Wandel. 2006. "Adaptation, adaptive capacity and vulnerability". *Global Environmental Change.* P: 282-292.

SNS. 2011. White Reintroduces Bill to all Landowners to reclaim Mineral Rights: Says its Critical to verify ownership and claim the Marcellus Shale Boom, continues in Western PA. States News Service. *Academic OneFile.* From http://www.
galegroup.com/apps/doc/A246129649/AONE?u=s8405248&sid=AONE&xid=25cb723e.
Accessed 12/5/2017

SRBC. ND. Natural Gas Well Development in the Susquehanna River Basin. Information Sheet. From www.srbc.net
Accessed 12/22/2017

Staaf, E. 2012. *"Risky Business: An Analysis of Marcellus Shale Gas Drilling Violations in Pennsylvania 2008-2011"*. PennEnvironment Research & Policy Center.

Stateimpact. 2017. Deep Injection Wells: How Drilling Waste is Disposed Underground. From https://stateimpact.npr.org/pennsylvania/tag/deep-injection-well/

Accessed 12/12/2017

Stateimpact. 2011. Pennsylvania Drilling Counties: active wells and drilling violations. From http://stateimpact.npr.org/pennsylvania/drilling/counties/lycoming-county/
Accessed 11/22/2017

Stateimpact. ND. Act 13. https://stateimpact.npr,org/pennsylvania/tag/act-13/
Accessed on 7/1/2017

Stolz, J. 2011. The Environmental Impacts of Shale Gas Extraction. From https://www.fracktracker.org/2011/03/the-environmental-impacts-of-shale-gas-extraction/

Accessed 3/15/2018

Stroud, ND. The River Continuum Concept. Stroud Water Research Center. From https://stroudcenter.org/continuum/
Accessed 12/30/2017

Sungazzette 2014. Study: Shale drilling created a "boom and bust". http://content.sungazzette.com/?p=605790/Study-Shale-drilling-created-a-boom-and-bust-.html

Accessed on 7/24/2017

Susskind, L, W. Moomaw, and K. Gallagher. 2002. Transboundary Environmental Negotiation. Jossey-Bass. San Francisco.

Thomas, D.S.G., and C. Twyman. 2005. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. *Global Environmental Change* 15: 115-124.

Tietenberg, T. and L. Lewis. 2016. Environmental & Natural Resource Economics. 10th edition. Routledge. New York.

TME.2009. Compressor Station a side-effect of Marcellus Drilling. The Marcellus Effect. From https://marcelluseffect.blogspot.com/2009/11/compressor-stations-side-effect-of.html
Accessed 12/8/2017

Tradingeconomics. 2017. United States Unemployment Rate. From https://tradingeconomics.com/united-states/unemployment-rate

Accessed 12/07/2017

UCS. 2008. Climate Change Impacts and Solutions for Pennsylvania. Union of Concerned Scientists. http://www.ucsusa.org

Accessed on 12/13/2017

Upstream 2011. Fracking Waste in Ohio. From https://upstrm.wordpress.com/tag/ijection-wells/ Accessed 3/12/2018

Veil, J.A. 2010. Final Report: Water Management Technologies Used by Marcellus Shale Gas Producers. DOE Award No.: FWP 49462.

Warner, N.R., C. A. Christie, R. B., Jackson, and A. Vengosh. 2013. "Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania". *Environmental Science & Technology.* 47: 11849-11857.

WatershedCouncil 2017. Hydraulic Fracturing Overall Layout. From https://www.watershedcouncil.org/hydraulic-fracturing.html

Accessed 3/15/2018

Waterworld. 2017. Shale Gas Fracking: Water Lessons from the US to Europe. From http://www.waterworld.com/articles/wwi/print/volume-27/issue-2/regional-spotlight-europe/shale-gas-fracking.html

Accessed 12/12/2017

Weatherbase.com.ND. Koppen Classification for Pennsylvania. From http://www.weatherbase.com/

Accessed 12/13/2017

Weather.gov. ND. Map of the Susquehanna River Basin. From www.weather.gov Accessed 02/07/2018

Weaver, J. 2011. A County Planning Perspective on Source Water Protection & The Marcellus Shale. Northern Tier Natural Gas Summit. From http://www.northerntier.org/upload/nt%20MSG%205-18-11%20%5BCompatibility%20Mode%5D.pdf

Accessed 12/5/2017

Weible, C. M. and P. A. Sabatier. 2009. Coalitions, Science, and Belief Change Comparing Adversarial and Collaborative Policy Subsystems. *The Policy Studies Journal*. 2:195-211.

Weidner, K. 2013. *A Landowner's Guide to Leasing Land in Pennsylvania.* Ag Communications and Marketing, Pennsylvania State University. p. 20.

Wilkes University. 2012. *Natural Gas:  A summary of the history, uses, and consumption with a discussion on the influence of domestic shale drilling.* Available from www.institutepa.org/PDF/Marcellus/ngdhistory12.pdf
Accessed on 6/30/ 2017

Williams, J.H. ND. The Marcellus Shale Gas Play: Geology, Development and Water Resource Impact Mitigation. New York Water Science Center. From https://ny.water.usgs.gov/projectsummaries/CP30/Marcellus_Presentation_Williams.pdf
Accessed 9/3/2017

WLCC. 2017. Lycoming History. Williamsport/Lycoming County Chamber of Commerce. From http:// www.williamsport.org/Lycoming_ History.php
Accessed 12/3/2017

Woodall, C. 2016. *Oil and gas drillers facing bankruptcy as prices crash.* Pennsylvania Real-Time News.
From http://www.pennlive.com/news/2016/01/oil_and_gas_drillers_facing_ba.html
Accessed 11/17/2017

Worldpress 2014. Hydraulic Fracturing: What the media doesn't say. From https://thetruthabouthydrofracking.worldpress.com/2014/12/10/hydraulic-fracturing-what-the-media-doesnt-say/
Accessed 3/15/2018

Zeller, T. 2015. Does Anyone Really Know How Long the Shale Gas Boom Will Last? Forbes Magazine. http://www.forbes.com/sites/tomzeller/2015/01/05/does-anyone-really-know-how-long-the-shale-gas-boom-will-last/#55e7cbf925ef
Accessed on 7/1/2017