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NATURAL GAS DEVELOPMENTS IN THE MARCELLUS SHALE:

ENVIRONMENTAL FOOTPRINTS AND MITIGATION MEASURES

A Thesis in

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by

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ABSTRACT

The development of shale gas formations has been a focused aspect of onshore exploration and production in recent years. The process of getting this done is intensive and involves risk to the workers and residents of the communities where these operations are carried out. It has been predicted by The U.S. Energy Information Administration that unconventional sources such as the Marcellus Shale gas play will account for 50% of natural gas production by 2030 (US EIA, 2007).This projection suggests that there will be more drilling and hydraulic fracturing activities carried out with several factors at risk and huge consequential environmental effects. These risks include (1) contamination by drilling waste (muds, flow-back water, produced water etc.) also emissions from drilling sites and runoffs (2) natural gas leaks and oil spills (3) direct effects on human health. Statistics have shown that 0.5-1% of wells drilled for exploration result in blowout. The causes of these risks are identified to be due to (1) Violations (2) Operational Pollution (accidental spills and leaks (3) Operators policy (inefficient production practices and waste management policies).

In the quest of addressing this concern, an extensive review of literatures with experimental findings was done, and also the potential effect of these activities on the environment was evaluated with statistical analysis (SAS) of all violations by operators in Pennsylvania from January 2008 to November 2010. Doubly repeated measure ANCOVA was used to validate the most significant causes of environmental damage and most violators. The lower 25% of all violations fall below the weighted average of 4, while the upper 25% fall between weighted averages of 6-8. The category effect and interaction effect were used to proof the usefulness of the developed model, the level of significance of category interactions were analyzed, out of 65 operators, only 27 of them were found to have p-values < 0.05, which shows they are significantly different in comparison. The most significant incidents are rank 3, 5,9,10, which account for 67% of all the violations. These data reflect several environmental concerns that are currently prevalent in the Marcellus area. This research work identifies environmental incidences, causes and prevention in the Marcellus gas play.

The research presents guidelines for feasible options to minimizing environmental risks and human health effects on the people of the commonwealth. Recommendations on how to mitigate these impending problems were proffered.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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PROBLEM STATEMENT

The major obstacles in the petroleum upstream industry include;

1. Reservoir development lacking public trust
2. Substantial water problems and environmental pollution due to uninhibited release into the environment
3. Losses that are economically considerable due to reclamation costs, lost time resulting from inept production jobs.

Also an incorrect perception of O&G operators is widespread mostly by the media, which in some cases have resulted in operators relinquishing significant investments of time and resources.

This research focused on appraising the potential causes of pollutions that impact the “social license to operate” (SLO) in the Marcellus Shale gas play, also proffer pertinent strategies which include prevention technologies in accomplishing the best corporate performance with respect to standardized environmental sustainability, community and social responsibility and also profits to the industry and for posterity.

CHAPTER 1

CHAPTER 1: LITERATURE REVIEW

1.1. INTRODUCTION

Due to the enormous natural gas deposits discovered in the Marcellus Shale formation, there has been an increase in gas extraction activities in the Marcellus area. A huge investment is being made in developing extraction technologies to adequately recover natural gas from formations of very low permeability, which necessitated the use of the horizontal drilling and hydraulic fracturing techniques. These methods are very helpful in reaching the pay zone and also creating fractures or connecting natural fractures in the formation, after which the gas can be extractable and optimum recovery attainable. The use of hydraulic fracturing method in the stimulation of reservoirs of tight formations in the Marcellus area is gaining more momentum as energy demand across the region, and/or over the world increases. Recent advances in directional drilling made shale formations, very accessible and more prolific. It has been estimated by The United States Geological Survey (USGS) that there is a technical possibility of recovering up to 200 TCF (trillion cubic feet) of natural gas from shale gas formations. Towards this end, there has been a huge capital intense investment in the Marcellus Shale by some International Energy firms in developing productive fields, providing advanced technology and in the exploration of the natural resource of interest (Gas).

These events are new to many towns that never experienced drilling and production activities and are intensified in regions that previously experienced little petroleum development activities. Inasmuch as the production of natural gas for the purpose of meeting current energy consumption requirement is quintessential to the prosperity of the human population at large, it may also damage the environment if not with careful operations. There has been a growing concern over the stimulation of the Marcellus Shale, ranging from contamination of drinkable well water, to excessive water withdrawal from the watersheds and other related environmental/ psycho-social effects of both drilling operations and the disposal of flow back fracture fluids. Wastewater is usually produced alongside the gas and they contain total dissolved solids in high concentrations and the chemical additives added to the hydraulic fracturing fluid. Data provided by the Pennsylvania Department of Environmental Protections (DEP) confirm the various violations by the operators in the Marcellus Shale area. It is evident that in some areas of the commonwealth, these fluids (wastewater and undiluted fracturing chemicals) were either accidentally spilled to the waters of the commonwealth or in some cases, were discharged into water bodies due to the unavailability of proxy treatment plants.

The goal of my research is to provide an overview of environmental challenges in the Marcellus Shale area and their impacts on the gas exploration and production industry as a means of providing responsiveness to environmental risks, highlighting the need for the industry's sustainability when controllable risk are mitigated or minimized. Statistical facts are presented to show the different interactions of risk factors and how they trend in response to environmental concerns, also pollution prevention methods. The sources of pollution of high interest in industrial operations are hazardous air pollutants, waste water, spills and operational waste materials. Fortunately, technological advancements have led to improvements in reducing the effects of these pollutants to the environment. Technology improvement positively impacts cost savings in the oil and gas industry, such as implementing innovative technology for exploration, production, processing, transportation and storage operations, leading to a better scenario of environmental protection and compliance.

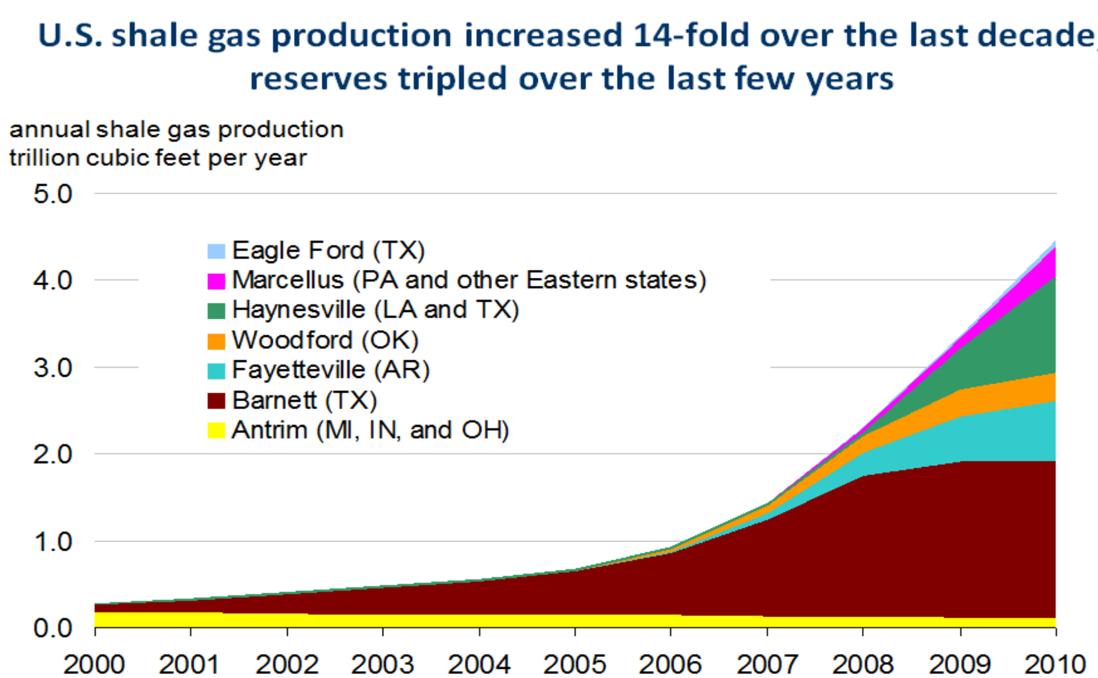


Fig 1 US Gas Production EIA 2010

The comprehensive overview and consideration of issues, facts, and data based on generated waste, disposal and the magnitude of environmental effect in the Marcellus Shale sustainability together with mitigation measures are presented in this research work.

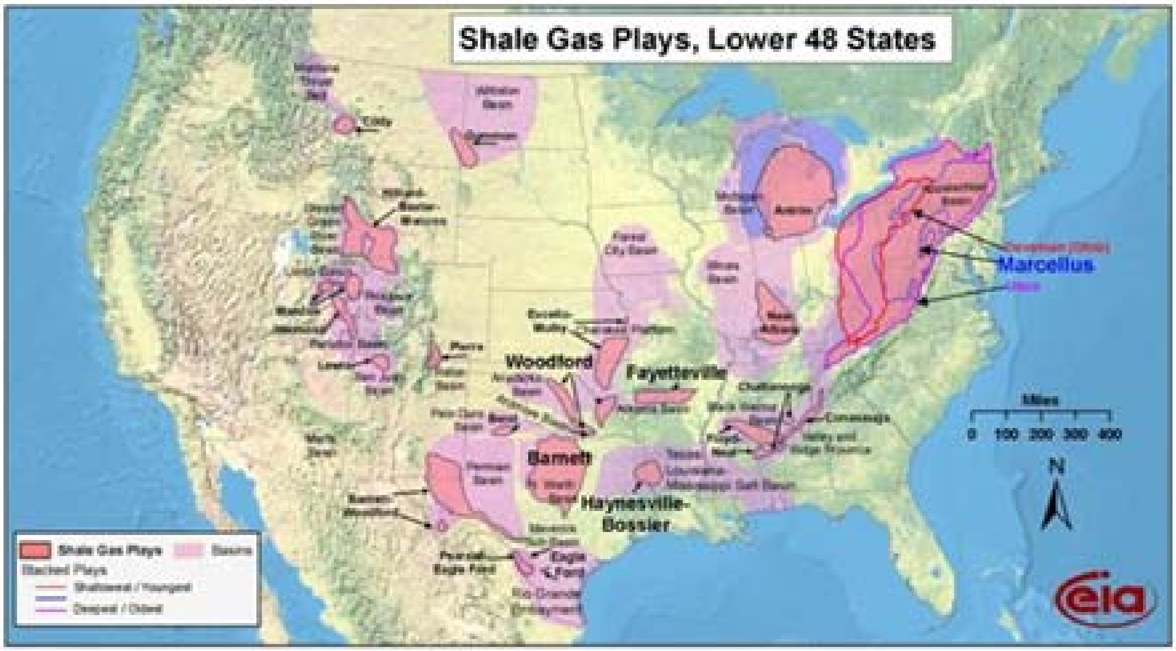


Figure 2: Shale Play in the US: Courtesy: EIA

1.2 MARCELLUS SHALE

Shale is a rock formed from the compaction of fragments of other materials, usually silt and clay size particles; it is a sedimentary rock with fine-grained texture that forms from the compaction of silt and mud. The geologic age of the Marcellus Shale is Devonian (350 – 415 million years ago). The Devonian period was marked by substantial deposit of organisms and algae as sea bottom which was devoid of oxygen, these organisms were able to settle and decomposed due to low circulation and the prevalent anaerobic conditions. After a period of time, the decomposed matter was transformed into carbon, and once hydrated it became what we call hydrocarbons. These hydrocarbons include petroleum and natural gases, such as crude oil and methane gas. The deposition cycle during the Devonian that formed the Marcellus Shale is basically carbonate richer than other shale formations. Natural gas is mostly stored in the fractures of these rocks as free gas or as absorbed gas on the clay surfaces and kerogen within the shale rock matrix (Shale Gas, 2006. The porosity of a rock is the amount of pore spaces in the rock per total pore volume, and these pore spaces accommodate fluids. Due to the grain arrangement in shale rocks, movement is curtailed and the fluids, once formed remain within the pores. The shale rocks trap the fluids and make it challenging to extract these fluids commercial from the rock, except natural fractures or induced fractures are created.

1.2.1. LOCATION

The Marcellus Shale is situated in the eastern region of the United States cutting across into some parts of Canada. The lateral extent of the Marcellus shale is approximately 965.6Km (600 miles) (Durham, 2008), from the New York which is to the south, it cuts across mostly the western part of Pennsylvania and extends through West Virginia and the eastern side of Ohio (Sciencedaily, 2008). The Marcellus shale is approximate to be a bit larger than the state of Florida with an area of about one hundred and forty square kilometers (54,000 square miles) (Mayhood, 2008). The shale has a variable depth all across its extent, which ranges from about 40 feet in Canada to 250 feet in thickness in New York (see Fig. 3).

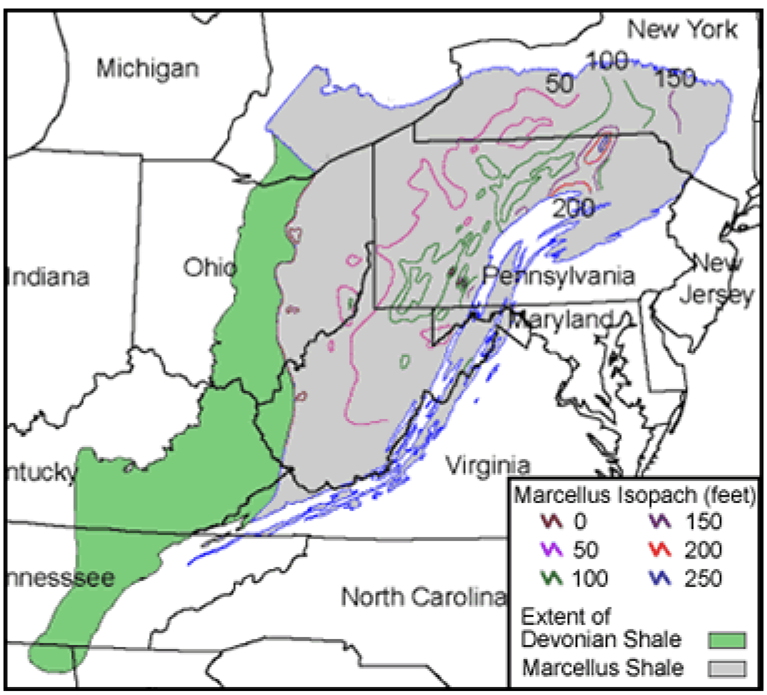


Figure 3: Marcellus Shale Thickness: US DOE, 1993

The above map which illustrates the Isopach (depth to bottom) of the Marcellus Shale was created by Wallace de Witt et al, 1993 with the aid of maps prepared by Robert Milici and Christopher Swezey, which was made available by, the US Department of Energy (DOE) published in the Atlas of Major Appalachian Gas Plays.

1.2.2. GEOLOGY

Sedimentary rocks of black shale formations rich in organic content occur largely throughout geologic time. The shale rocks occur in Pennsylvania mostly in all the Paleozoic and Triassic rocks and in the southeastern basin of Gettysburg and Newark (Fig. 4). These Pennsylvania shale rocks are credited for being the source of petroleum resources both in the sandstone and carbonate reservoirs found in the region (PA. Geology, 2008).These organic-rich Marcellus shale rocks are easily mapped due to their high radioactivity responses which is in the range of 10 parts per million to 100 parts per million (AAPG, 1958, 1981). Although the Marcellus shale is a low permeability rock formation, it has many advantages also. The favorable mineralogy suggested by the high porosity and low density makes the formation economically important, since it contains more gas content (American oil & gas, 2008). Most parts of the State of Pennsylvania sit on the Marcellus Formation but there is variability in organic-rich content from area to area. The northeastern part of the state has the maximum organic-rich content development (PA Geology, 2008) but development of these resources in commercial quantities just began recent despite the fact that gas has been discovered in the Marcellus for a long period of time now. (as shown in Fig.5)

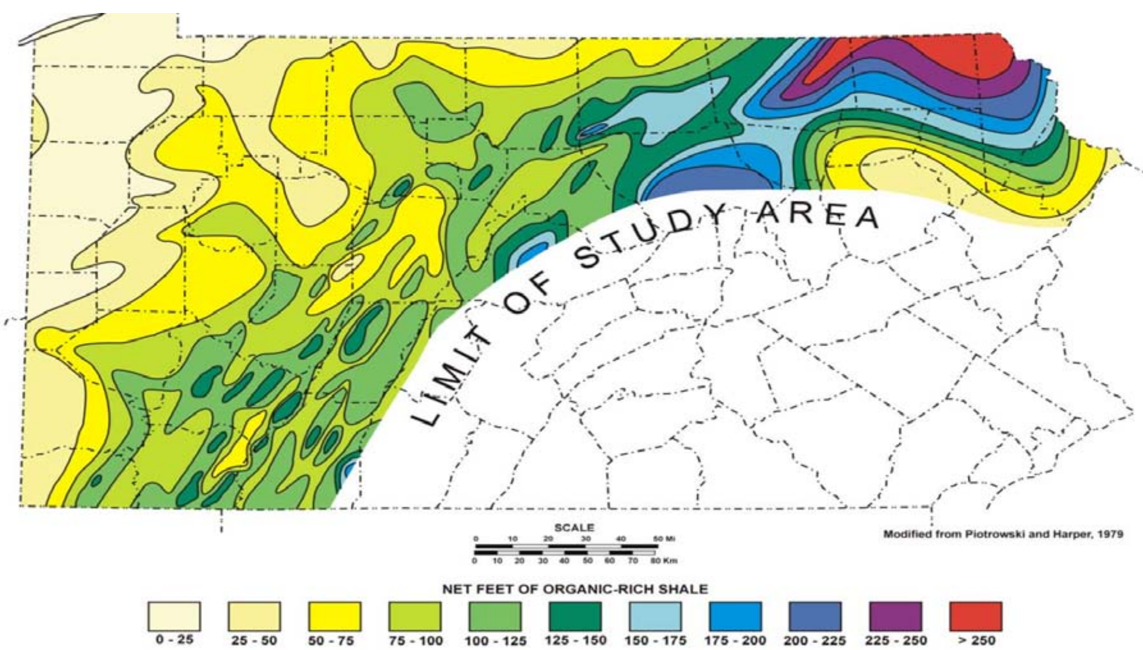


Figure 4: Net feet of organic rich shale in Pennsylvania Marcellus Formation

The Map above by Piotrowski, R.G.and Harper, J.A., 1979 shows the net feet of organic richness in the Marcellus shale Formation.

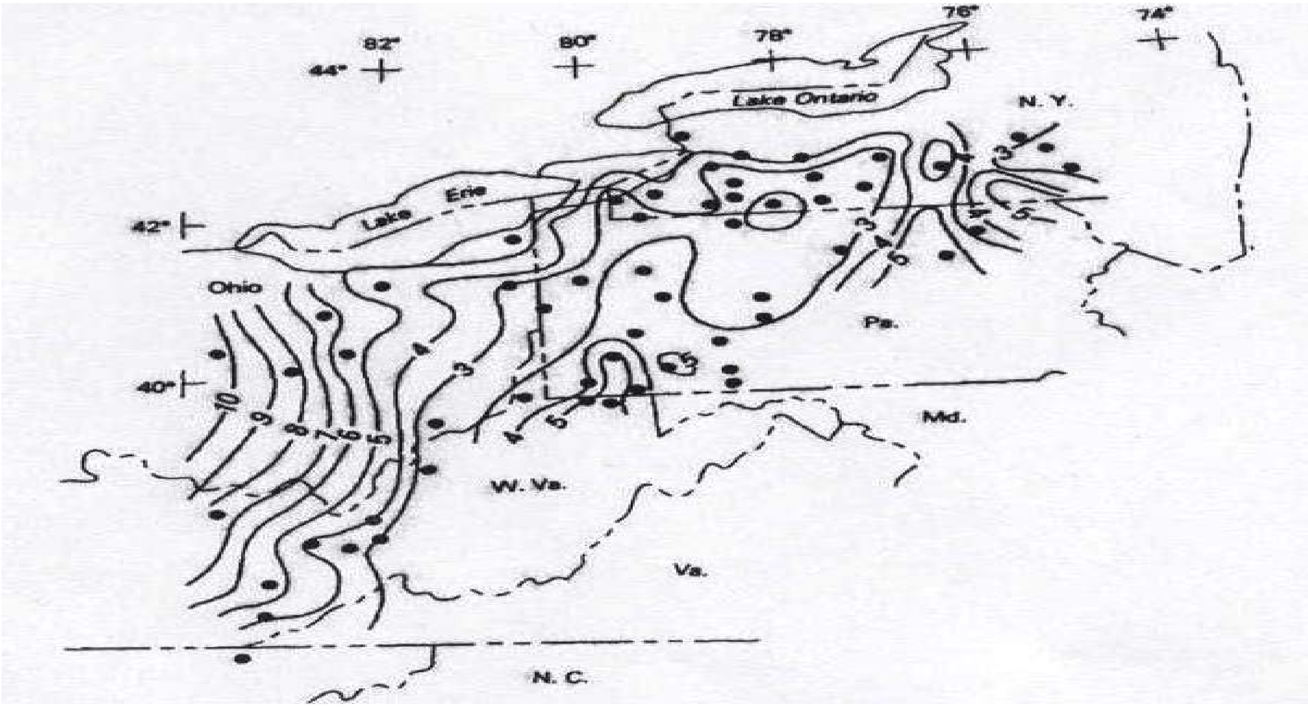


Figure 5: Average Organic Content of the Marcellus Shale, (the numbers are in percentage) (American oil & gas reporter, 2008).

There is variability in the depth to the Marcellus formation, with an increase in depth from the northeastern part across to the southwestern parts (American oil & gas reporter, 2008). Most of the rock formation occurs at an average depth of about 9,000feet, while a few outcrop at the surface in New York area. This outcrop was responsible for the naming of the formation as Marcellus, since the outcrop was noticed in the New York State, close to a town called Marcellus in an 1839 United States Geological Survey (USGS) (Mayhood, 2008).At different locations the Marcellus shale displays variable characteristics across the play, from the slightly geopressured north to the under pressured southern areas with natural fractures, the entire Marcellus Shale region is undeniably prolific. The thin and shallow western part has more organic content and primary production began in this area, but unlike the western part, the eastern area is thicker and deeper with low organic content but more quartz content mineralogy. The eastern parts are deeper, more brittle and thicker but ironically, the organic content is lower in these eastern shale formations.

1.2.3. POTENTIAL OF MARCELLUS SHALE RESOURCES

A conservative estimate for the potential of the entire Marcellus formation was made by two researchers and professors Terry Engelder of the Pennsylvania State University, alongside another geosciences professor from the State University of New York, Gary Lash had estimated the total gas in place for the Marcellus Shale which only about 10% is technical recoverable (api.org, 2010; Pletcher J., 2008) to be 168 TCF, but Professor Engelder speculated that the real estimate could be up to 516TCF of gas in place in the Marcellus Shale.

According to US EIA (2006), approximately 21 TCF of natural gas was consumed in the U.S. which means that the Marcellus Shale reserve estimate can support local consumption for up to two and a half years according to current Engelder and Lash estimate.

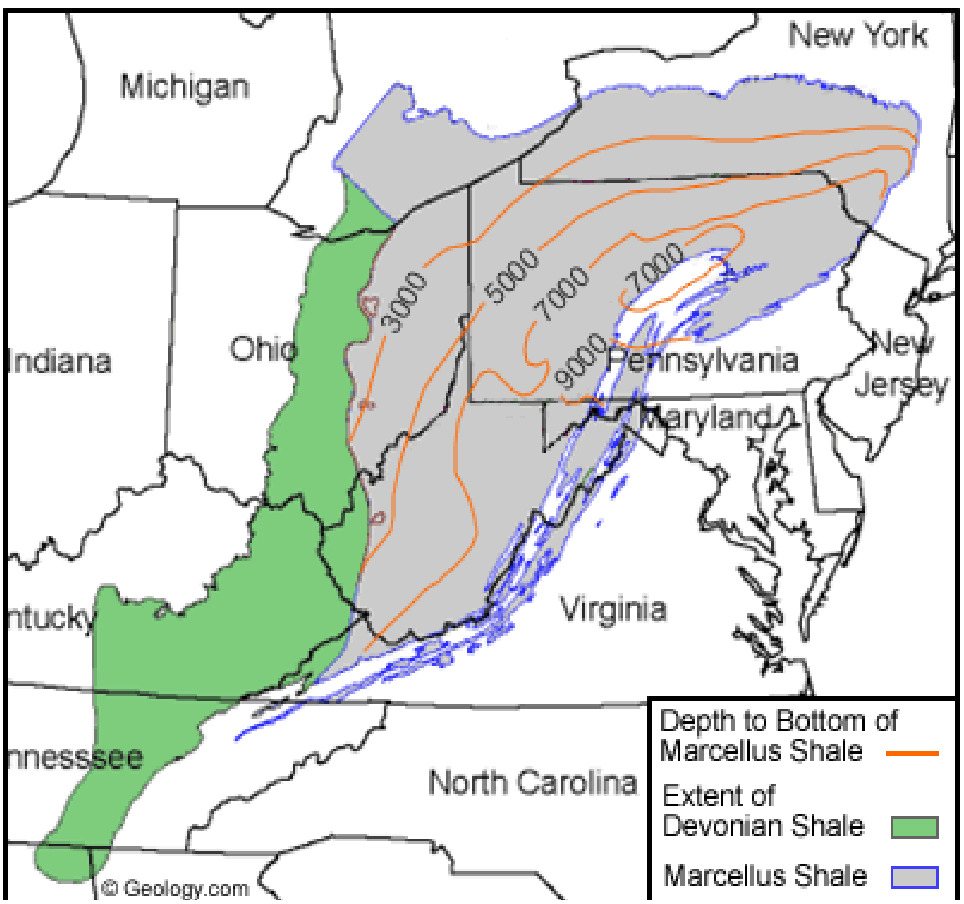


Figure 6: Depth to the Marcellus Shale: www. geology.com

1.2.4 GAS OCCURRENCE IN THE ROCK

Gas naturally occurs in the shale rock present in the Marcellus region in the following way;

- contained in porous areas of the shale rock;
- inside fractures that occur naturally, fissures or joints that are created in the shale; and,
- contained on organic materials and mineral grains in adsorbed form.

Majority of the gases of interest that are recoverable are contained in the pore spaces, but due to the restriction posed by poor pore space interconnectivity, the movement of the gas is difficult.

1.2.5. TRANSPORTION OF GAS THROUGH MARCELLUS SHALE MATRIX

The low permeability prevalence in the Marcellus Shale has been a major impediment in gas production since gas was discovered in the Marcellus shale formation. Many geologists that have worked in this area were easily convinced that the gas present was formed from the black shale sequence and they also asserted that majority of the produced gas during the initial flush production stages were contained in the network of natural fractures present in the shale formation. While the gas production that ensued for a longer period was from the shale matrix represented by a gradual decrease in production. The gas in the matrix occur through a gradual process of desorption moving into the fracture networks, which was possible due to the dynamic equilibrium of this process and the ability of the well to produce gas at the prevailing reservoir pressure. The possibility of producing this gas at large quantity was determined by the ability of the wellbore to intersect the network of natural fractures containing the gas, and or connected by absorptive conduits to the fracture systems, by enhancing the shale rock permeability through advanced technologies called the well stimulation (Charpentier, R., 1993). This enables the free flow of gas from the permeable fractures, since the volume of gas present in organic materials in the shale matrix desorbs and transition slowly into the fracture network stays at equilibrium with the gas volume moving into the well bore from the fractures.

CHAPTER TWO: DRILLING AND COMPLETION

2.0. DRILLING

The processes of gas extraction from the organic rich shale rocks involves the calculated planning of the entire activities it entails, by making sure the suitable procedures such as the right drilling methods and drilling fluids together with the right materials, equipment and even the location are all taking into consideration appropriately with regards the rocks properties. For a higher gas production and recovery, deviated wells such as horizontal wells and multilateral wells are used to penetrate larger areas of the pay zone.

2.1. DRILLING METHODS

In the Marcellus Shale play, there are you basic drilling methods currently employed, they are;

1 Vertical drilling

2 Horizontal drilling, (as shown in Figure 7), (Sumi Lisa, 2008)

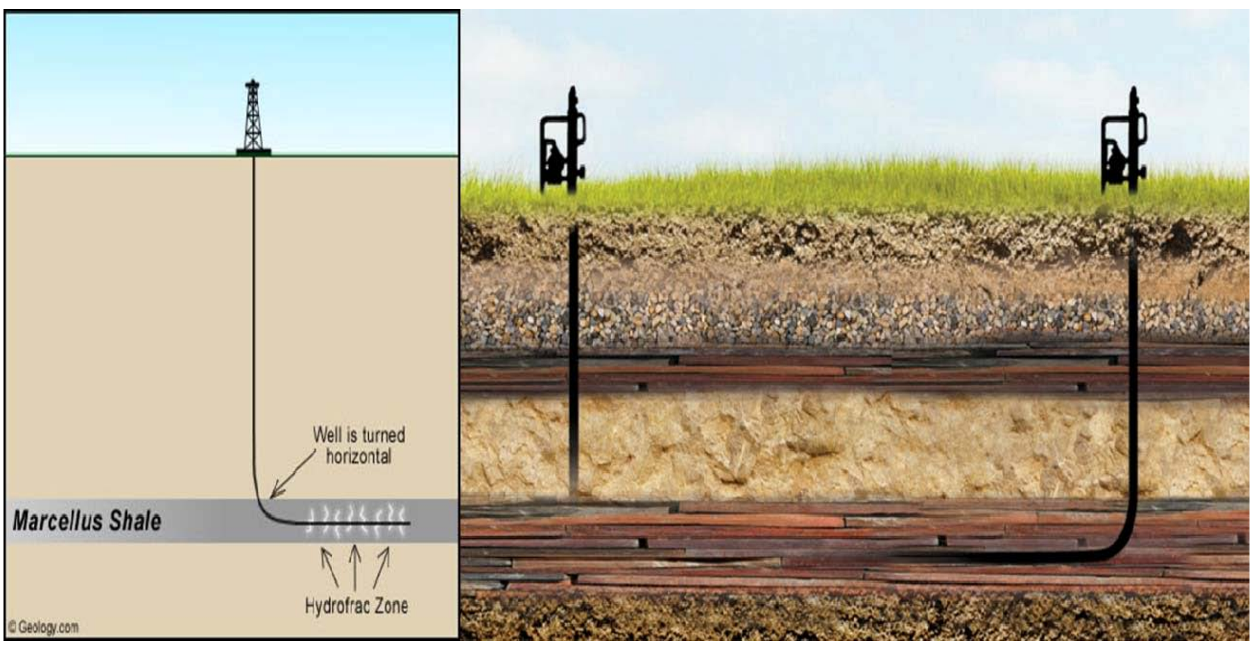


Figure 7: Drilling Methods (Vertical and Horizontal drilling, Geology.com)

The most favorable Marcellus shale wells drilled involved the two technologies illustrated above which are considerably novel methods in gas production in the Appalachian. A vertical well is drilled and completed in some cases, the vertical well is deviated at depth and drilled further laterally into the formation with the aim of achieving deeper penetration that cut across several rock fractures of vertical orientation contain fluid of interest. To the left of figure 5 is a well stimulation technology called the hydraulic fracturing which involves pumping water with some additives at high pressure into the rock formation to forcefully open up fractures in the rock formations. This method is very effective in increasing the permeability of the shale reservoir extensive fracture lengths and consequently increasing the recovery of gas (Geology.com). The pioneer of this type of drilling technology in the Marcellus Shale development is Range resources with a total of 50 horizontal wells as of 2008 and about 200 more wells were drilled vertically in the same year. The company at the Pennsylvania State University Natural Gas summit in 2008 reiterated that there were plans to drill 200 vertical and a total of 250 horizontal additional wells in 2009 (Pinkerton,J., 2008)

2.1.1. VERTICAL DRILLING

This type of drilling method is the conventional method used to drill in conventional reservoirs, where there are no seals barricading the pay zone from drilling contacts. It basically involves the use of drilling systems, e.g. the rotary rig (Fig 6) to bore through into the sub surface until the zone of interest is reached. But this method becomes very inapplicable and utterly too expensive to employ where are obstructions such as developed areas, seas, mountains etc.

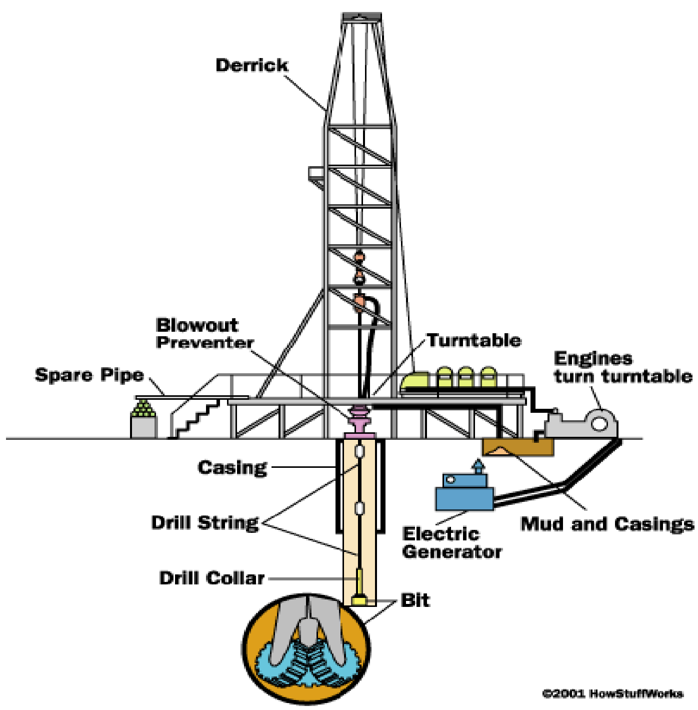


Fig 8: Rotary drilling (www.n5asa.com/Oil/oil.htm)

2.1.1.1 Demerits of Vertical Drilling

Vertical wells are designed to drilled straight down into the sub surface and they can only penetrate a single spot that cut vertically into the shale reservoir. There are a total of 551 vertical wells drilled in the Marcellus Shale as of 2010, the low number of vertical wells in the Marcellus Shale compared to that of horizontal wells suggest its limitation as the chances of intersecting more natural fractures are slimmer than when a horizontal well is drilled through the formation.

2.1.2. HORIZONTAL DRILLING

A total number of 1450 horizontal wells have been drilled as of 2010. This method is favorable than the conventional vertical drilling in that it allows for more fracture systems to be intersected and consequently leading to better recovery, though it is more expensive. There are no significant differences between the vertical drilling method and the horizontal drilling method. Except for the fact that at a desired depth based on the zone of interest, the vertical drilled hole direction is deviated at the kickoff point which is mostly at the top of the pay zone. The directional drilling hits the reservoir at an entry point and continues farther laterally into the formation at an angle between 70^0 -110^0 (Hernandez R., 2007), cutting through several interconnected fracture networks and giving room for more gas to flow towards the horizontal wellbore which eventually flows to be recovered at the surface.

2.1.2.1 Merits of Horizontal Drilling

Horizontal wells are twice or three times more productive than vertical wells. Horizontal wells can also be used to reactivate uneconomic vertical wells, by increasing the access to more fractures and better recovery. Most gas reservoirs are u ultimately recoverable by the use of hydraulic fracturing in addition to horizontal drilling

Some benefits of horizontal drilling include; (Graham Stephen, 1994)

- The usefulness of horizontal drilling over vertical drilling cannot be over emphasized, for most thin that are more extensive laterally than vertically, using a vertical method of drilling will limit the potential to capture more of the resources to a large extent. Horizontal drilling has the capability to penetrate into reservoirs that have flat orientation.
- Since horizontal drilling penetrates laterally extensively, it guides against having to drill several vertical wells, consequently reducing surface impacts and when compared to the

drilling of equivalent vertical wells, it is more economical.

- It gives optimum contacts with pay zone, in such a way that a large quantity of gas can be produced from the drilling of a single horizontal well.

2.2 DRILLING PROCESSES

The process of drilling for petroleum resources successfully involves several stages including; borehole drilling, drilling fluids design, and completion designs such as casing design and cementing. The process starts with well drilling and testing, and then the determination of the productivity capacity of the well is done to ensure that it will produce commercially. After which the well is then completed through cementing and the installation of casing, tubing and perforation are carried out afterwards.

2.2.1 DRILLING LANDS IN THE MARCELLUS SHALE AREA

It is a routine for drilling companies or operators to obtain permission from the government and the land owners. All these processes are completed before site installation takes place on the land. In the Marcellus Shale, the two most regular types of wells drilled are the vertical and horizontal wells. The preferred drilling method is the horizontal drilling due to the ability to capture majority of the zone of interest. But in cases where the vertical wells are to be used, they are usually drilled at close intervals in terms of spacing due to the low interconnectivity of pore spaces resulting to low permeability of the shale rock housing the fluid of interest. In the case of vertical wells, it necessitates the drilling of more such wells as against drilling just one horizontal well, that laterally penetrates through the zone of interest universally. Vertically drilled wells also suggest the use of more lands; more permits to be obtained from the appropriate authorities, more facilities such as well pads, production facilities. Road construction and its impact, all these consequently increase the foot print of the operator in the environment and their presence would be felt more in these cases. A larger surface presence presents more likelihood for environmental disasters to occur in the environment, such as accidental leaks and spills, impacting the soil and water supplies of local residents.

It is technically and economically sound to employ the horizontal drilling method in the Marcellus Shale area, since there would be less need for multi well heads, production facilities, equipment and infrastructure that supports individual well development. Table 1Shows the drilling areas of wells in different locations and sources.

Sources	Vertical Well Area (acres)	Horizontal Well Area (acres)
Independent Oil & Gas Association (Gill Brad, 2008)	-	200-640
Tompkins County Water Resources Council (Wilsea Kathy, 2008)	-	640
Susquehanna River Basin Commission (Michael Brownwell, 2008)	40	200-400
Upper Monongahela River Association (Shuck Zane, 2008)	40	640
W. Virginia Surface Owner's Rights Organization (Arthur Daniel, 2008)	40	160
Chesapeake Energy (Sumi Lisa, 2008)	160	-
XTO Energy (Marvin Chuk, 2008)–West Virginia	80–100	-
Atlas Energy southwestern PA	40	-

Table1.Drainage areas of wells from various sources

According to Daniel Johnston (2003), the design and spacing requirements of any well type has to be with regards to states regulations where the wells are drilled, where the most common spacing permitted by regulars is a well per drilling unit or section, where a section is approximately 640acres of land. Unless otherwise necessary, the operator may request to drill more wells within these drilling units if the purpose would result to better productivity in the area.

2.2.2 DRILLING FLUID

The drilling process involves a cocktail of fluids known as the drilling fluids, which functions are as follows (NYC DEC, 2008)

- Lubricating and cooling of the drilling bit facilitating circulation.
- Release cuttings from bit and cleaning the hole underneath the drilling bit.
- Carriage and dropping of cuttings on the surface
- Stabilizing the well bore prior to casing and control of subsurface pressure.

2.2.3. TYPES OF DRILLING FLUID IN MARCELLUS SHALE

The type of drilling fluid used during a drilling process depends largely on the prevalent conditions, e.g. pressure, formation type, design method etc. in Shale drilling, there are a couple of drilling fluids types mostly used, they are;

- Aqueous or Water-based fluids (WBF's)
- Oil-based fluids (OBF's)
- Synthetic-based fluids (SBF's)
- Air and foam fluids

The constituent of the different types of drilling fluids outlined above vary considerably. For water based fluids, the constituents are listed below;

- Water-based fluids (WBF)
- Brine/water ... ... … … … 76%
- Barite .... … … … 14%
- Clay/polymer … … … … 6%
- Other ………… … … … 4%

While for the non-aqueous fluids, they are composed of the following;

- Non-aqueous fluids
- Non-aqueous fluid …. … … 46%
- Barite …………….. … … 33%
- Brine ……………… … … 18%
- Emulsifiers ……….. ... … … 2%
- Gellants /other …… ... … … 1%

The barite added is a weighting material while bentonites are extenders, they aid in eliminating cuttings, forming mud cakes and sticking to the well bore. Other additives used are;

- Viscosifiers.
- Biocides
- Filtration Control Materials.
- Chromate corrosion inhibitors (O&G, 2005)

- ❖ Materials that control alkalinity and hydrogen concentration ion (pH)
- ❖ Lost circulation control
- ❖ Lubricants e.g.diesel lubricants
- ❖ Shale Stabilizing Materials.

Examples are chrome lignosulfonates and lignites, these are viscocifiers that help the mud to remain in the liquid state.

2.2.4. DRILLING FLUID TYPES IN OTHER SHALE

As mentioned earlier, the choice of a drilling fluid depends on the condition and type of formation. For instance, in the closer Devonian Shale, the rotary drilling method is often used alongside oil based fluid system for drilling in these areas (Cluff, R. and Dickerson D., 1981). While away into the Barnett Shale, additives such as soda ash, detergent, gel, sodium bicarbonate, lime etc. are used as additives in fresh water or water based fluids to effect the drilling. Other parts of the Barnett Shale where formation and borehole stability is in doubt (Kinley Travis et al, 2008), the oil based fluid is usually employ to tackle this challenge. Air can also be used as fluids for drilling; this method is used effectively in the San Juan basin (Carden R. 1993). The best drilling fluids are used with respect to the properties of the shale rock in question. The properties of these shale rocks can be determined from thorough analysis of the formation and after which the driller makes the right decision based on the result.

2.3 WELL COMPLETION

The next stage in a well development after drilling is the completion stage which precedes production. The main purpose of well developers is to optimize production, and well completions are just a pathway in making this aim a reality. The well is stimulated to increase the interconnectivity of gas bearing pores in the shale; this fit is achieved technologically by the process of hydraulic fracturing. In terms of drilling, the hole may be designed to follow a vertical direction or horizontally drilled direction. The horizontal well is mostly the focus of well stimulation compared to the vertical wells (Jim B. et al, 2008), there are several considerations to be made before this process begins, they include; formation analysis, hydraulic fracturing design, selection of casing types and other solutions as pertains the life cycle of the well.

In well development design, the reservoir thicknesses as well as the reservoir effective radius are of prime importance. It is usually expected that the reservoir radius would be larger than the thickness for most commercially prolific reservoirs. For the purpose of maximum yield and optimal production, fractures are intended to be created in the transverse direction by drilling the well in the least or minimum principal stress. With the fore knowledge of whether or not the well would require any form of stimulation prior to the drilling and completion, a good well design would eventually yield optimally if the information are appropriately executed in the planning (Jim B. 2008).

Open hole completions are the most common technique used for directional drilled wells such as the horizontal wells. Several factors are considered during the a well completion design, these include the depth to the formation, formation pressure, pressure differential, drag and torque, perforation effects, thermal expansion of materials, the piston effect etc. (El-Sayed A. et al, 1991; Bourgoyne Jr. A. et al, 1991). The ability to stimulate or produce solely from a particular payzone or zone of interest is now possibly due to the advancement in technology by the use of multi-zone and multi-stage completions (Aldrigde Don, 1996).

2.3.1 Well Casing

The drilling process involves the appropriate design of drilling fluids, casing and cementing carried out at designated stages in accordance to the well develop plan. A pipe is installed in the borehole called casing, after the hole is drilled through the formation, which separates the formation from the drilled hole. Well casing are ran at variable intervals during the drilling process, the casing serve many purposes in addition to the separation of the formation from the well bore, which include serving as a permanent stable housing for the bore hole with a defined well bore casing diameter in which further well developments could be effectively carried out. The casing is cemented in place so as to keep it steady. Another purpose of running a casing is to prevent drilling fluid loss or gain through the walls of the formation, and ultimately preventing formation fluids inter flow. It also guides against the influx of water into producing formations, while it allows for selective production and perforation from only the pay zones or zones of interest. The formation pressure can be greatly controlled with the aid of casing present in the well bore, and it is also a means by which fluids flow are contained, as surface valves such as rams and blow- out preventers (BOP’s) are fastened to it for the well control.

There are basically four categories of casing which depends on the aim they were designed to serve.

Figure 7 illustrates the different types of casing installed; which are conductor, surface, intermediate and production casings respectively.

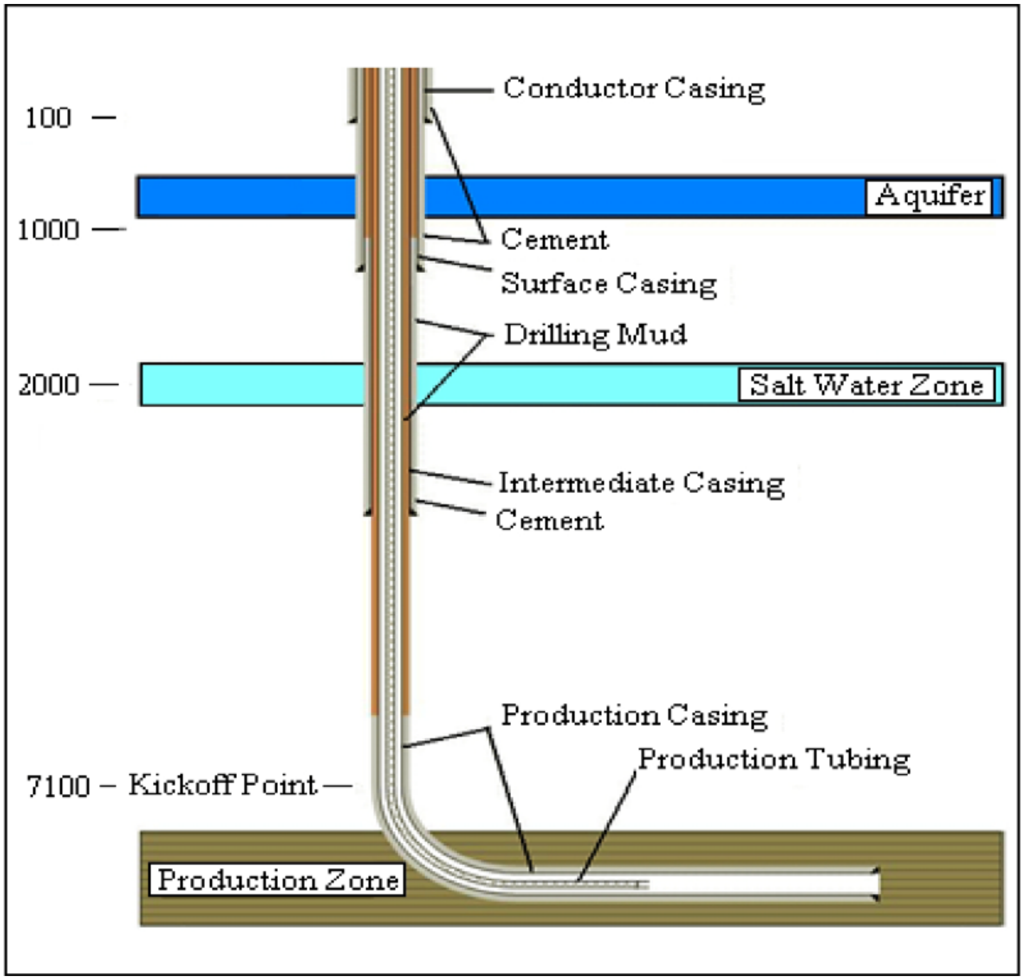


Figure 9: showing the four types of casing run in a well: Source: GWPC. Not to scale.

2.3.2 Well Cementing

This is the process of mixing up cementing materials and making them into slurry which are placed in the space that separates the casing and the open hole called the annulus. Well cementing may be primary or secondary depending on the purpose of use. The secondary cementing can also be referred to as remedial cementing. The cementing process provides stability and rigidity for the well casing which inadvertently prevents the free flow of formation fluids from the annulus to the surface. As seen in figure 7, the conductor casing prevents the inflow of drilling fluids into the aquifer and vice versa, but the cementing of the area around the annulus ultimately prevents the contamination of fresh water in the aquifer. Other functions and usefulness of cementing in well bore development include; prevention of fluids in and out of fractured formations, blocks out lost circulation zones as well as unusual pressures, it also prevents the casing strings from being corroded. Cementation makes it easy to close off unneeded portions in a well or abandoned wells.

The cement slurry make up is determined by the purpose of the completion job and it is necessary to observe that during a cementing job, the cement continues to exhibit desirable properties while it yields a slurry of favorable density. It is also important to ensure that while the cement is setting, it is resistant to annular gas, the casing and formation bond strength develop alongside the slurry strength very quickly. Also that the rheology of the slurry satisfies the maximum property requirement and can be conveniently mixed, pumped and used for the job to facilitate the removal of drilling fluids.

2.3.3 Well Tubing

Another steel pipe is conducted into the well bore which in this case has a smaller diameter (3-11.5cm) than the well casing pipes; it is called the tubing and it comes in sets of 10meter length. It has a primary aim of transporting fluids from the bottom of the well bore to the surface. Several grading of these tubing exist which when effectively combined in accordance to the American Petroleum Institute (API) standard enables fluids production economically. The tubing deters produced fluids from corroding the well casing strings.

2.3.4 Surface Equipment

In addition to the above mentioned processes of casing, cementing and tubing, several surface equipment are installed in the well, such as the choke for well control. The choke is primarily used for fluid flow control, it is either fixed or adjustable contingent upon the specific usage, if this orifice is small, this signifies the existence of lower flow rate prevalent. The wellhead is also put in place; this is a steel fitting at the surface directly above the hole, installed permanently and it is made up of casing heads which supports the casing components. Also installed is gas flow control valve equipment called the Christmas tree, this consist of about five different and distinct components, namely; wing, master and swab valves respectively and also a choke, alongside a pressure gauge.

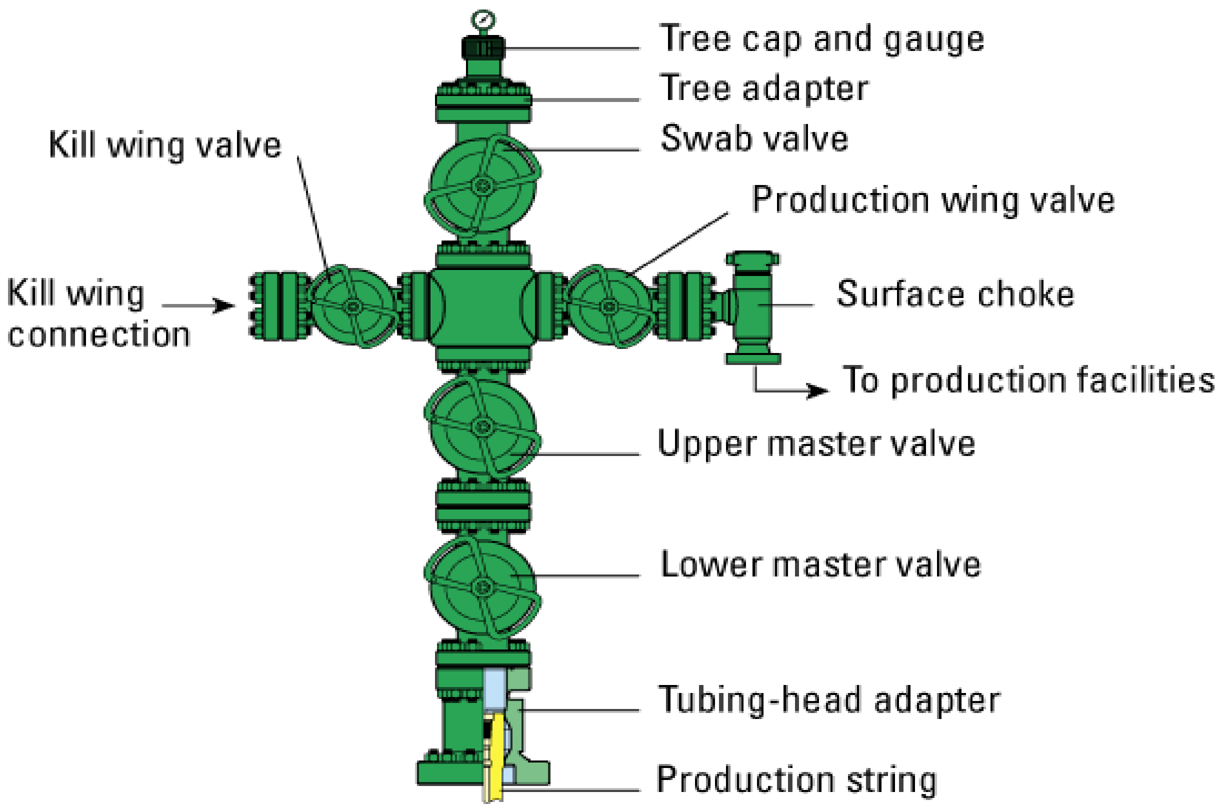


Figure 10: Diagram showing a Christmas tree assembly (Oil field Equipment Company)

CHAPTER THREE: WELL STIMULATION AND PROCESSES

3.0 INTRODUCTION

With the advent of newer technologies such as directional drilling and hydraulic fracturing, it is now economical to recover natural gas from shale gas reservoir with very low permeability (Halliburton, 2009). This novel technology which has been widely successful in other shale plays such as the Barnett Shale (Halliburton, 2009) has been introduced into the Marcellus Shale development with the purpose of optimum production.

There are distinct methods used in well stimulation, these include; acidization, where acids are injected, water and gases injection. These are done with the purpose of improving the productive capacity of the formation, by increasing the permeability of the shale rock. Once the fluids are pumped into the formation at very high pressure, they extend the natural fractures present in the formation while simultaneously creating new ones. The geology of the formation determines the type of fracture fluids used to stimulate the well; some of the fluids used include carbon dioxide (CO_2), slickwater, nitrogen and hydrochloric acid (HCl) (naturalgas.org, 2009). Slickwater is the preferred fluid used in shale formations compared to acidizing, acids are more costlier than water, they are not easy to clean up and with the use of acids, the drainage radius and the effective fracture lengths may not be achievable (Paktinat J., et al, 2007). Some schools of thoughts however prefer the use of carbon dioxide over slickwater since water is valuable and carbon dioxide is a byproduct of several forms of energy, and using carbon dioxide reduces the need of water which in turn requires later treatment.

3.1. TECHNOLOGY

The Marcellus Shale development benefits hugely from the advancement in technology that makes unconventional reserves very economical (Lonnes S., et al 2005). Exxon-Mobil introduced the multi-zone technology which includes the Annular Coiled tubing Fracturing (ACT-frac) and the Just-in- Time perforating (JITP). But between the two, the Annular Coiled tubing Fracturing is ideal over the Just-in- Time perforating since the JITP poses the ball-out problem. Other technologies of interest that are currently employed in the Marcellus Shale which effectively stimulates the well of interest and consequently yields optimum gas production are the Tailored Pulse Fracturing (TPF) (DOE, 2009) and the Hydra jet- Fracturing (HJF) (Surjaamadja J. et al, 2009).

3.2 Hydraulic Fracturing

The hydraulic fracturing technique was ushered into the petroleum industry by Clark J. B., 1948 in his paper "hydraulic process for increasing the production of wells". Beeler P.F., 1963 recounted that carbon dioxide was successful used for fracturing purposes and subsequently sand was added for the stimulation of vertically drilled wells in 1982 (Lillies A.T. & King S.R., 1982), which also was later used in the stimulation of other vertical wells in the Devonian Shale formations in 1993 (Yost A.B. et al, 1993).

Hydraulic fracturing technology is required for formation stimulation and for optimal recovery, since the technology was developed about 70years ago, over seven (7) billion barrels of crude oil and six hundred (600) trillion cubic feet of natural gas have been produced (api.org, 2010). The method enhances the ability of fluid to move more freely within the rock pores by creating cracks in the formation which serves as pathways for the oil or gas to reach the wellbore and travel to the surface. Fracturing fluids are made up mostly of water and other chemical additives Fig. 9 (added to stall the growth of scale and bacterial around the wellbore), which are pumped at high pressures into the formation through a designed section of the well casing.

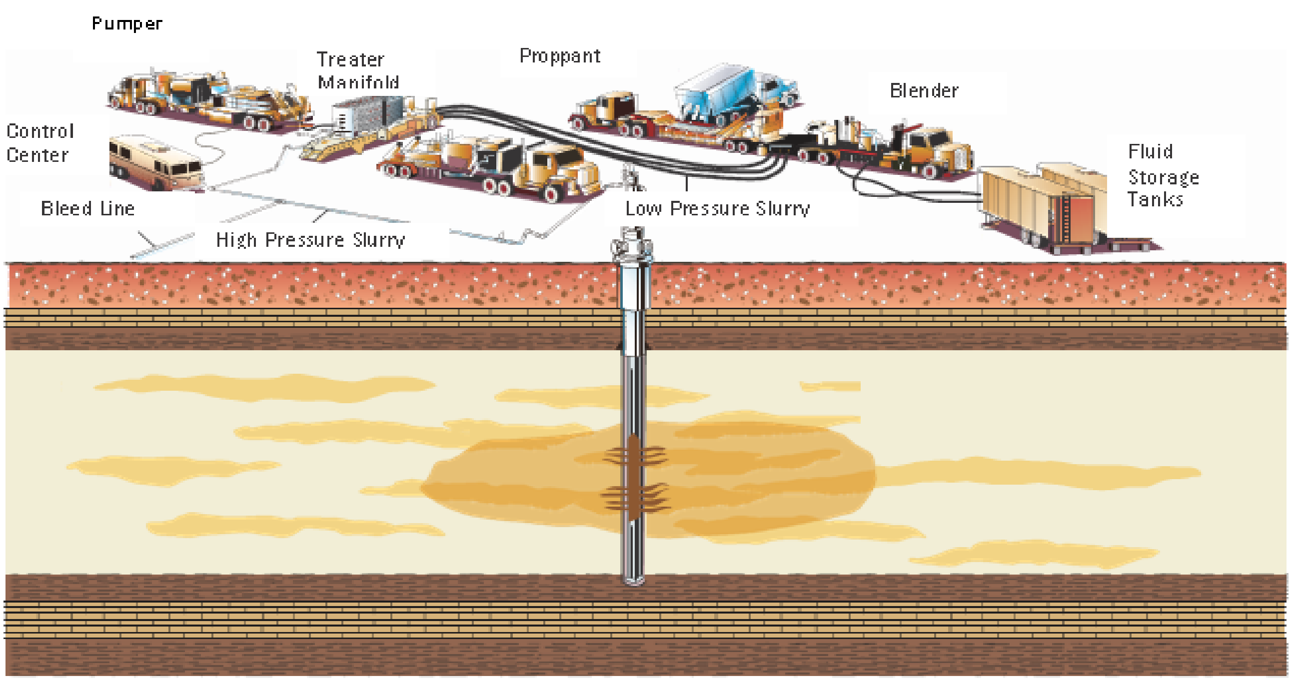


Figure 11: Hydraulic fracturing process, Courtesy: U.S. Department of Energy

The pressure is allowed to increase steadily during the process until it reaches a satisfactory level that works with the formation’s specific properties, then hydraulic fractures are created which open up the rock formation and the fractures propagate along the perpendicular plane with regards the wellbore. The fracture propagation extends vertically and in each direction through the shale thickness to about 500 to 800 feet, while the operators observe the fracture pressure to avoid extensive vertical fracture growth outside the pay zone (Economides M. and Nolte K., 2000).

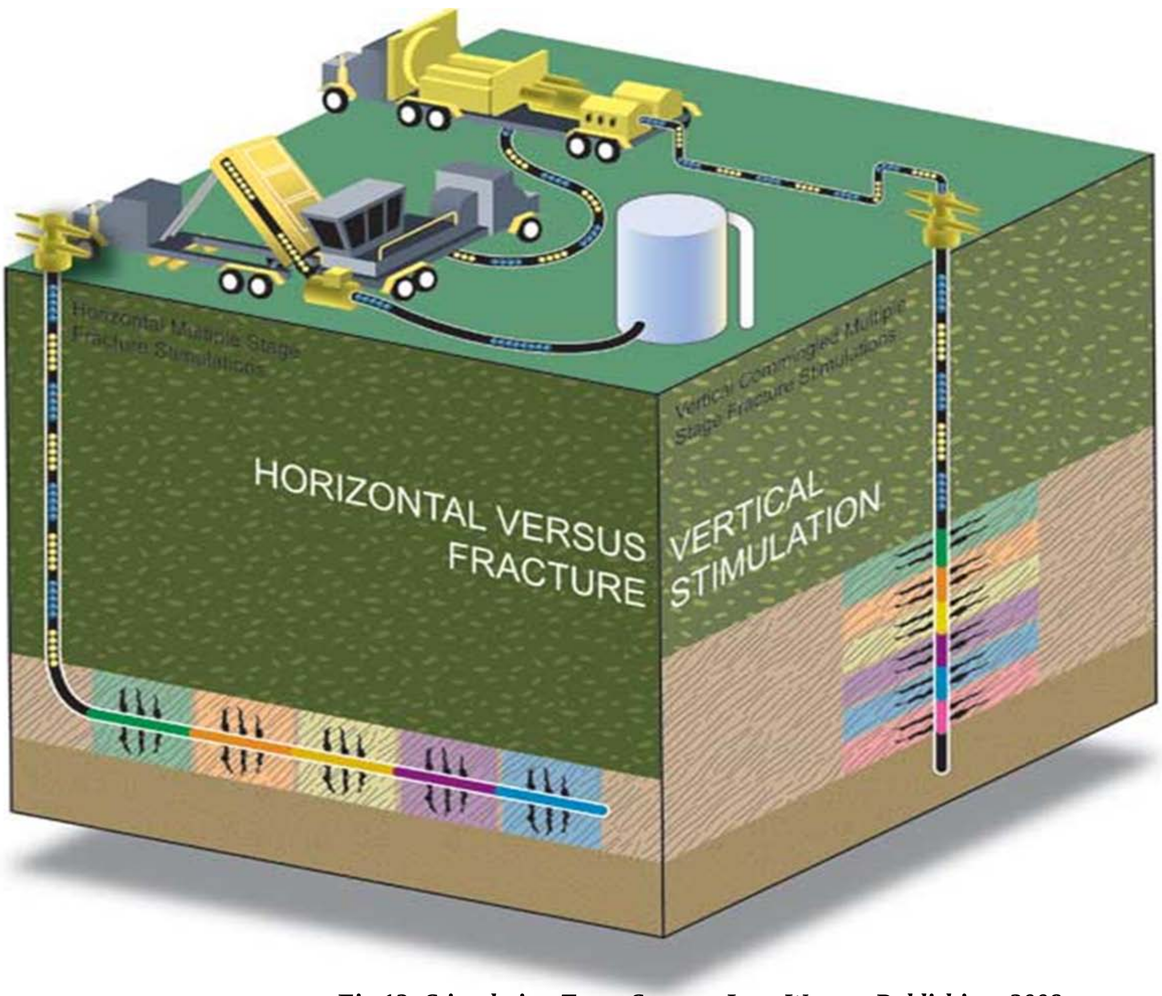


Fig 12: Stimulation Types Source: June Warren Publishing, 2008

The duration of completion of a single horizontal well may take just a few months but the well can actively produce for up to four decades. There are numerous impacts associated with the well activities from inception to abandonment, this include land encroachment, erosion, noise, dust, pollution, air and greenhouse gas emissions. There is an alarming situation of ground water contamination in most parts of North America due to the unsafe practices of operators and lack of adequate regulations. Hydraulic fracturing is a potential cause of air pollutions, groundwater poising, surface water and soil contamination, surface disturbance and earthquakes (Zoback et al, 2010).

Improper completion jobs such as failure to case and cement the wellbore surrounding creates risk and safety issues to water supplies. Natural gas, formation water and fracturing fluids with very high concentrations of total dissolved solids (TDS) may leak through improperly sealed annulus contaminating the aquifer containing drinkable water. The 2007 incident in Bainbridge, Ohio clearly shows the possibility of future occurrence, the incident occurred as a result of improper cementing of the well that was drilled into a tight sand formation at a depth of about 4,000 feet. Methane gas leaked into the aquifer and contaminated drinking water, but continued to leak further towards the surface until there was an explosion in the basement of one of the residents in the area (Ohio DNR, 2008).

3.2.1 HYDRAULIC FRACTURING FLUID

A large amount of water mixed with sands called proppants and other additives are pumped into a well at a pressure greater than the fracture pressure in the formation to crack open the formation and creating networks of fractures (NY DEC, 1992). Some of the additives used in a fracturing job are presented in Table 2 below, some of these additives are common substances that people use every day and they are very useful in gas shale well development.

Table 2: Fracturing fluid additives, main compounds and common uses

Additive Type	Main Compound	Common Use of Main Compound
Acid	Hydrochloric acid or muriatic acid	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Cold sterilant in health care industry
Breaker	Sodium Chloride	Food preservative
Corrosion inhibitor	N,n-dimethyl formamide	Used as a crystallization medium in Pharmaceutical Industry
Friction Reducer	Petroleum distillate	Cosmetics including hair, make-up, nail and skin products
Gel	Guar gum or hydroxyethyl cellulose	Thickener used in cosmetics, sauces and salad dressings.
Iron Control	2-hydroxy-1,2,3-propanetricaboxylic acid	Citric Acid it is used to remove lime deposits Lemon Juice ~7% Citric Acid
Oxygen scavenger	Ammonium bisulfite	Used in cosmetics
Proppant	Silica, quartz sand	Play Sand
Scale inhibitor	Ethylene glycol	Automotive antifreeze and de-icing agent

(Source: Hydraulic Fracturing Considerations for Natural Gas Wells of the Marcellus Shale, 2008)

Commercially, carbon dioxide is sometimes used in the supercritical state as the fracturing fluid because it has a number of advantages too. About sixty percent of carbon dioxide in the presence of emulsion and gel forms foam which is also used as fracturing fluids; other additives to these are surfactants for the aim of lowering the frictional pressure and surface tension in enabling the fluid move deeper through the fractures created. Solid carbon dioxide in form of ice called dry ice has been used for fracture creation into formations; this is possible due to the phase changing process from solid CO_2 to the gas phase of CO_2, this increases the volume immensely and leads to gas expansion and increase in pressure which propagates fractures into the rock. The compression and cooling of CO_2 forms a liquid, and soluble in water and hydrocarbon. The dissolution in water yields a weak acid called the carbonic acid which in turn dissolves minerals that are made up of carbonates; this leaves an area of weakness in the rock forming fractures.

Carbon dioxide is very useful and applicable as fracturing fluid because when used, it usually removes emulsion and water blocks, enhances the formation of larger fractures in carbonate formation by increasing the permeability, it hinders acids to react with the formation, guides against swelling of clay and also the formation of hydroxides of aluminum and iron.

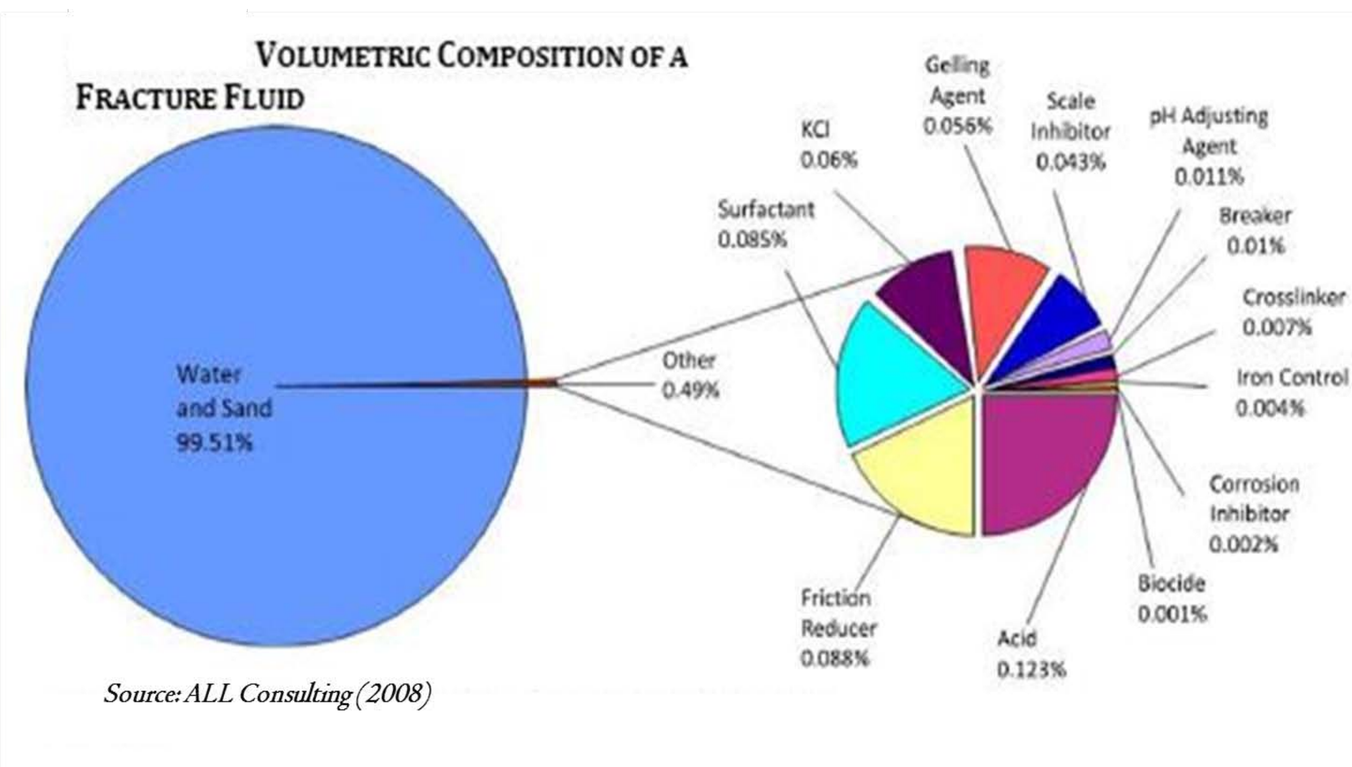


Fig 13: Volumetric Composition of a Fracture Fluid

3.2.2. WA TER AVAILABILITY, POLLUTION AND DISPOSAL

Water Availability

The quantity of water needed to drill or/and hydraulically fracture a horizontal gas well in the Marcellus Shale is huge. Water requirement is between 2-5 million gallons which mostly often times comes from surface water bodies such as lakes, rivers and streams. But it sometimes comes from different sources such as underground water, municipal and private water, and recycled produced water. Although the water needed for the development of a shale gas well in the Marcellus Shale may seem enormous, it represents a very minute percentage (about 0.1-0.8%) of the water resource available and in use in the Appalachian basin. It is also important to note that though this quantity is small compared to the overall water available in the area, the withdrawal of these water resources over a short period continuously would have a large effect on the local water shed in the area. During the design stage of any well in the Marcellus Shale, it is important to identify a suitable water supply that would satisfy all stages of the well development without affecting the water need of the community hosting the development.

The recharge of water through precipitation in the Appalachian basin is about 43 inches, indicating that it is recharged more than the average areas in the continental United States with 10 inches more each year (ANOA, 2005). Marcellus Shale area receives between 710 billion – 1.25 Trillion gallons of water each year making the area highly feasible for gas developmental activities (Arthur Daniel et al, 2008)

A major issue in this area is the prevention of contaminants entering into the drinkable water aquifer. Several arguments can be made about this, as some refer to the distance between the production zone which is relatively about 9000feet, and the aquifer is about 850ft, as a reason whereby pollution into the water regions is not possible. But during the initial stages of drilling into the formation, the aquifer is intersected and drilled through, there exist tendencies that drilling fluids and other contaminants could travel through into the water bearing aquifer and contaminating it. However there exist state regulations that require operators to ensure the proper use of casing and cement to protect the aquifer. Aside the contamination of underground water sources, the surface water is also at risk of uncontrolled drilling fluids, additives, fracturing fluids, flow back water and produced water. The design of a fracturing job would include taking the waste water and drilling fluid spill incidences into consideration and also the storage of these fluids.

The waste water is made up of mainly the flow back and produced water which is as a result of the well stimulation process and production respectively. These fluids are retrieved and stored in containment tanks which are then treated for re use in some cases. Other operators transport the waste water to nearby treatment facilities with tanks or through waste water pipe lines, after which it is discharged into the river. Other options of disposal include dumping the flowback and produced water into deep disposal wells, but there are strict regulations that do not favor this option (Arthur Daniel et al, 2008).

3.3 CHEMICALS AND ADDITIVES

Fracturing Fluids and Additives

The process of hydraulic fracturing as discussed about involves the pumping of hydraulic fracturing fluids at high pressure into the well with the aim of opening up fractures in the formation. The fracturing fluids used must be compatible with the formation of interest in terms of materials and fluids already present in the formation. The fracturing fluids are designed to have low frictional pressure and low fluid loss capabilities, which enables the formation to be cleaned up easily and readily. It must also be able to effectively transport and suspend the added proppants into the fracture networks and also, it must have low operational cost and stability.

The importance of a proper additive selection cannot be over emphasized as this will enable the pad to be very effective. Some of the additives added are listed in Table 3 below.

Additive type	Main Compound	Purpose
Diluted acid (15%)	Hydrochloric or Muriatic	Dissolve minerals and initiates cracks in rock
Biocide	Glutaraldehyde	Bacterial control
Corrosion inhibitor	N,n-dimethyl formamide	Prevents corrosion
Breaker	Ammonium persulfate	Delays breakdown of gel polymers
Crosslinker	Borate salts	Maintains fluid viscosity at high temperature
Friction reducers	Polyacrylamide	Minimize friction between the fluid and the pipe
	Mineral oil	
Gel	Guar gum or hydroxyethyl cellulose	Thickens water to suspend the sand

Additive type	Main Compound	Purpose
Iron control	Citric acid	Prevent precipitation of metal oxides
Oxygen scavenger	Ammonium bisulfite	Remove oxygen form fluid to reduce pipe corrosion
pH adjustment	Potassium or sodium carbonate	Maintains effectiveness of other compounds (e.g., crosslinker)
Proppant	Silica quartz sand	Keeps fractures open
Scale inhibitor	Ethylene glycol	Reduce deposition on pipe
Surfactant	Isopropanol	Increase viscosity of fluid

Table 3: Additives in Fracturing Fluids

There are different characteristics of fracturing fluids;

1. Slick water: If the majority of the fluid constituent is water then it is called slick water. This is very economical than acid, oil condensate and methanol in the case where a delayed cross linked gel is added. Other merits of this type of fluid include non-combustibility, good viscosity control, easily pumped into well, better suspension of proppants, good leak off, and minimal pressure requirement. While the demerit is that a large amount of water is needed for the fluid make up and this result to some difficulty during clean up.

2. Form-based fluid: This is very important as it reduces the amount of fluid and water used and also more of the fluids are recovered due to the essential energy in the gas. The cleanup process is easier after the stimulation job is over. However, one major disadvantage of using a form based fluid is that variations in the gas water mixing rate could destabilize the foam and the density of nitrogen foam is low, which means that it would require more pumping pressure and polymer stabilizers.

3. Energized fracturing fluid: The advantages of these types of fluids include the fact that flowback fluids can be recovered faster and the fluid loss behavior is very good. There is better fluid efficiency with the addition of inert gases in the fracturing fluids.

   This fluid type has low efficiency of proppant suspension, it requires high quality equipment and also the fracturing fluid base might be affected by the CO2 solution.

There is an estimated amount of about 2-8 million gallons of water used for a hydraulic fracturing job in the Marcellus Shale, out of which 10- 12 percent of the fracturing fluid serves as the pad and about 75 -85 percent of the fluid serve as sand slurry using a proppant concentration of 2.0 pounds per gallon, with a pumping rate of about 70 – 100 bpm.

Exposure to some of the chemicals used during this process can cause several kinds of discomfort and injury, for example it could lead to kill burns or irritation, kidney problems, heart and liver mal function and adverse harm to aquatic life.

3.4. WATER REMOVAL

Hydrates are easily condensed due to temperature and pressure variation in natural gas systems in presence of water. In preventing this hydrate formation, it is important to get rid of the existing water from the system. To achieve this, glycerol dehydration can be used in a process of extraction using di-ethylene glycol solution and also the adsorption dehydration can be employed with the use of silica gel.

CHAPTER FOUR: ASSOCIATED & POTENTIAL ENVIRONMENTAL IMPACTS

4.1 General

The objectives of this assessment are to identify and describe the potential environmental impacts associated with the developmental activities, predict the likelihood and magnitudes of such impacts, evaluate the significance of changes likely to result from them, and then proffer measures that will be taken to mitigate the predicted impacts.

4.2 Impact prediction methodology

The assessment of the potential environmental impacts was undertaken by means of the environmental, social and health assessment tool. The process included projects activities and environmental sensitivities interaction, impact identification, description and rating (a term that includes the prediction of magnitude, consequence and significance of impacts). The EIA process not only considers interactions between impacts of the various project activities and the sensitivities, but it also includes the interactions among the sensitivities. It is therefore an all-inclusive process.

4.3 Rating of impacts

There are six stages in the rating of an impact. The succession of events in impact rating is illustrated as follows:

STAGE 1:

Description: Five characteristics

- Positive/negative
- Direct/indirect
- Duration:
- Chronic (long period)/Acute (short period)
- Enormity: localized or extensive
- Reversible possibilities or irreversible

→

STAGE 2:

Qualification: Likelihood
Five ratings:

- High probability 80-100% (very likely)
- Medium high probability 60-80% (likely)
- Medium probability 40-60% (possible impact)
- Medium low probability 20-40% (unlikely)
- Low probability 0-20% (very unlikely)

→

STAGE 3:

Qualification: Potential Consequence:

Five rating definitions for environment, social, health and reputation. (see text)

- Extreme
- Great
- Considerable
- Little
- Hardly Any

→

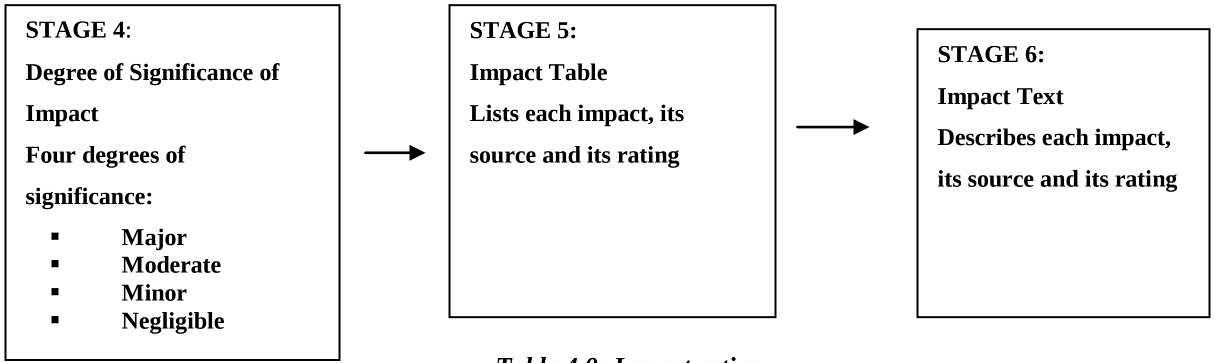


Table 4.0: Impact rating

The details of the procedures for the method are as follows:

Once an impact has been identified, it is described and a rating ascribed.

Stage 1: Description of impact

The following characteristics are used to describe each impact:

- Positive/negative (beneficial/adverse)
- Direct/indirect (directly/via intermediate factors that influences the determinants of an impact).
- Duration: Chronic (long period)/ acute (short period)
- Enormity: localized or extensive
- Reversibility possibilities/irreversibility: can the impact revert to previous condition or does it remain permanent?

Once each impact has been described, a rating is allocated.

Stages 2 and 3: Qualification of Impact.

This is based on two assessment characteristics:

Stage 2: Likelihood of occurrence – this is an appraisal of the likelihood of the effect occuring.

Stage 3: Potential consequence – this is the actual result and scale that an effect might have.

The application of each of the two characteristics is described in Tables 4.1 and 4.2.

Table 4.1: Likelihood of occurrence

Impact probability	Likelihood	Frequency
High probability (80-100%)	A very likely impact	Very frequent impacts
Medium high probability (60-79%)	A likely impact	Frequent impacts
Medium probability (40-59%)	A possible impact	Occasional impact
Medium low probability (20-39%)	An unlikely impact	Few impacts
Low probability (0-19%)	A very unlikely impact	Rare impacts

Table 4.2: Potential consequence

Potential Consequence	Effect
Extreme consequence	A massive effect
Great consequence	A big effect
Considerable consequence	A substantial effect
Little consequence	A slight effect
Hardly any consequence	A trivial effect

The potential consequence of an impact depends on two things: the magnitude of the potential changes to the environment, caused by a hazard, and the level of sensitivity of the receiving environment. This is depicted in Table 4.3

Table 4.3: Potential consequences classification matrix

	Magnitude of Effect		
Receptor sensitivity	**Low change**	**Intermediate change**	**High change**
Low receptor sensitivity	Insignificant effect	Minor effect	Substantial effect
Intermediate receptor sensitivity	Minor effect	Significant effect	Large effect
High receptor sensitivity	Substantial effect	Large effect	Enormous effect

Stage 4: Degree of significance Table 4.4 shows the impact significance with associated impact rating.

Table 4.4: Degree of Impact Significance

Impact Significance	**Impact Rating**
Major significance	Major impact
Moderate significance	Moderate impact
Minor significance	Minor impact
Negligible significance	Negligible impact

Stage 5: Impact Assessment Matrix

The potential impacts were evaluated using the Impact Assessment Matrix shown in Table 4.5

Table 4.5: Impact Assessment Matrix

	Potential consequences					
Likelihood	**Positive**	**Negative**				
		Hardly any	Little	Considerable	Great	Extreme
High		Moderate	Moderate	Major	Major	Major
Medium		Minor	Moderate	Moderate	Major	Major
Medium		Minor	Minor	Moderate	Moderate	Major
Medium		Negligible	Minor	Minor	Moderate	Moderate
Low		Negligible	Negligible	Minor	Minor	Moderate

After the rating for each impact, the determination of mitigation measures follows.

From the Table above, only moderate and major impacts were considered for impact mitigation. Continuous improvement practices will address low impacts. The positive impacts shall be monitored and enhanced when expedient.

4.4 Impact identification

The environmental sensitivities likely to be affected by the activities in the Marcellus Shale include the following: (the numbers represents the code for each sensitivity level)

1) Air quality	25) Access to communication facilities	49) Access to secondary health care
2) Light/Solar radiations	26) Access to learning and education facilities	50) Access to emergency services
3) Level of noise and sound	27) Access to recreational facilities	51) Access to voluntary health organizations
4) Surface water quality	28) Access to sanitation and waste management facilities	52) Respect for human rights
5) Groundwater table/quality	29) Balance in gender	53) Respect for labor rights
6) Soil and sediment quality	30) Balance in age	54) Promoting equal opportunities
7) Household water quality	31) Ethnic balance	55) Promoting opportunity for representation
8) Access to household water	32) Religious balance	56) Social exclusion abatement.
9) Quality of fish	33) Functioning of family structure and traditional institute	57) Poverty alleviation
10) Access to farmlands	34) Functioning of government services	58) Morals and family values
11) Availability of markets for agricultural products	35) Healthy and clean housing and living conditions	59) Exposure/ attack by bees, snakes, scorpions, wild life attack/ contact with poisonous plants
12) Quality of habitat	36) Ability to obtain fresh drinking water	60) Third party agitation (communities, NGO, CBO, etc.)
13) Biodiversity/Genetic resource	37) Exposure to nuisance (dust, noise etc.)	61) Access to electricity
14) Farmland complex	38) Level of disease vectors	
15) Sense of place/wellbeing /aesthetic value	39) Exposure to STIs/HIV/AIDS	
16) Access to ancestral and culturally significant sites	40) Exposure to marine and road traffic accidents	
17) Conventional occupations	41) Mortality rate	
18) Level of income and financial flows	42) Morbidity rate	
19) Cost of living and inflation	43) Lifestyle	
20) Opportunities for contracting and procurement	44) Alcohol and drugs abuse/violence	
21) Opportunities for local and national employment	45) Physical activity	
22) Access to housing	46) Hygiene	
23) Access to transport	47) Exposure to commercial sex workers	
24) Access to roads and waterways	48) Access to primary health care	

Table 4.6 Environmental Sensitivities Identification

A diligent application of the criteria in the assessment system for the identification and management of impacts associated with the different phases (site preparation/ construction, operations and decommissioning) involves:

a. The production of project activities and environmental sensitivities matrix.
b. Determination of associated and potential impacts.
c. Mitigation measures
d. Management plans.

4.4.1 Project activities and sensitivities interaction matrix

The evaluation of the interactions between the activities and the above listed environmental sensitivities on the one hand and the interactions between the sensitivities on the other hand made in a table for the construction, operations and decommissioning phases of the project respectively have been considered**.**

4.4.2 Determination of environmental impacts

The impacts in the Marcellus Shale activities on the biophysical, social and health components of the environment were identified and appropriate mitigating measures proffered.

4.4.3 List of identified impacts

The negative (moderate and major) and positive impacts identified for the different phases of the activities were listed as follows:

Construction phase

- Reduction of access to natural environment and its resources.
- Loss of revenue from traditional occupations
- Increased demand for water for domestic use, construction and, other water related activities.
- Enhanced opportunities for employment, contracting, services and income.
- Increased demand for food
- Pressure on exiting roads and their users with the possibility of increased accidents
- Emission of noxious substances to the atmosphere/noise.
- Increased social vices, drug abuse, commercial sex workers (CSW), teenage pregnancies, etc.

- Imbalance in the gender and age group in the immediate vicinity of project area
- Increased level of disease vectors.
- Destruction of vegetation (medicinal, economic and food).
- Loss of habitat for fauna, microorganisms etc.
- Exposure of field workers/community members to attack by poisonous snakes, bees, spiders, scorpions.
- Shift from traditional occupations (farming, hunting).
- Nuisances (noise, emission, vibrations) from heavy machinery.
- Change in the topography through sandfilling and leveling
- Impairment of air quality leading to increased respiratory tract diseases.
- Contamination of surface/ground water quality.
- Impairment of health of aquatic life
- Rise in water borne diseases thereby putting pressure on existing health care facilities.
- Poor sanitary conditions and hygiene
- Hearing impairment from noise generation.
- Improved access to electricity.
- Enhancement of development (industrialization) and income generating activities (services)
- Increased third party agitation.
- Consequence on corporate reputation.
- Inhibition of reproductive phase of plants.
- Loss of assets and properties.

Operation phase

- Increased opportunities for employment/contracting, services and income.
- Improved aesthetics.
- Improved corporate reputation.
- Exposure of workers to attack by poisonous snakes and scorpions.
- Increased social vices, (drug abuse, CSW and teenage pregnancies).
- Increased third party agitation.
- Impairment of air quality from emissions leading to respiratory tract diseases.
- Contamination of surface and groundwater.

- Impairment of health of aquatic life.
- Shift from traditional occupation farming.
- Alleviation of poverty
- Increased level of disease vectors (mosquitoes, rats, cockroaches, flies etc.).
- Increased potential for road accidents.
- Hearing impairment from noise.
- Imbalance in gender and age groups
- Degradation of terrestrials habitat leading to reduction in biodiversity
- Poor sanitary conditions and hygiene
- Nuisance from obnoxious odor
- Attraction of insects
- Exposure to burns and injuries
- Loss of assets and properties.
- Effect on corporate reputation.

Decommissioning

- Improved corporate image and promote third party participation.
- Increased third party agitation.
- Pressure on existing roads
- Increased opportunity for employment, contracting, income and service provision.
- Shift in traditional occupation
- Increased levels of nuisance (sound, dust, vibration, emissions etc.).
- Possibility of road traffic accidents/injuries.
- Exposure to noise
- Increased worksite accidents/ injuries
- Nuisance from obnoxious odor
- Exposure to burns and injuries
- Contamination of surface and groundwater, soil and vegetation from handling of hazardous substances and materials.
- Increased level of disease vectors.
- Impairment of air quality.

4.5 Description of Impacts

The impacts outlined above for the three phases (construction, operations and decommissioning) of the Marcellus Shale activities are discussed as follows.

4.5.1 Construction Phase

4.5.1.1 Land take/surveys

Lands area acquired permanently for the following purposes: Drilling/well head activities, offices, telecom facilities, roads outside current lease areas, contractor camp and facilities, lay down/contractor area (offices and workshops), site for excavated top soil and upgrade of existing roads. All activities are restricted to the presently acquired land. The impact was described as direct, negative, long term, local and reversible with a rating of moderate.

4.5.1.2 Water Supply

Water shall be required during the construction phase for human consumption (drinking, laundry, cooking, washing etc) and construction activities. These could be sourced from nearby streams or supplied in water tankers by contractors, the required volume for domestic purposes. High volumes of up to 10-12 million gallons may be required for the construction activities.

The impacts of water supply include;

- Increased demand for water for domestic use and other water related activities

  Increased demand for water for domestic use and other water related activities could lead to pressure on available water. The pressure could lead to scarcity of water. Water scarcity with poor hygiene could lead to water related diseases like diarrhea, cholera etc. This impact was described as direct, negative, short term, local and reversible, with a rating of moderate.

- **Opportunities for contracting**

  The use of indigenous contractors for water supply will enhance the income of the service providers and labor force. This will provide opportunities for small and medium enterprises to supply water/containers. The impact was described direct, negative, short term, local and reversible with a rating of positive.

Pressure on existing roads and their users with the possibility of increased traffic accidents

Increase in roads traffic as a result of transportation of construction equipment and materials could result in pressure on existing roads. The use of heavy-duty vehicles on the busy high ways leading to the site could obstruct and inconvenience other road users and predispose to accidents with the resultant injuries. This impact was direct, negative, short-term, local and reversible. It was rated as moderate.

4.5.1.3 Energy requirement

Construction activities could require the provision of electrical energy. The impact associated with this activity is:

- **Emission of noxious substances to the atmosphere**

Energy would be required during construction and drilling of wells. The generation of the required energy could produce noxious emissions (CO_x, NO_x, SO_x, NH_3, HC) and suspended particulate matter, which could impair air quality and subsequently affect the health of animals (including humans) and plants. The impaired air quality could exacerbate existing respiratory diseases like asthma, bronchitis etc and could lead to new cases. The impact was direct, negative, short-term, local and reversible. It was rated as moderate.

4.5.1.4 Labor requirement

During the construction phase, about 60 labors will be required. The associated impacts are;

- **Increased employment, services and income**

The labor required for construction/drilling activities would be provided through local, national and international employment leading to skill acquisition and poverty alleviation. The impact was direct, short-term, widespread and reversible. The impact was rated as positive.

- **Increased social vices**

The presence of the labor force could lead to an increase in social vices such as attraction of commercial sex workers (CSW), alcohol and drug abuse, increase in crime rate, violence and smoking. The increase in CSWs and workforce without their spouses could lead to increase in sexually transmissible infections (STIs), including HIV/AIDS, and teenage pregnancies. The impact was described as direct, negative, short-term/long-term, local/widespread and reversible/irreversible. It was rated as major.

4.5.1.5 Site Preparation (vegetation clearing)

A major activity in site preparation is vegetation clearing. An area within the acquired land will be cleared. The impacts associated with vegetation clearing are:

- **Loss of habitat for fauna, microorganisms**

Site clearing could result in the destruction of the habitat for wildlife and often microorganisms. The types of wildlife in the project area include giant rats, squirrels, duikers, grass **tc.**

The job opportunities created by construction activities could encourage some social vices such as drunkenness, violence, and drug abuse. It also attracts commercial sex workers (CSW) and teenage girls to the area. The influx of these categories of people to the area has the potential to increase the spread of sexually transmissible infections (STI) including HIV/AIDS, and increased teenage pregnancies. The impact was direct, negative, short term/long term, local/widespread and reversible/irreversible. It was rated as major.

- **Increased nuisance from dust, emissions, noise, vibrations etc**

The use of heavy equipment for construction activities could generate nuisance in the form of dust, noise, emission, and vibrations. The noise from these activities might impair hearing. The emissions (SPM, CO_x, SO_x, NO_x) from construction equipment could impair air quality. The noise level would be highest in areas where heavy machinery is being operated, but it would fade off with increasing distance from the construction/drilling site. The workforce, nearby communities and wildlife could be exposed to nuisance. However, the soils are moist for most part of the year; hence dust generation would be minimal. The impact was assessed as direct, negative, short term, local and reversible. It was rated as minor.

4.5.1.6 Waste generation (emissions)

The sources of the emission will include construction dusts and emissions and construction/drilling equipment emissions. The possible impacts are;

- **Impairment of air quality leading to Increased respiratory tract diseases**

The construction/drilling activities could lead to emissions of noxious substances such as SPM, CO_x, SO_x, NO_x, HCs, leading to impairment of air quality. This could affect the health of people particularly the asthmatics and other respiratory tract diseases. The impact was assessed as direct, negative, short/long term, local and reversible/irreversible. It was rated as moderate.

4.5.1.7 Waste generation/discharges (effluents)

The sources of the effluents include effluents from construction and drilling activities spent chemicals, sewage, and domestic effluents from camps. The impacts associated with these are:

- **Contamination of surface/ ground water quality**

Effluents from these sources could contaminate surface and groundwater thereby altering their quality. The impact was described as direct, negative, short term, local/ widespread, and reversible/irreversible. It was rated as major.

- **Impairment of health of aquatic life**

The effluents if discharged into surface waters or soil could contaminate the receiving environments, and consequently impair the health of aquatic life. Bioaccumulation and biomagnification of the contaminants may occur along the food chain and ultimately could affect human health. The impact was direct, negative, short/long term, local and reversible/irreversible impact. It was rated as moderate.

- **Decline in income generation from traditional occupations (farming etc.)**

Effluent discharges, if they contain toxic substances, could render water bodies and farmlands unsuitable for farming. This could result in decline in income from these occupations. The impact was described as direct, negative, short term, local and reversible. It was rated as minor.

- **Rise in water borne diseases thereby putting pressure on existing health care facilities**

Contamination of nearby water bodies including aquatic foods could result in increase in water borne diseases especially diarrhea. If this involves several people it could put pressure on the fragile health facilities in the area. The impact is described as direct, negative and short term. It is rated moderate.

4.5.1.8 Waste Generation- Solids

The solid wastes that could be produced are spent woods, excavated top soil, waste pipes, domestic wastes, plastics, paper, metal containers, drill cutting, drilling waste.

The impacts associated with solid waste generation are:

- **Increased income from opportunities for employment and contracting**

The solid wastes generated from construction activities and drilling would require be managing and disposed. This could involve contracting and hiring of labor. It could thus enhance income levels. The impact was described as direct, short term, local/ widespread and reversible. It was rated as positive.

- **Poor sanitary conditions and hygiene**

Improper handling and disposal of the waste could lead to poor sanitary conditions and hygiene of the project environment. The impact was direct, negative, short term, local and reversible. It was rated as minor.

- **Third party agitation**

This could arise from improper storage and disposal of drilling waste, solid waste disposal as well as perceived inequitable contracting opportunities for community members. The impact was described as direct, negative, short term, widespread and reversible. This impact was rated as major.

- **Contamination of surface and ground water**

Leachates from solid wastes could contaminate surface/ groundwater and render them unsuitable for human use. The impact was described as direct, negative, short/long term, local/ widespread, and reversible/irreversible. It was rated as moderate.

- **Impairment of health of aquatic life**

Contamination of water bodies by solid waste could adversely affect the health of aquatic organisms like fishes, crab etc. If the affected organisms are consumed, human health could be impaired. The impact was described as direct, negative, short/long term, local, and reversible/irreversible. It was rated as moderate.

- **Increased level of disease vectors (mosquitoes, rodents, cockroaches, flies etc)**

The solid waste generated if not disposed of in a sanitary manner may constitute suitable habitats for some disease vectors such as rodents, cockroaches, and houseflies etc, which are abundant in the project area. The diseases they transmit could cause increased morbidity and/or mortality on the local community. This impact is direct, negative, short term, local and reversible. The impact was rated moderate.

- **Rise in water borne diseases thereby putting pressure on existing health care facilities**

The contamination of the water bodies could give rise to an increase in water borne diseases like diarrhea. This could put pressure on the fragile health systems in the area. The impact was described as direct, negative, short term, local and reversible. It was rated moderate.

4.5.1.9 Power Generation

Power required during the construction/drilling phase could be generated using electrical generators. The impacts identified for the generation of power are:

- **Hearing impairment from noise generation**

High level of continuous noise would be produced during power generation for construction activities. The workforce at the locations and nearby communities could be exposed to noise impact resulting in hearing impairment. The impact was described as direct, negative, short/long term, local and reversible/irreversible, and was rated as moderate.

cutter and various avian populations. Destruction of their habitat could disperse wildlife into surrounding areas, thereby exposing them to the danger of attack and/or capture. This could further threaten the mammalian population.

Clearing of the vegetation removes the vegetation canopy over the soil leading to evaporation by solar radiation, with subsequent dryness of soil, which is unfavorable for microorganisms. The impact was direct, negative, long term, local, and irreversible. The overall rating was major.

- **Traditional occupations like farming could be affected**

The land to be cleared could have been used for traditional purposes such as farming. Once the land is cleared, it would no longer be available for its traditional purpose. The resultant effect could be a shift from traditional occupations to construction labor temporary. The impact was described as direct, negative, long-term, local and reversible. It was rated as moderate.

- **Nuisance (noise, emission, vibration) from heavy machinery**

The use of heavy equipment for site clearing and leveling could generate nuisance in the form of noise, emission and vibration, which might impair air quality, hearing and health. Nuisance of this nature could lead to third party agitation and impinge on company reputation. This impact was described as direct, negative, short-term, local and reversible and rated as moderate.

4.5.1.10 Site preparation (sand filling, piling concreting cellar preparation etc)

Other activities in site preparation include pilling, sand winning /sand filling, grading and concreting to provide space for installation of land rig. Sand will be borrowed from an acquired site and transported to the project site. The potential impacts of these are;

• Increased social vices, drug abuse, CSW, teenage pregnancies eImproved access to electricity

If electricity generated during the construction phase is supplied to host communities, this could improve their quality of life and lead to development of small-scale industries and income generating activities. The impact was direct, short term, local and reversible and was rated as positive.

4.5.1.11 Generation of nuisance – noise and vibrations

The construction activities/drilling could generate noise and vibrations. The impacts associated with noise and vibrations are:

- **Impairment of hearing**

The workforce at the locations and nearby communities could be exposed to noise and vibration resulting in possible hearing impairment. The impact was described as direct, negative, short/long term, local and reversible/irreversible, and was rated as moderate.

4.5.1.12 Generation of nuisance – continuous light

The continuous light required for construction could become a nuisance. The impacts associated with continuous light are:

- **Inhibition of reproductive phase of plants**

Uninterrupted illumination of the construction environment could disturb the photoperiodic rhythm of flowering plants, thereby inhibiting the reproductive phase and encouraging the vegetative growth phase. The effect of this is that flowering/fruiting could be reduced or totally eliminated in such affected plants. The impact is direct, negative, long-term, local and reversible. It was rated as moderate.

4.5.1.13 Incidents

Some unintended releases of fuel, chemicals, sewage/drilling wastes could occur during construction activities. Also incidents such as spills (oil and chemicals) fire and vehicular accidents could occur. These incidents could have the following impacts:

- **Impairment of health of aquatic and terrestrial life**

Unintended release of domestic effluents, chemicals, fuel etc could contaminate the receiving environments and consequently impair the health of the terrestrial and aquatic organisms. The impact was described as direct, negative, long term, local/ widespread, and reversible/ irreversible. The impact was rated as minor.

- **Increased opportunity for employment and contracting**

Management of the incidents could involve contracting and hiring of labor. The use of indigenous contractors and personnel could provide employment and contracting opportunities. The impact was rated as direct, short term, local/ widespread and reversible. It was rated positive.

- **Decrease in income generation from reduced traditional occupations**

Incidents like fire, spills etc could affect farmlands, and water bodies and consequently reduce output (produce and income). The impact was described as direct, negative, short term, local and reversible and was rated as moderate.

- **Loss of assets and properties/Third party agitation/Effect on corporate reputation**

Incidents such as fire chemical spills etc during construction activities could result in considerable damage leading to loss of assets and properties. This could cause third party agitation and affect corporate reputation. The impact was described as direct, negative, short/ long term, local/widespread, and reversible/irreversible. It was rated as major.

- **Shock and poisoning from wildlife attack**

The workforce could be exposed to attack by bees resulting in shock and in extreme cases death. Snakes could also affect the workforce resulting in death.

- **Pressure on existing health care and emergency response facilities**

Incidents like fire, spills, vehicle accidents etc if it’s massive could affect several people thereby putting pressure on any existing health care and emergency response facilities including medical, fire service etc.

4.5.1.14 Decommissioning of construction facilities/drilling rig

Decommissioning activities at the end of construction will include dismantling of contractor camps and facilities (offices and workshops), removal of left over materials, removed of rig from site cleaning etc. The impacts of these activities include:

- **Third party agitation arising from labor and human right issues (loss of employment)**

Decommissioning of construction activities could cause loss of employment by a large fraction of the construction workforce. This could have a spiral effect on their families, local and national communities. The economy of the communities could become depressed due to unemployment. Labor and human rights issues could arise, leading to third party agitation. The impact was described as direct, negative, short term, local/ widespread and reversible. It was rated as major.

- **Increase in employment and contracting opportunities**

Decommissioning activities could provide contracting and employment opportunities. The use of indigenous contractors and workforce for the various jobs could enhance the income of these service providers and labor force. The impact was described as direct, short term, local/ widespread and reversible. It was rated as positive.

- **Increased accidents and injuries/pressure on healthcare facilities**

Accidents resulting in injuries/fatalities could occur during decommissioning activities. They could exert pressure on emergency services, and healthcare facilities. The impact was described as direct, negative, short/long term, local, reversible/irreversible (if fatal). It was rated as moderate.

- **Pressure on existing road network**

This demobilization could involve the movement of the drilling rig and a of lots of items from project site using heavy vehicles. These movements could exert pressure on existing road network. The impact was described as direct, negative, short term, local and reversible. It was rated as moderate.

4.5.2 Operational Phase

4.5.2.1 Maintenance of acquired land facilities flowlines and flowstation etc

The land taken prior to construction activities has to be maintained during the operational phase. The maintenance of the acquired land, flowlines and other facilities put in place however some impacts have on the environment:

- **Increased opportunities for employment/contract**

Maintenance of the acquired land and flowlines ROW could require the services of contractors and labor force. The use of indigenous contractors and labor force for the maintenance jobs could provide additional opportunities for contracting and employment. The impact was described as direct, long term, local and reversible. It was rated positive.

4.5.2.2 Exposure of workers to attack by poisonous snakes and scorpions

The maintenance of the acquired land, well heads would be manually carried out. This exercise could expose the workforce to the danger of attack by poisonous snakes and scorpions. The attack could result in increase in injuries, bleeding, shock and death. These would necessitate need for emergency health services. The impact was described as direct, negative, long-term, local, reversible/irreversible. It was rated as minor.

- **Third party agitations**

Maintenance of facilities in the field, flowlines, pipeline could generate third party agitation if contracting issues are not well handled with community. The impact is direct, negative, long term, local and reversible. It was rated major.

- **Improved aesthetics**

Maintenance of facilities in the field will improve the aesthetics of the surroundings and increase sense of place. The impact is direct, long term, local and reversible. It is positive.

- **Shift in traditional occupations**

The principal traditional occupation in the area is farming. Existence of opportunities for quick money in supplies could lead to shift away from this traditional occupation. During the operational phase only few persons would be required to maintain the facilities. The impact was direct, negative, long term, local and reversible. It's rated minor.

4.5.2.3 Energy requirements

Generating plants will be used for power generation during this phase. The potential impacts are:

- **Impairment of air quality from emissions leading to respiratory tract diseases**

Generating plants will emit Sox, Nox, Co, Co2 etc. These could impair air quality leading to respiratory diseases and worsen existing ones like asthma, chronic bronchitis etc. The impact is direct, negative, long term, local and reversible. Its rated minor.

- **Hearing impairment from noise.**

The continuous noise from the generating plant could impair hearing either partially or permanently. The impact was direct, negative, long term, local and reversible/ irreversible. It was rated moderate.

4.5.2.4 Labor requirement

Unskilled and semi-skilled staff will be recruited from the communities. The impacts associated with labor requirement are:

- **Increased employment, services and income**

The recruitment of labor from the host and neighboring communities could reduce the number of unemployed youths and enhance the income profile of the employed labor force. The income of service providers could also be enhanced through boosting of petty trading to provide food and other items for the workforce. The impact was direct, long term, local, reversible and rated positive.

- **Increased social vices**

The job opportunities created by operational activities could encourage some social vices such as drunkenness, violence and drug abuse. It also attracts CSW and teenage girls to the area. The influx of these categories of people to the area has the potential to increase the spread of sexually transmissible infections (STI) including HIV/AIDS, and increase teenage pregnancies. The impact was direct, negative, short term/long term, local/widespread and reversible/irreversible. It was rated as moderate.

- **Community agitation**

Impacts from operational activities could attract third party agitation arising from perceived inequitable employment opportunities of community members. This could stir up intra family and inter community disputes and also agitation by Community Based Organisations (CBOs) and NGOs. The impact was direct, negative, long term, local and reversible. This impact was rated as major.

4.5.2.5 Waste generation (emissions)

Emissions of noxious substances (CO_x, NO_x, SO_x, NH_3, HC) could occur during operations and maintenance of operational facilities. The sources of these emissions are transport dusts and exhaust, generating plants etc. There shall be no gas flare during the operational phase

4.5.2.6 Incidents

The types of incident that could occur in the operational phase include: fire from explosion, spills (oil/gas/chemicals) and fire/water system discharges during fire/explosions. These incidents could have the following impacts:

- **Contamination of surface- and ground-water**

Releases from operational incidence could contaminate surface- and ground-water, and render them unsuitable for intended uses. The impact was described as direct, negative, long term, local/widespread and reversible/irreversible. It was rated as moderate.

- **Impairment of health of aquatic life**

Unintended releases from incidents could contaminate the receiving environments and consequently impair the health of the terrestrial and aquatic organisms. Impairment of health was described as direct, negative, long term, local and reversible/irreversible impact. The impact was rated as minor.

- **Increased opportunity for employment and contracting**

Spills/releases and repairs from incidents would require management, which could involve contracting and hiring of labor. The use of indigenous contractors and personnel could provide employment and contracting opportunities. The impact was described as direct, short term, local and reversible. It was rated positive

- **Exposure to burns and injuries**

Incidents such as fire outbreak, spills, explosion and vehicular accidents could result in injuries, burns and fatalities. These could exert pressure on available medical emergency services. The impact was described as direct, negative, long term, local, reversible/irreversible. It was rated as moderate.

4.5.3 Decommissioning

The expected life span of the project could be around 20 - 25 years after which decommissioning would take place. It will involve the dismantling and removal of the structures and site restoration. The associated activities are:

4.5.3.1 Consultations

This shall be with Government, Communities, Regulators and other stakeholders. The impacts of consultation are:

- **Improves corporate image and promotes third party participation**

Consultations with various strata in the communities, gender, religious bodies, ethnic groups, labor groups, human rights groups, NGOs, regulators, governments, CBOs would enlighten the various stakeholders about the decommissioning process. This could improve the corporate image of the company and promote third party participation in the process. This impact is direct, short term, local/ widespread and reversible. It is positive

- **Increased third party agitation**

Decommissioning could involve disengagement of staff recruited from the community. Labor issues could arise. Local economy could become depressed and dissatisfaction could arise. Third party agitation could set in. The impact was described as direct, negative, short term, local/widespread, and reversible. It was rated major.

4.5.3.2 Incidents

- **Contamination of surface- and ground-water**

Releases from incidents could contaminate surface- and ground-water, and render them unsuitable for intended uses. The impact was described as direct, negative, long term, local/widespread and reversible/irreversible. It was rated as moderate.

- **Impairment of health of aquatic life**

Unintended releases from incidents could contaminate the receiving environments and consequently impair the health of the terrestrial and aquatic organisms. Impairment of health was described as direct, negative, long term, local and reversible/irreversible impact. The impact was rated as minor.

- **Increased opportunity for employment and contracting**

Spills/releases and repairs from incidents would require management, which could involve contracting and hiring of labor. The use of indigenous contractors and personnel could provide employment and contracting opportunities. The impact was described as direct, short term, local and reversible. It was rated positive

- **Exposure to burns and injuries**

Incidents such as fire outbreak, spills, explosion and vehicular accidents could result in injuries, burns and fatalities. These could exert pressure on available medical emergency services. The impact was described as direct, negative, long term, local, reversible/irreversible. It was rated as moderate.

- **Third party agitation**

Incidents such as fire, explosions, spills etc during operational activities have unpleasant consequences, which are unacceptable to local, national and international communities. These could result in considerable damage leading to loss of assets and properties. This could arouse third party agitation and affect corporate reputation. The impact was described as direct, negative, long term, local and reversible. It was rated as major.

4.5.3.3 Site Remediation

Site remediation after the decommissioning exercise shall lead to:

- Improved aesthetics
- Improved corporate image
- Increased opportunity for employment and contracting

The impact is described as direct and long term. It is rated positive

4.6 Impact of Drilling

The idea most people have about natural gas drilling in the Marcellus Shale is that the rig used for the drilling activity is permanent, or long-term, equipment on the site. The rig is one of the first and most conspicuous equipment for the development on site. For this development, the flex drilling rig unit was used to drill horizontal wells. This was about the best choice and was selected over other units so as to meet the environmental polices regulated by the state. The flex rig was selected due to its low noise hence providing a reduction in the noise level usually caused by the regular rigs. According to Chesapeake 2009 publication on drilling the Marcellus shale “In urban settings, a sound engineer measures current background noise at the drilling site and evaluates the topography and proximity of neighbors to determine what sound reduction measures are necessary”. Other environmental factors considered where; it’s low emission capacity so as to meet the Clean Air Act, then its speed and accuracy (which reduces the occurrence and release of NORMS) and its safety. As earlier discussed, Drill sites are selected based on a number of factors, these include the availability of land suitable to drill on; state drilling permits; nearness to buildings, parks and other infrastructure proximity to natural gas pipelines or the feasibility of installing new pipelines; ; geologic considerations; as well as a company's lease position in the area. One major environmental consideration made by the team for this natural gas drilling development was the surface disturbance required for access roads and well pads and then the conclusion was to go with horizontal drilling. As described further in the literature, horizontal drilling brings a significantly reduction to surface disturbance and other potential environmental effects.

4.7 Impact of Drilling Fluids

The environmental impact of the drilling fluid used for the shale development practices is a very important aspect of the process. So many factors are considered before use of drilling fluids. For the development, as a result of space availability, the drilling team decided to use steel storage tanks and pits so as to secure the fluids from environmental hazards. As discussed in the previous section, drilling is a regulated practice managed at the state level, and while state gas agencies have the ability to require operators to vary standard practices, the agencies typically do so only when it is essential to safeguard the gas resources and the environment. Also these pits may also serve as a storage facility for additional make-up water for drilling fluids or to store water used in the hydraulic fracturing of wells. The water impoundments were used also to contain water for hydraulic fracturing needs and are usually lined to minimalize the loss of water due to infiltration. The use of pits as water storage facilities are becoming an important tool in the shale gas industry because the drilling and hydraulic fracturing of these wells often requires significant volumes of water as the base fluid for both purposes. The Synthetic based Mud-fluid (SBM) was used since it was available effective and met the environmental standards required by the state. The SBMs was preferred over water-based fluids in our process for both their ability to drill a gauge hole, thereby minimizing drilling problems and little or no environmental impact.

4.8 Economic Losses

There are several economic consequences to environmental problems that are generated as a result of gas shale development. But there are three major areas to concentrate on when analyzing these economic importance, they are,

1. Claims from personnel injury or accident
2. Cost of drilling fluid
3. Cost of environmental remediation

Cost of Injury and Accidents

It is important to examine the contributing factors to this incidence or accidents before any monetary value is attributed to this and analyze or evaluate the associated expense of the claims.

Below are some of the contributing factors to personnel injury and accidents:

- Unchecked drilling fluid release on the drill floor, leading to slippery surfaces
- Unchecked drilling fluid spills and drops on the drill floor, causing hypothermia
- The risk of airborne chemicals inhalation from drilling fluids and additives during stimulation jobs, which in some cases are carcinogenic

Associated direct costs include:

- Shun –in due to stop work orders resulting to production lost
- Compensation assessments of personnel
- The replacement and repairs of affected equipment
- Legal fees, compensations and fines
- Insurance premiums hikes

Indirect costs will include:

- Lesser productivity and greater staff turnover because of low morale
- Lost of customer and public trust due to smeared reputation
- Employment and training phase for replacement employees
- Recovery salaries and also salaries for replacement employees

4.8.1 Drilling Fluid Cost

The costs of acquiring the drilling fluids for fracturing jobs are perhaps considerable. The costs that are significant include the cost of getting enough water for the operation, cost of additives and muds, cost of mixing etc. During and after a drilling job has been completed, it is quite economical to recover a lot of the drilling fluids, after which they are reused for further drilling jobs at nearby wells. There is a variable cost associated to drilling fluids, since the cost of the three major types of drilling fluids are different. During the initial stages of the drilling job, the water based mud (WBM) is commonly used which is interchanged with oil-based mud at lower well depth, for the bore hole stability and lubrication capabilities, until it gets to the limit of the WBM. It is more expensive to use the synthetic based mud although it is more environmentally friendly and performs about the same as the oil based mud.

4.8.2 Environmental Reclamation Costs

The extents of damages to the environment by drilling fluids are dependent on the prevalent conditions of the environment it is used and most importantly the kind of fluid used. This will also determine the cost of recovery or remediation to the existing environment. It has been noted that drillers working offshore have a preference to use the water based fluids over the more effective and better performing oil based or synthetic based fluids because the oil based fluids have inimical effects of aquatic organisms, plants and animals. While onshore, environmental problems are widespread with discharges of drilling fluids during operations (water based drilling fluids), due to the high saline content, and the chemistry of additives which were used to enhance the viscosity and density of the mud. The presence of these are perhaps more detrimental compared to the challenge caused by the hydrocarbon content of interest. A large amount of money is usually spent each time a land is intended to be reclaimed back to its initial state, which also includes several other liabilities that are related to waste generation in the industry.

4.9 Solution

In an attempt to avoid spending money on reclamation, liability and compensation, an innovation that both takes care of the environmental land in which the drilling takes place and the water resources in the locality was developed. This new environmental protection strategy works to reduce uncontrolled releases of drilling fluids, preserve the health and safety of workers and locals and also increase the rig operations safety. This is called a Zero Spill Technology, (Figure 12). This safeguards the accidental spill of drilling fluids on the rig floor or into the water ways during a well drilling operation and also contains most of the drilling fluid in such a way that it can reduce the drilling fluid loss to spills, recover a larger quantity of the fluid, recycle the drilling fluid for reuse. This is a positive develop in the upstream industry as companies can incur cost saving measures while efficiently producing and conserving the environment in which they operate adequately.

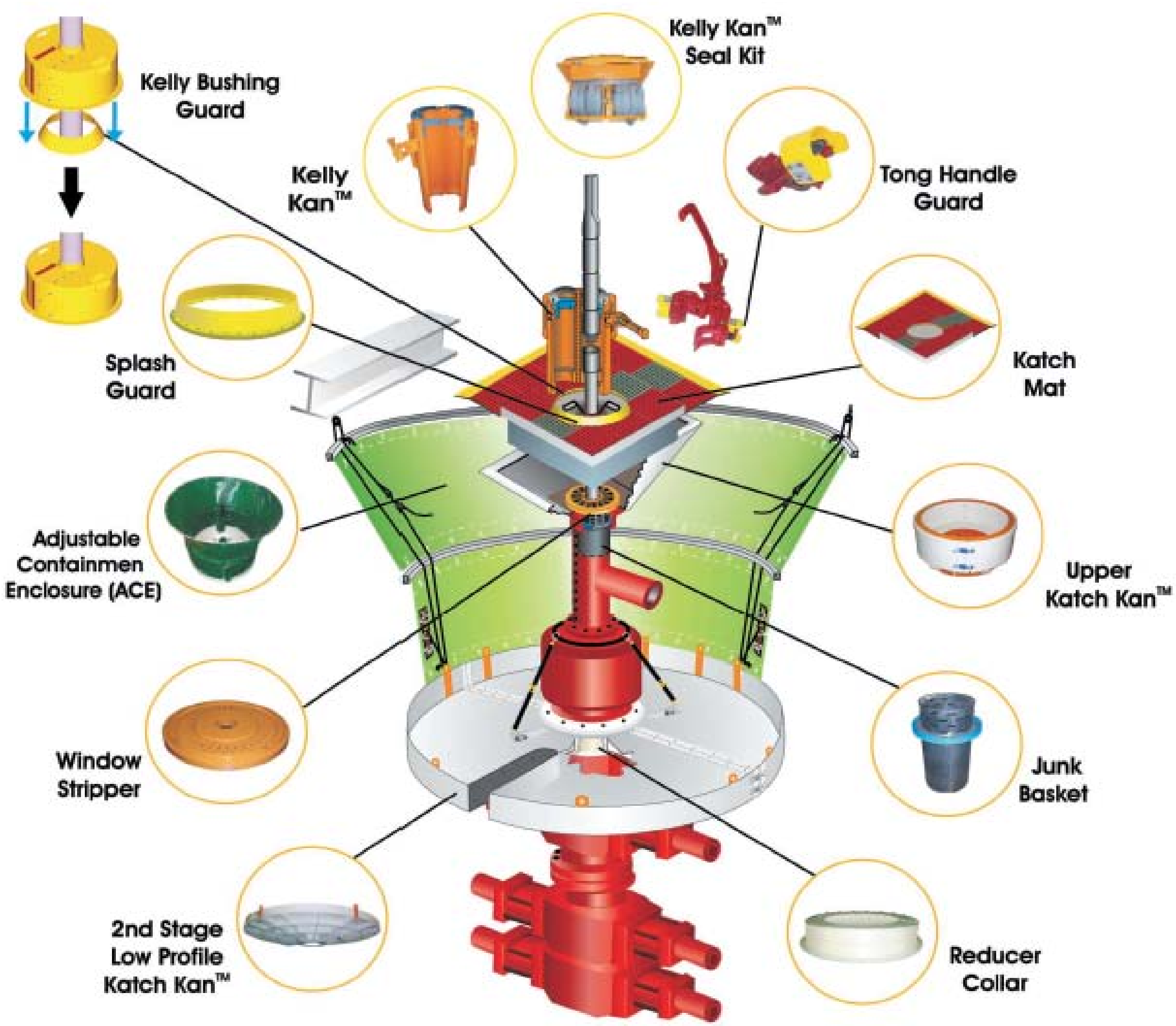


Figure 14: Zero Spill Technology Integrated Components Courtesy Katch Kan^{TM} 1994

There are several parts to the equipment serving different purposes, which tackles all the imminent problems encountered during exploratory drilling rig and also the applicable to the service rig and finally the abandoned wellhead. For the drilling rig solutions the following components are present on the equipment: mud bucket composed of polymers, safety, traction and containment mat, drilling fluid splash guard, tray composed of polymers, junk basket, window stripper, lower collection tray, reducer collar and adjustable containment enclosure. The interaction and full system operation of all components on this equipment makes the job of reducing fluid spill more effective, while recovering more fluid which in turn saves money and the environment from degradation. The drilling fluid containment is fully achieved when this system is properly installed and used on the rig, consequently enabling the recycling of drilling fluids and eventual reuse.

CHAPTER FIVE: ENVIRONMENTAL POLLUTION AND POTENTIAL EFFECTS IN MARCELLUS SHALE AREA

5.0 HEALTH, SAFETYAND ENVIRONMENT

Emily J. Knaus et al., (2008) reiterated the need to consider financial savings and environmental benefits during gas shale development with a view of significantly reducing the impact of drilling activities on the environment. Gas shale development entails drilling and consequently stimulation and these activities come with some environmental effects. These environmental risk and concerns can be mitigated or eliminated during the development phase with the advent of novel technologies and also regulations/ policies guiding the development operations in the state. The most outstanding of all these environmental concerns is the problem of waste water treatment and disposal which contains large amounts of total dissolved solids, hydrocarbons and heavy metals. The waste water is recovered from the well after the stimulation job and during production as flow back water and produce water respectively. They are initially stored in open waste pits prior to transportation to treatment plants or other disposal options available such as injection wells. During this temporal storage period, evaporation of some chemical constituents of the waste water could transpire, in addition to this, some of the waste water could seep through leaks in the walls of the pit into the earth. In other cases, due to high precipitation from rain or snow, there could be runoff and overflow of the waste pit. A better way to taken this problem is to effectively treat the waste water obtained and use them for irrigation or other applied uses.

Thorough assessment of the health, safety and environment of operation is quintessential at all stages of shale gas development. This would limit any further damage as they ensue if the proper procedures are implemented. There are structures put in place by the federal, state and local regulators in form of policies and guidelines for natural gas development. Arthur Daniel et al, (2009) believe that these regulations are primarily obligated at the state level which include the handling of waste materials, prevention of waste contamination on the environment, making sure that gas resources are conserved, air quality preservation, rights protection for land owners and mineral owners as well as ensuring that the environment is adequately protected.

The occurrences of pollution in the environment due to gas developmental activities are in the different stages such as during seismic data collection, during the drilling of exploratory wells, while extracting, transporting and storing the products. These pollutions could happen both intentionally and unintentionally depending on the prevailing circumstances. There are significant impacts by these pollutants on the environment during any gas development operation in the Marcellus Shale, the pollutants are in different forms ranging from solids, liquid, gas, sound/noise, aerosols and other unrestricted emissions.

The best management practice (BMP) by operators are discussed in this research work with a view of Marcellus shale gas development, assessing the need for better environmental awareness by operators and residents in these areas to issues such as waste disposal, air quality control, protection of water sources from contaminates emanating from drilling operations and finally ensuring that all safety concerns that put the environment and people at risk due to the gas development are appropriate taken care of as necessary. Several violations by operators were also analyzed in this research, the violations were due to no compliance by some operators in the area which adversely affected the environment, threatens human health, sanity and livelihood.

5.1 POLLUTION SOURCES AND ENVIRONMENTAL RISKS

The materials used for drilling operations alongside the waste generated during and after the well development are potential contaminants. Materials such as the drilling fluids, additives, and chemicals as well as the waste materials such as produced water and waste water find their way into the environment through intentional, unintentional and sometimes permitted releases. The following sections discuss contaminants generated from the activities, process waste, characteristic quantities and the possible effects on the environment.

5.1.1 Process Wastes and Contaminants

Typically, the major kinds of produced wastes from onshore Marcellus shale gas development that are environmentally troubling include;

- drilling-waste: fluid types
- drilling-waste: solids types,
- produced water, and volatile organic compounds (VOCs)

Drilling Wastes: Fluids types; Drilling waste are very potent and they degrade the environment in so many ways. The estimated volume of drilling waste generated from each well during development is 1,000 – 5,000 cube meter, and where there is a number of wells present, the waste generated also increases exponentially (Patin, Stanislav and Cutler Cleveland2008). Constituent of these waste include; drilling mud such as barite and bentonite, lubricants, biocides, emulsifying agents, diesel oil and numerous other additives that are mixed to make up fluids for well drilling. Drilling cuttings taken out of the drilling mud have a composition that is both intricate and unpredictable. The drilling fluids circulated through the well borehole contain lethal materials which include lead, oil and grease, cadmium, mercury, chromium, and naturally occurring radioactive materials (NORM).

The factors that are responsible for these compositions are as follows;

- Rock type
- Drilling regime
- Composition of drilling fluids (most important)
- Cutting separation and cleaning technology, etc

The least toxic of the drilling fluids is the water- based mud while the synthetic and oil-based mud is more toxic. Drilling mud occur as releases in the environment as a result of direct release into water bodies; through unlined impoundment which temporarily stores the fluids, giving room for seeps into the underground water network; onshore vaporization of volatile organic compounds (VOC's), unintended discharge from holding facilities; soils and sediments absorption. The united States Environmental Protection Agency (EPA) has a standard for hazardous waste materials, if the chemical concentrations of the drilling mud are detected to exceed the acceptable limit, then the waste must be disposed off at a certified facility or another option is that a deep disposal well can be used, but in most cases, the waste are within the range of waste rated by EPA not to be in the red alert rating and are taken to the landfills for disposals.

Drilling Waste: Solid types: These consist of the base level of drilling-mud sump materials; they could also include drill cuttings, additives and flocculated bentonite. Other wastes associated with the drilling process are; spent oils, toxic organic compounds and chemicals in cement.

Produced Water: Produced water is derived during the production of a gas, during drilling operations, the original reservoir water called the formation water, is encountered and this water is produced along with the gas. Produced water may include technological water, formation water or injected water (e.g. hydraulic fracturing fluids). The mineralized water is highly saline and the extent of salinity may depend on the formation type, its salinity is about 300g/l which is way higher than that of sea water, also the heavy metal content is very high (Patin, Stanislav, 2008 - Neff et al., 1987). Randium-226 and Radium 228 are present in flow back and produced water, although the amount may not be alarming. The quantity and quality of water produced from shale gas development activities are of enormous concern since it is expensive to get rid of appropriately without destroying the ecosystem and environment. Table 5 below shows the specific characteristics of produced water and their risk levels to human health and the environment.

TABLE 5

Parameter	Range Tested	No. of Samples
pH	3.1-6.47	16
Specific Conductance	136,000 - 586,000	12
Pollutants (in mg/L)		
Alkalinity	0 - 285	13
Bromide	150 - 1,149	5
Chloride	81,500 - 167,448	22
Sulfate	<1.0 - 47	13
Surfactants	0.08 - 1200	13
Total dissolved solids	139,000 - 360,000	15
Total suspended solids	8 - 5484	5
Aluminum	<0.50 - 83	19
Arsenic	<0.005 - 1.51	5
Barium	9.65 - 1,740	28
Cadmium	<0.02 - 1.21	19
Calcium	9,400 - 51,300	19
Copper	<0.02 - 5.0	14
Iron	39.0 - 680	21
Lead	<0.20 - 10.2	18
Lithium	18.6 - 235	18
Magnesium	1,300 - 3,900	18
Manganese	3.59 - 65	21
Nickel	<0.08 - 9.2	18
Potassium	149 - 3,870	16
Silver	0.047-7	4
Sodium	37,500 - 120,000	21
Zinc	<0.02 - 5.0	20

Sample Characteristics of Produced Water (Clark, Bryan M., January 2002)

Air Pollution Potential: Natural deposits contains hydrogen sulfide gas and some volatile organic compounds that when released to the environment are very toxic and can harm the health of local residents, workers and organisms in contact with this toxins. The potential effect of exposure to this substances ranges from unconsciousness to several chronic conditions that could lead to death just from a few breaths of inhalation. Clark, Bryan M, (2002), asserted that 0.5-1% of all exploratory drilled wells lead to a blow out incidence that consequently generates dangerous emissions into the air. Aside blowout incidences, flaring of associated gases are also potential sources of these noxious substances in the air, which are considerably significant. Several research worked have confirmed that gas flaring contains a record number of 250 different compounds that are considered toxic in nature. These include carcinogenic compounds such ad benzene, also contains nitrogen oxides which affect the respiratory system, sulfur oxides, which affect the heart and lungs, while toluene affects the reproductive system. These pollutants though produced locally, have the potential to cause widespread problems as they are easily carried by the wind to other places outside the location of operation, thereby affecting not only the health of the local residents and environment negatively, but also having potent effects on other places the toxic substances could get to. Apart from the incidence of blowout which are rare in the gas drilling operations, another source of these pollutants include leaks of the gas at the site or facilities. In this case, methane is leaked into the environment, which is swiftly disseminated into the atmosphere and it is of great risk to the climate, environment and human health, since it could lead to both acute and chronic damages.

5.2 ENVIRONMENTAL POLLUTION: INCIDENCES, CAUSES & PREVENTIONS

Several unintended pollution incidences are connected to accidental leaks of gas and spills of fluids undesirably during the production of the well and also during the distribution process. These occur due to failure to enforce proper safety procedures and incidences relating to pipeline transmission failure.

5.2.1 LEAKS, SPILLS, BULK SAND VENTING AND BLOWOUTS

Besides the identified and usual pollution sources discussed, which represent the direct effect of gas operations and development, there exist other pollution sources consequent upon unintended activities. The drilling sites for the gas development are of enormous danger in terms of spills, accidental leaks, and blowouts. Most identified accidental leaks or spills transpire as a result of pipeline damage or uncontrollable drilling mud ditch.

5.2.1.1 Blow out:

Another serious hazard to be considered in well drilling operations is the consequence of the failure of a blowout preventer (BOP). The BOP is a very useful and important component installed to safeguard the well from uncontrollable pressure that may arise due to any accidental outburst. The consequences of blowouts are potentially deadly, which could result to serious injuries or death of employees, first responders and even community residents. A blowout incidence is an environmental disaster, since the contamination of the aquifer, surface water, soil, air and even explosions are all likely to occur. A blowout occurs when drilling operations encounter a geologic formation that has an unusually high pressure, resulting to the quick release of fluids from the well. The environmental risks that leaks and spills pose are similar to regular expulsion of produced water and drilling wastes. Since the target fluid in the reservoir is methane, if blowout or leaks occur, methane gas is the fluid that is released at large quantities and this greatly threatens the environment because methane is hazardous. Aside environmental irritation and chronic effects of these incidences, other impact of these occurrences include project economics, remediation cost, liability cost, equipment repairs, lost time due to shut in, well abandonment in some instances (Clark, Bryan M, January 2002).

A good example of the consequence of a well drilling blowout is the BP Gulf of Mexico oil spill in 2010 (Maykuth Andrew, 2010), which was acclaimed as a significant environmental catastrophe with a rare record in the United States. Similarly, in West Virginia and Pennsylvania, there have been cases of well blow outs due to well drilling into highly geopressurized regions and also the pumping of high volume hydraulic fracturing fluids into the formations (Vicki Smith, 2010).

Although in some cases there were BOP's installed to prevent such mishaps, but the operators in the Marcellus Shale area agreed that the BOP showed inadequacy in handling unanticipated pressure rise. A well exploded in June 2010 in West Virginia, burning seven workers (Maykuth Andrew, 2010). Blow out also occurs even before the well is completed and BOP installed, an example was in West Virginia where drillers hit a pocket of methane about 1,000 feet into the subsurface62. On June 3rd, 2010 a well belonging to EOG Resources leaked over 35,000 hydraulic fracturing fluids to the environment in Clearfield County, PA. An environmental hazard cited by the Pennsylvania DEP as a “serious incident” (Anya Litvak, 2010). The three categories of blow out events are listed as, diverter controlled events, (category 1), Mechanical failure events, (category 2), Uncontrolled production loss, (category 3)

5.2.1.2 Bulk sand venting:

Proppant sand are generally dust free since they are usually washed to get rid of the fines, but less attention is commonly paid to a very important hazard that directly affects the environment, the expulsion and dispersion of sand silos into the atmosphere. During hydraulic fracturing, and when these sand silos are filled or emptied; it produces a lot of dust that creates a cloud of fine silica in the atmosphere. While the workers/ personnel are properly guided with personal protective equipments (PPE) for the job, the effect of that ensued might not only be local, but could be carried by wind to distant areas, harming innocent residents where ever they settle.

5.2.2 Statistics and Sources of Accidents

In the quest of understanding the extent of environmental impacts from gas development operations in the past, we can plan ahead for the future with a view of preventing most of the causes of this incidences and finding effective mitigations for those that are uncontrollable.

Gas Development: The leaking of natural gas from pipeline whether by sabotage or by natural disasters pose a great danger to the local residents in contact with this pollution and the environment at large. It is on record that the frequency of occurrence is quite high and in year 2000 a total number of 37 people died from these incidences, which happened 234 times due to gas transmission and distribution (S. Rana, 2010). Natural gas leaks are disastrous owing to the nature of the gas being easily combustible which means it can burn until it is contained. In onshore exploration, hydrogen sulfide gas is another huge risk that has the capability to degrade the environment and harm immensely the health of residents. If the drilling activity encounters a pocket of soar gas during a blow out regime, the well would pour out all its content faster due to the built up pressure of its content and the unrestrained discharge of hydrogen sulfide would occur. It was reported that for every one thousand (1000) exploratory wells in new fields, there would be seven (7) wells that blows out on average. This figures show that the probability of occurrence is low and some researchers put the estimated blowout per exploratory wells drilled to be one in every 10,000 wells (Patin, Stanislav, 2008). Although the likelihood of occurrence maybe low, but whenever one occurs, it always result in disasters, claiming human lives and causing chronic environmental harm.

TABLE 6

Chemicals of Concern (Oil & Gas operations) and Effects on Human Health

(Clark, Bryan M., January 2002))

Chemical /Substance	Effects on Human Health
Lead	A heavy metal frequently encountered in oil and gas drilling muds, is of special concern to human health. Ingestion of lead by at risk populations, such as children, the elderly and young women, can have significant impacts at miniscule levels. In fact, the U.S. EPA states that, "It appears that some of these [adverse health] effects, particularly changes in the levels of certain blood enzymes and in aspects of children's neurobehavioral development, may occur at blood lead levels so low as to be essentially without a threshold" (emphasis added).
Methyl	A by-product of mercury contamination in conjunction with high levels of organic material in soils, has
Mercury	been associated with central nervous system effects in humans even at the level of 0.003 mg/kg/day. Mercury contamination would be part of almost any drilling waste discharge. Methyl mercury is a known human neurotoxin, or nerve-destroying, compound. The chemical has also been shown to cause mental retardation and cerebral palsy in developing fetuses. Given the dangers of bioaccumulation associated with methyl mercury, as well as the difficulty associated with removing it in drinking water processing at municipal water sources, additional methyl mercury contamination would be a tremendous concern in the Great Lakes area.
Chromium	Specifically chromium VI, has been given a reference dose of 0.003 mg/kg/day. Exceeding the reference dose can produce non-carcinogenic effects. However, the chronic and sub lethal effects of chromium VI are not well known, nor is the existing literature sufficiently developed to provide high confidence in the reference dose. Existing evidence indicates the potential impacts from chromium VI exposure are as diverse as allergic contact dermatitis (skin rash), decreased fertility, embryo toxicity (decreased birth weight and increased mortality rate), developmental defects, and cancer. Chromium VI is a known human carcinogen for inhalation exposure, but has not been assessed for carcinogenicity due to ingestion.
(PAH)	include known human carcinogens such as benzene and potential human carcinogens such as naphthalene. Numbering in the hundreds, PAHs are frequently found oil and gas drilling wastes. Because many toxicologists now recognize that no safe dose exists for carcinogenic materials, the introduction of PAHs into the Great Lakes ecosystem will always pose a serious threat to human health.
(NORM)	Found in produced waters are further cause for concern. These materials have been identified as cancer causing agents. Because no safe exposure level exists for cancer-causing agents, any exposure to radioactive produced waters can cause cancer in humans and wildlife. The levels of naturally occurring radionuclides can be expected to vary widely from area to area due to variation in geology. Canadian natural gas industry studies have produced evidence of human health effects from exposure to normally occurring radioactive materials.

*PAH= Polycyclic Aromatic Hydrocarbon, NORM= Natural Occurring Radioactive Materials

Toxic Emissions from Drilling Sites: It is common for the idea of water contamination to resonate at the instance drilling operation pollution is mentioned, but also associated with gas development activities are air pollutions. Due to the heavy equipments used for drilling activities, a lot of substances unfriendly to the atmosphere are released which causes the degradation of the air quality in the region. A large amount of polycyclic organic matters such as the polycyclic aromatic hydrocarbon and also particulate matters such as heavy metals are discharged into the air during these activities. Nitrogen oxides, Sulfur oxides, carbon oxides, volatile organic compounds, hydrogen sulfide, and smog are examples of constituent of the emissions. Table 6 above shows the different hazardous chemicals released in the air due to gas development activities and their potential effects on human health.

5.2.3 Common Causes of Spills

Generally, petroleum spills are caused by pipeline leaks, overflow, and other unidentified/undocumented causes. There is a wide range of reasons for this spills that occur in the petroleum industry, they include; corrosion of pipes and containers, failure of equipment due to uncontrollable factors such as storms and floods, material failure and human error. A major problem in the industry is the spill associated with brine storage, near site fuel spills and muds. Primarily, spills attributed to pipeline leaks as a result of corrosion represent 45% of all occurrences, 2% is due to human error, materials failure account for 6% and equipment failure is 4%. Petroleum sector operations have some environmental impacts caused by spills of unwanted chemicals or substances which were due to the following causes listed in Table 7 below in approximate percentages.

Petroleum Sector Activities Spills by Various Causes	**Percentage**
Corrosion	24%
Equipment failure	24%
Human Error	18%
Material failure	3%
Gasket joint	2%
Damage by equipment	2%
Unknown	14%
Other	13%
Total	100%

Table 7: Causes of Spill (S. Rana, 2010)

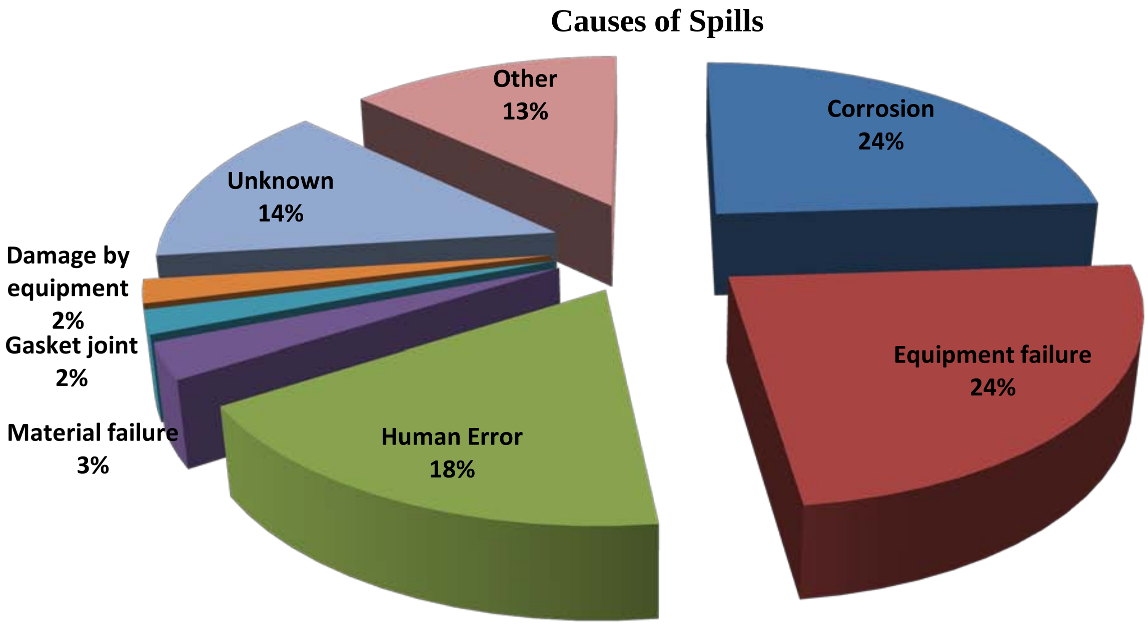


Figure 15: Causes of Spills in the Petroleum Industry

5.2.4 ACCIDENTS

Accidents are as a result of unexpected occurrences, such as tectonic activities, floods, equipment failure, human error and material failure. These accidents pose a huge risk to the environment when they occur as hazardous substances are discharged and the impact is mostly devastating.

5.2.4.1 Drilling accidents

Drilling accidents occur as a result of the factors mentions above, which lead to unpredicted blowouts of gaseous and liquid hydrocarbons due to unusual pressure emanating from the well when those zones are intercepted. Another cause of accidental discharges into the environment is the record number of times tankers and trucks carrying fluids and gases are involved in accidents and spill out the content of the container they are carrying. Basically there are two major types of drilling accidents prevalent in the industry. One of them is the blowout accidents due to drilling activities in new fields into zones of abnormally high pressure resulting to severe and protracted gushing of hydrocarbons from the reservoir. These types of accidents are catastrophic and require more advanced technology to deal with the situation, though the probability of occurring is very low.

For the second type of accidents, which are mostly caused by regular drilling activities that resulted in spills of hydrocarbon materials into the environment due to minor blowouts, can be curtail with the help of installed blow out preventers, which shuts in the well once a blow out occurs. The situation of the blowout may be minimal but the environmental impacts are huge due to release of noxious substances to the surrounding.

5.2.4.2 Transportation and Storage Related Accidents

Pipelines: Pipelines transport natural gas and oil from one location to another according to desired destination and purpose. They are made up of complex structures that are also extensively laid over long distances. The construction of this pipeline during gas development in the Marcellus also creates some level of environment risks, in addition to the risk created by tankers and the main drilling operations. Accidental spills happen due to pipelines damage, the factors that may lead to pipeline damage include;

- Pipeline corrosion
- material failure
- erosion on the pipeline right of way

Pipelines are a source of sudden blowout, short time and long time leaks depending on what lead to the damage, which could be due to ruptures, excavation or cracks on the pipe material. The formation of hydrates during transportation of the gas may also be a reasonable cause of rupture if external forces act on the pipe. When some of these pipelines right of way passes through major river channels or are laid on the path that are close to big rivers, and these accidents occur, the impact is usually intense as aquatic lives are affected terribly.

5.2.5 Violations:

Inspection failures and some neglect of industry’s regulations also result to environmental disasters. It is however important for a proper inspection of facilities, equipment and personel to be routinely done so that the issue of violations of the codes and regulations that guide the industry’s operations are not defiled. This will enormously reduce the impact and foot prints of gas development in the Marcellus Shale area.

5.2.6 OPERATIONAL CONCERNS:

In an attempt to propagate fractures into the formation allowing free movement of natural gas for recovery purposes, the drillers utilizes a cocktail of fracture fluid made up of water in millions of gallons, proppants, emulsifiers, acids, gellants, biocides, resins, viscosifiers, and corrosive inhibitors. This mixture is pumped into the formation at monitored pressure to crack the rock formation open, while the proppant keeps the cracks open for easy passage of the gas to the wellbore (John Harper, 2008). This process creates risk and safety concerns to health, environment and some social impacts.

A variety of environmental risk and safety concerns in the Marcellus Shale play have been pointed out with regards the potential impact plagued on the environment by the development of natural gas in this area by operators with the use of the hydraulic fracturing technique. This research outlines the best management practices (BMP) by operators which GWPC and ALL Consulting 2009, reiterated that Marcellus Shale developers implement these BMPs in an attempt to responsibly guarantee the effective treatment and disposal of drilling and production wastes, protect the water supplies, ensure quality air is preserved and tackle all safety concerns within the premise of their operations.

Also, the failure of these petroleum operators to comply by the regulations which could consequently lead to possible environmental considerations and challenges (GWPC, 2009) that potentially poses threat to human lives, human sanity, and the degradation of the environment as a result of natural petroleum gas extraction in the Marcellus Shale area.

5.2.7 Marcellus Shale flow back fluids:

Hydraulic fracturing in the Marcellus shale is a to and fro process which involves pumping fluids into the sub surface to retrieve gas economically and at the end of each stage in the fracturing process, the fluid is flowed back to allow for easy passage of gas through the fractures towards the wellbore where it is eventually gathered into flow lines ready to be processed. About 25% of the total volume of water pumped into the sub surface is flowed back in a typical Marcellus Shale well (Thomas Hayes, 2010) and can take hours or sometimes weeks for the flow back to be complete but up to several months after the hydraulic fracturing, some of the injected fluids are continuously produced with the gas (GWPC, 2009). Waste water is produced as a result of this which is quite challenging to get rid of in a safe manner.

Although it may not be as simple and problem free as it may sound, when the fracturing fluid is flowed back to the surface, as it travels through its underground path, it collects enormous amounts of total dissolved solids and contaminants such as mercury, arsenic, benzene, formation water (with high salinity), and radioactive materials (e.g. radium 226, which are considered carcinogenic) (Amy Mall, 2007). The high concentration of this TDS makes the salinity of the waste water 5 times more than regular sea water (Sapien Joaquin, 2009). Also part of the flow back constituent are biocides that are made up of possible human carcinogens such as polynuclear aromatic and polycyclic organics. Water sources are at great danger if this water leaks into the environment and this portends greater hazards to human lives and the biosphere.

A few methods are available for the proper disposal of flow back, produce or waste water, one of which is the use of injection wells. This is process whereby the waste water is pumped into a well to return to rock formations, but even this is hazardous and creates high risk to ground water sources. Even at that, it is still difficult to make use of this method since there are few of these wells in the Marcellus Shale area, with Pennsylvania having as few as 10 injection wells (Class II) (Jeff Jollie, 2010). Due to this constraint, operators dispose waste water on the surface, such as into rivers and streams (GWPC, 2009) since treatment facilities are insufficient in the Marcellus Shale to take care of this huge waste generated from gas drilling, even in cases where they are available, there is not enough capacity to effectively handle the high salt concentration present in produce or waste water. This caused an unprecedented set back in the provision of drinking water to over 350,000 people that depend on the Monongahela River in Pennsylvania due to a huge increase in the concentration of total dissolved solids (TDS) in the river (Sapien Joaquin, 2009).

The initial handling of the flow back fluid before the initiation of treatment processes is also very important. The transportation and provisional storage of such wastes posses another set of risk factors to the environment, as evaporation pits that are either lined or unlined are used as temporary storage of fluids (GWPC, 2009). This has the potential of leaking into the surrounding soil and/or contaminated runoff created by heavy precipitation (Delaware River Keeper.org). An example of waste water transportation incident occurred in 2009 when pipeline carrying waste water belonging to Range Resources leaked over 4,200 gallons into Cross Creek, Washington County, Pennsylvania killing several invertebrates and fish (PADEP, 2009). The same operator in 2010 was fined thousands of dollars by the DEP for discharge of waste into the waters of the commonwealth (PADEP, 2010). Currently in Pennsylvania, there is no treatment plant that has the capability to remove TDS from the waste water and none in the foreseeable nearest future. Meanwhile DEP expects an increase of 10 million more gallons of waste water a day in addition to the 9 million gallons produced daily in Pennsylvania alone in 2008, making the total predicted waste water production per day in 2011 to be 19 million gallons (Sapien Joaquin, 2009).

5.2.8 Ground Water Contamination:

Figure 14 (GWPC, 2009) shows the depth to the base of the aquifer in major shale plays including the Marcellus Shale and there exist in most cases a huge distance with rocks separating the water bearing aquifers embodies drinkable water from the pay zone in the shale formation (GWPC, 2009). Many researchers and government studies have debunked the possibility of ground water contamination that could arise from hydraulic fracturing processes. The question most people ask is that, “Is it possible for the created fractures to extend through thousands of feet from the deep shale formation to the aquifer near surface releasing methane into drinking water regions?” From an engineering perspective, it is easier for life to exist on Mercury than for fractures to propagate over 7,000 feet upwards from mere pumping of fluids and sands into formations. The base of the deepest aquifer in the Marcellus Shale area lies at an estimated depth of 850 feet (GWPC, 2009) while the depth from surface to the top of the Marcellus Shale formation is estimated to be in the range of 4,000-8,500 feet running from Pennsylvania, New York, Ohio and W. Virginia (Arthur Daniel, 2008). In between the aquifer and the shale gas in the Marcellus, geologist have recognized and identified nine separate impermeable layers of shale rocks that are about half a mile thick (Arthur Daniel, 2008), this alone clearly suggests the unlikelihood of hydraulic fracturing causing fractures to propagate to sources of drinkable water and contaminating the aquifer with dangerous fluids.

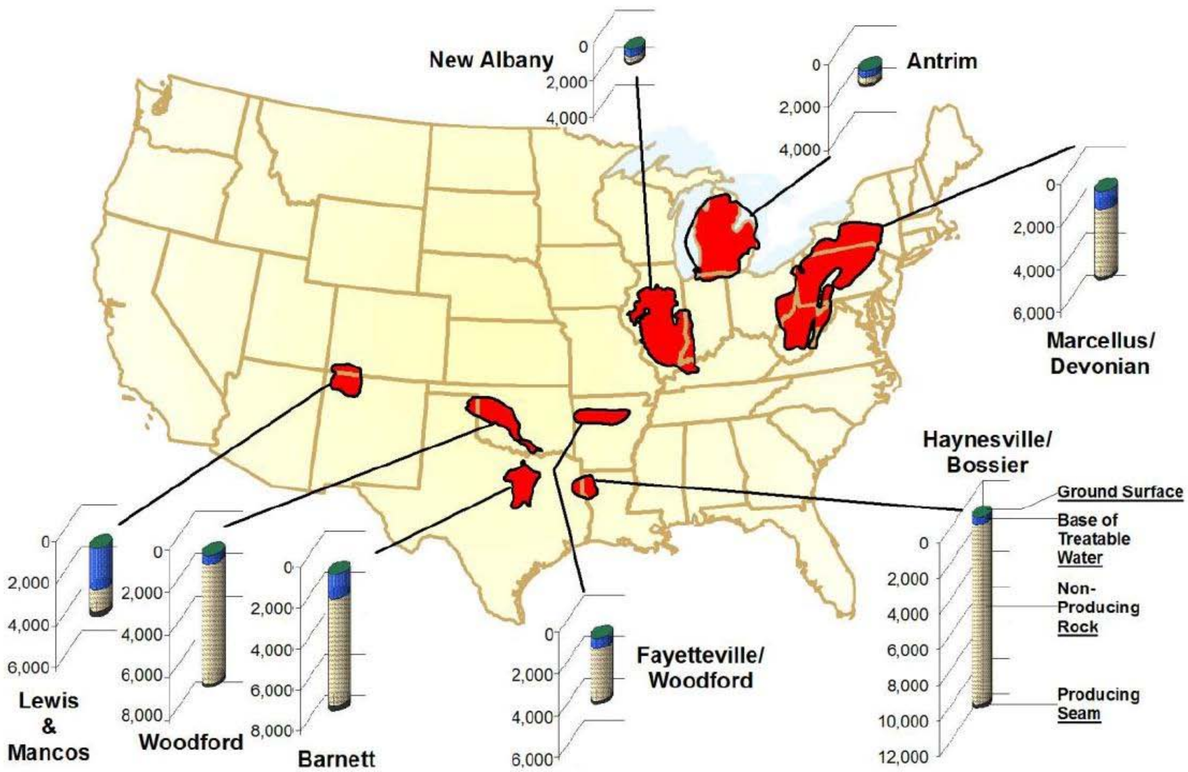


Figure 16: Showing base to Groundwater and Shale Depth in Marcellus Shale and other Shale Plays

Source: GWPC 2009

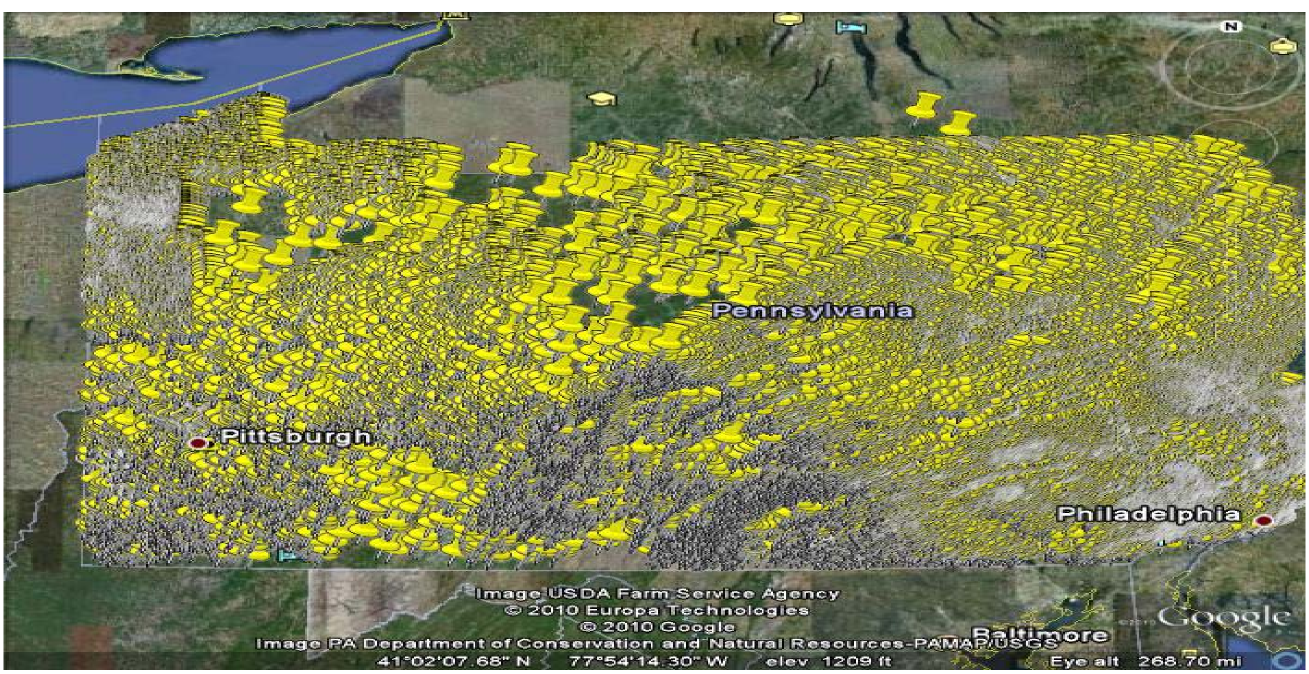


Figure 17: Water Well Locations in the Marcellus Shale Pennsylvania area: USDA 2010

There are two types of gases that are in contention of whether they can leak into sources of drinkable water, the biogenic and the thermogenic natural gases. The former is formed from organic materials that are decomposed and are formed into pockets of gases close to ground surface. While the thermogenic gas is formed at great depths due to very high pressures generated from subsurface rock formations, such as the Marcellus Shale. Either of these gases may find their way into water supplies due to drilling activities. Drilling processes could provoke the migration of Biogenic gases close to the surface, due to the puncturing of the gas pockets allowing a free flow into the aquifer.

Some operators fail sometimes to abide by State laws and regulations that guide their operation, exposing the environment to enormous risks. The best way to protect the ground water from contamination from fracture fluids and other chemicals during and after hydraulic fracturing is by having a proper well completion done. The well must be properly cased with metal casing and cemented to safeguard the ground water from drilling fluid, waste water, and the emerging natural gas. To prevent casing and cement failure, several measures and standards are put in place to reduce this risk. These standards are put in place and updated by The American Petroleum Institute (API) which requires the use of steel casing and up to standard cements for well completion jobs (Navigant Consulting, 2008). Violations of these standards have in many cases exposed the environment to very high risk, for example the 2007 Bainbridge, Ohio incidence where an improperly cemented well gave way to passage of methane through the annulus into groundwater resources, resulting to a surface explosion.

Other evidences abound of local water well contamination by hydraulic fracturing fluids in areas of drilling operations. EPA in 2009 asserted that 11 wells were contaminated with chemicals out of the 39 wells analyzed in pavilion, Wyoming and the contamination was strongly tied to gas drilling (URS Corp., 2006)

The Department of Environmental Protection in Pennsylvania made it known that there have been over 50 cases of accidents potentially caused by methane from drilling activities in the State (Wilbur Tom, 2010). One of them was in Jefferson County, Pennsylvania were three people died in a house in 2004 as a result of an explosion caused by methane leaking into formations and then the surface, similarly The Ohio Department of Natural Resources attributed a house explosion in 2007 to hydraulic fracturing and a faulty well (ODNR, 2008). Others in this drilling areas claim that their taps can be lit on fire (Boyd Shaun, 2009). Gas is becoming ubiquitous in homes around where drilling activities are ongoing; this presents a huge risk to the safety of residents of the Marcellus Shale area, property and to the environment in general.

5.2.9 Local Water Depletion:

A large volume of water is required to carry out a fracturing job and the water is acquired either from surface or underground sources (Arthur J.D., 2008), which basically affects local water resources by drawing down the volume of available water. Common sources of water for Marcellus shale development are from underground wells, surface and private water, municipal water and also wastewater that are reusable. Residents of these development areas also rely on these sources of water for individual usage in terms of domestic use, farming, community use, ranching or for wildlife sustenance, but the availability of quality water to the people of the commonwealth is becoming increasing challenging due to drought as a consequence of the Marcellus Shale drilling To carry out fracturing of a single horizontal well, millions of gallons of water are used to complete the hydraulic fracturing job (Harper John, 2008). The impact the huge water withdrawal has are inimical to the environment, resulting to aquifer depletion, reduction in stream flow, water scarcity during drought, destruction of aquatic habitat, stream use degradation. There has been a conspicuous change in the drying up of streams in Pennsylvania since drilling began (WTAE, 2008).

Watercourses in the northeastern part of the United States, such as the Susquehanna and Delaware River Basins, and the New York City watershed coincidentally, overlay the entire area where Marcellus shale drilling activities are prevalent. These are the purest waterways in the region and are subjected to the intense drilling activities in the Marcellus Shale play such as water withdrawal and disposal (Arthur J.D. et al, 2010). The disposal of produce water is a major problem in the development process of the Marcellus Shale, injection zones in the area are not sufficient for disposal to be done appropriately. Operators try to improvise a solution in handling this disposal challenge by employing other methods such as the use of treatment plants, or transporting the waste water to available treatment plants nearby, or better still recycle or reuse the waste water for further fracturing jobs (Arthur J.D. et al, 2008).

5.2.10 Surface Water Pollution and Soil Contamination:

The entire components of the hydraulic fracturing process lie on ground surface, where chemicals are stored, mixed and pumped on site, solid wastes are treated and disposed, and several other volumes of liquids stored, transported and disposed. These processes often expose the soil and surface water to severe risk considerations, such as accidental spills, mechanically failure of chemical carrying equipments, waste disposal and flow back fluids. Over 17 million residents across Pennsylvania and New York depend on the pristine watershed in the region. According to a report (Americanrivers.org, 2010) the Upper Delaware River which topped the list of the most endangered Rivers in the country, used to be the most free flowing and cleanest watershed in the United States.

Figure 18:Foams from hydraulic fracturing in the the Cowden well location belonging to Atlas Energy Resources West Middletown, Hopewell Township - Washington County PA Courtesy: DEP eFACT.com 2009.

Figure 19:A connection surface water transfer line belonging to Range Resources failed discharging over 10,500 gallons of flow back fluid containing 1% chloride salt into a tributary in Brush Run, Hopewell Township Washington County PA, killing more than 250 fish in October 2009 .

Second on the list of most endangered rivers in the United States is the Monongahela River which cuts across the States of West Virginia and New York, this however signifies a clear signal that contamination of these Rivers is largely due to the Marcellus Shale gas development. Most of the contaminations and pollution to the surface water and soil in the Marcellus area comes from waste generated from drilling activities. This include large volume waste such as drilling cuttings, waste water and drilling fluids are generated alongside associated waste such as completion fluids, production storage tank and pit sludges, wash out water etc (Wilmar Subra, 2009).

5.2.11 Air Pollution in the Marcellus Shale area

The drilling and gas development industry has a massive carbon footprint and other related air emissions that can be considered detrimental to the sustainability of the environment. Drilling and stimulation processes emit a large amount of pollutant into the atmosphere due to the use of pumps and engines that are diesel powered. Combustible gases are released in the air from motors and compressors at drilling and production locations, after which these gases, motivated by heat and sunlight react with volatile organic chemicals (VOC) to create a gas layer called the ground level ozone. In some cases, flow back gas is flared when the pressure to gather this gas into a sales line is insufficient, or failure of pipeline connectors and associated equipments may trigger leakages of gas into the air which could be very toxic and injurious once inhaled. Other means of air quality degradation due to air emissions in the Marcellus Shale region include; venting after well completion, smoke from the exhaust of vehicles, dust arising from vehicular traffic of unpaved roads and from fracturing fluid flow back open ponds and pits. Methane gas is usually produced together with other substances such as condensates, whereby very toxic VOC's are contained in the condensates such as ethyl benzene, sour gas, toluene, xylene. Air emission of these substances occurs at storage tanks and separation processing units. Benzene and other VOC's are possible causes of human cancer and several other diseases. Also once these VOC's react with the produced combustion gases; the ozone level is heightened in these communities resulting in intense respiratory problems to the workers and residents of the area.

The existence of methane gas in household wells is not only undesirable, it poses serious health hazard to the residents and to the environment. This is an indication that the process of hydraulic fracturing may not only have contaminated the source of drinking water, but also have polluted the air. Since the gas eventually comes out of the water and settles in the air, polluting the air human's breathe, which could lead to queasiness, vomiting, wooziness, and asphyxiation (Mathes On, 2008). Aside this concern, methane gas presence is very dangerous and likely to result to explosions, causing serious fatalities and injuries.

A resident of Hopewell Township in Washington County reported the pungent smell perceived in the community to the Pennsylvania DEP and also make a complaint of health issues experienced from the bad air that circulates in the area from drilling operations. The cause of this sickening smell was later found to be a fracturing pit, which combusted and destroyed the pit liner figure 16, leaking toxic fluids into the soil as well as polluting the air. The state of Pennsylvania in April of 2010 placed a moratorium on all drilling activities by Cabot Oil and Gas Company and was required to plug all leaked wells after an investigation indicted the company of allowing combustible gas migrate into the drinkable water sources in the Dimock Township, PA (Michael Rubinkam, 2010)

The aftermath of this emissions are not in any way environmentally friendly, as it accelerates the impact of global warming. The good news is that air pollution can be reduced effectively with some novel technologies (e.g. thermal evaporation and brine concentrator) in such a way that methane production increases as the air pollution reduces, this is very attractive both economically and environmentally but the cost of acquiring this technology remain the challenge.

Figure 20: Atlas Energy Resources: Pit fire, Hopewell Township - Washington County PA Courtesy: DEP eFACT.com March, 2010.

5.2.12 Radioactivity in Marcellus Shale

The high content of natural occurring radioactive materials (NORM) in the Devonian Shale makes the Marcellus Shale comparatively radioactive (Hill D.G., et al, 2004) and it is also a source of low grade uranium (Dyni J.R., 2003). The Ohio Marcellus shale contains NORM in trace amount, also in metamorphic rocks and in glacier deposits of granitic origin (Ohio DNR, 1997). The risk associated with drilling through formations that contain radioactive materials such as ^{226}Radium, ^{228}Radium, thorium and uranium is amplified in the Marcellus Shale area due to the fact that these NORM may travel alongside the gas or flow back water to the surface. Compared to other geological formations, the Pennsylvania State geosciences professor Terry Engelder believes that the Marcellus Shale relatively has more NORM but may not be alarming. But the danger in producing NORM together with the gas or wastewater is that it can get concentrated (rrc.state.tx.us) either by a change in the pressure and temperature conditions of the drilling operations or the reaction between ^{226}Radium/^{228}Radium present in the produce water with barium sulfate which could result to scaling around the tubular of the well as well as on surface equipments. This subjects the workers to a very high level of risk when faced with the task of reaming or cutting oilfield pipes or refurbishing the processing equipment (rrc.state.tx.us). When the produced gas undergoes processing in the natural gas stream, the associated NORM may appear as radon gas that decays to ^{210}Pb, then ^{210}Bismuth, ^{210}Polonium and lastly ^{206}Pb to form file around the inner surface of pumps, treatment units, valves, and inlet lines of ethane, propylene and propylene processing streams.

The half life of ^{226}Radium is one thousand six hundred and twenty two years (1,622 years), this bone seeking element is a human carcinogen that has the potential of causing both bone and lung cancers.

The National indoor average of radon (^{222}Rn) levels in homes is expected to be 1.3 picocuries per liter (pCi/L) (epa.gov). An air assessment study was carried out in 210 homes in the County of Onandaga, NY, the measurement from the basement of these homes stood at an average of 8.8 picocuries per liter (pCi/L) (Banikowski and Hand, 1987), this is a trend in the Marcellus Shale area as all the indoor air levels of homes sitting on this huge gas deposits, especially those close to gas drilling and development activities have ^{222}Rn to be more than double the level recommended by U.S. EPA.

5.3 Other Surface Impacts of Gas Development Operations

There are other sectors affected by drilling operations in the Marcellus Shale area, activities such as road pavements, pipeline right of way construction, and the development of forest land which also signifies another grave environmental consequence called deforestation.

5.3.1 Developmental Impacts

The Marcellus Shale gas development is fast encroaching into several urban areas of the State of Pennsylvania, as evidence in Pittsburgh PA. Different sets of environmental problems are faced by both the urban and rural areas, most of which include land encroachment, heavy traffic, air emissions, well pad lights and noise, dusty clouds and water issues. The effect that hydraulic fracturing has on rural America is enormous, the plight and concerns of residents most often times are not taken into consideration. Big companies act with Big money and in consonance with the politicians to make worse situations a recipe for disaster. Few States have proper legislation for the regulation of hydraulic fracturing, including the federal government. The United States Congress passed the Energy Policy Act of 2005 excusing hydraulic fracturing from the policy that would have protected the American waters, air and people from this impending extinction.

5.3.2 Effect on wild life

Wildlife habitat is fundamentally affected at every phase of shale gas development ranging from exploration to abandonment due to the disturbance of land surfaces (GWPC and ALL Consulting 2009) (GWPC, 2009). Inasmuch as operators try to minimize the level of land surface disturbance associated with their activities, with the use of multi-well pads and horizontal wells, vegetation destruction and habitat loss still occurs when right of ways are constructed alongside utility corridors. It is quintessential for operators to follow the BMP’s involved in drilling operations by paying special attention to sensitive habitats that houses endangered species, and also constructing barriers around wetlands, rivers, streams and exposed soils.

The use of multi-well pads may solve the problems of reducing the number of utility corridors, roads and facility infrastructure constructed; it also has its own set of challenges that could serve greatly increase the environmental footprints in the Marcellus shale area. The issue of erosion and sediment control is harder to deal with using the larger multi-well pads. Since there are no vegetation covers on the surface, compaction could happen faster and the surface then becomes impervious resulting to an undesirable enhancement of rapid storm water runoff, which leads to stream erosion and consequently degradation of water quality, flood damage and ultimately, habitat loss.

Figure 21: A run-off area, showing dead plants, the location close to Ullom Road Pond, it was reported that a frack job was concluded approximately 100-200yards from this stream, few weeks after the photograph was taken. Chartiers Township, Washington County, Pa (April 2009)

5.3.3 Traffic:

Increase in traffic is detrimental to the environment due to air emissions of NOx and SOx gases, CO_2, and other particulate matter. The Marcellus shale area have experienced an unprecedented increase in the flow of truck traffic carrying drilling equipment, water, well pads, fracture fluids, and pumps. Other substances such as the VOC's and even the produced methane may be emitted during the well process, it is important to note that gas methane is a serious threat to the

5.3.4 Threat to Human Health

The release of drilling fluids, flow back water and produced waters into the environment have a localized impact in the short term, while the effect spreads out in time. The areas close to these sites of operations are mostly heavily impacted when there are pollution incidences, putting the human health of local residents at a higher risk level. The discharge of drilling mud and waste

water into the environment of operation is capable of contaminating the sources of drinking water that humans consume, it also impact aquatic lives which humans feed on, due to several toxic chemicals contained in the released fluids. In addition to that, continuous accidental or intentional discharge of these drilling fluids and produced water with toxic compositions accumulates undesirable chemicals in the food chain of the local area. These chemicals get accumulated in organisms on the food chain and the level of concentration increases as the organism moves up from one level on the food chain to another, leading to an increase in overall toxicity within the system. The discharge of these drilling fluids into the environment is detrimental to human health as exposures to these pollutants are in most cases inevitable.

The population in the local environment is very vulnerable to the impact of these pollutants since the environment is already at risk, any other form of exposure would result to a more chronic effect on their health status. There exist several exposure routes for these pollutants with regards human health, they include; inhalation of chemicals by workers and local residents, ingestion of water and food that are contaminated from these pollutants, skin contact absorption etc. Several human health effects abound due to this pollution contamination; which could be acute or chronic. Some of which include; variations in the amount of some blood enzymes, adverse effect on the brain and the central nervous system, causes defect in the biobehavioral and neurobehavioral developments of children, skin and eye irritation, other carcinogenic and non-carcinogenic impacts etc. The severity of these human health impacts is dependent on the level and rate of exposure of the human subject to these toxic pollutants. Table 7 above lists out some chemicals of concern (COC) that are potentially impactful to human health if exposed to them.

Chemicals of Concern (specific to Exploration and Production of Natural Gas)

Acetaldehyde	Causes severe eye irritation. Harmful if swallowed or inhaled. Affects central nervous system, liver and kidneys. Causes irritation to skin and respiratory tract. Possible cancer hazard.
Acetic acid	Liquid and mist cause severe burns to all body tissue. May be fatal if swallowed. Harmful if inhaled. Inhalation may cause lung and tooth damage.
Ammonium bisulfite	May be fatal if swallowed or inhaled. Harmful if absorbed through skin. Causes burns to any area of contact. Causes respiratory tract irritation. Can liberate poisonous and flammable hydrogen sulfide gas.
Ammonium chloride	May cause irritation. May be harmful if swallowed. Avoid contact with eyes, skin, clothing.
Benzene	is a known carcinogen.
Crotonaldehyde	Harmful if swallowed, inhaled or absorbed through the skin. Eye contact may cause severe irritation or burns. Respiratory, eye and skin irritant.
Dodecylbenzene sulfonic acid	Contact can irritate and burn the eyes and skin. Can irritate the nose and throat.
Hydrochloric acid Hydrofluoric acid	Liquid and mist cause severe burns to all body tissue. May be fatal if swallowed or inhaled. Extremely hazardous liquid and vapor. Causes severe burns which may not be immediately painful or visible. May be fatal if swallowed or inhaled. Liquid and vapor can burn skin, eyes and respiratory tract.
Hydrogen sulfide	Hydrogen sulfide is a toxic chemical gas frequently found in natural gas deposits. Hydrogen sulfide has the potential to poison several systems of the body. High levels of hydrogen sulfide can cause unconsciousness or death within just a few breaths. Long-term low-level exposure can cause fatigue, loss of appetite, headaches, irritability, poor memory and dizziness.
Methane	During a land-based blowout, methane (primary ingredient of natural gas) will quickly disperse in the atmosphere. A prolonged leak can produce both acute (immediate) and chronic (long-term) poisoning of birds and other wildlife as well as humans that come into contact with the leak. Tests on the health effects of methane exposure have produced abnormalities of the animal's fetal brain, including brain hernia (extreme pressure inside the skull).
Nitrogen oxide	a known asthma trigger.
Potassium hydroxide	Causes severe eye irritation. Harmful if swallowed or inhaled. Affects central nervous system, liver and kidneys. Causes irritation to skin and respiratory tract.
Sodium hydroxide	Corrosive. May be fatal if swallowed. Harmful if inhaled. Causes burns to any area of contact.
Sulphur dioxide Toluene	a lung and heart irritant. a toxin linked to reproductive problems
Zinc bromide	Harmful if swallowed or inhaled. Causes severe irritation or burns to every area of contact. Affects central nervous system, brain and eyes.

Table 8: (Clark, Bryan M., January 2002)

CHAPTER SIX: MARCELLUS GAS DEVELOPMENT MITIGATION/ CONTROL MEASURES

6.0 MITIGATION MEASURES

6.1 Introduction

The impact magnitude and significance can be used to propose the mitigation measures for the impacts Marcellus Shale Gas Development. Mitigation measures are to be provided for those impacts rated as moderate and major. The mitigation measures proffered were to reduce the severity of identified negative (moderate/major) impacts and enhance the positive (beneficial) effects. The residual impacts that could arise despite the mitigation measures were also assessed.

The mitigation measures proffered for the predicted impacts from the gas play took cognizance of:

- Environmental laws in PA and US, with emphasis on permissible limits for waste streams
- Best available technology for sustainable development;
- Feasibility of application of the measures in the US;
- Social well being etc.
- World bank policy on Energy and Industry

6.2 MITIGATION MEASURES PROFFERED FOR THE VARIOUS CATEGORIES OF IDENTIFIED IMPACTS

6.2.1 Reduction of access to natural environment and its resources

Mitigation measures: Operators Shall

Identify alternative access route to natural resources.

- Plan and commence alternative income generating activities (micro-credits, youth developments scheme, women trade centers, aquaculture and improved farming techniques).
- Ensure that Land use changes within acquired area are limited to the minimum required.
- Use road upgrade methods that maintain and reduce erosion

The application of these measures shall reduce the impact from major to moderate

6.2.2 Third party agitation

Mitigation measures: Operators shall:

- Identify the relevant stakeholders/legacy issues.
- Carry out regular consultation with stakeholders (Relevant Government Agencies, Community, NGOs, etc.).
- Make adequate and prompt compensation where applicable.
- Set up Project Advisory Committee (PAC) to guide / MOU implementation.

The application of the above mitigation measures could reduce the impacts from major to minor..

6.2.3 Loss of revenue from traditional occupations

Mitigation measures: Operators shall:

Identify relevant alternative income generating activities (micro-credits, youth developments scheme, women trade centers, aquaculture and improved farming techniques) for those who will be displaced due to Marcellus Shale development activities

This will reduce the impact from major to a residual impact of minor

6.2.4 Destruction of indigenous plant communities; Loss of habitat for fauna, microorganism within the acquired land due to upgrade/drilling activities

Mitigation measures: Operators shall:

- Restrict land clearing to the minimum required
- Re-vegetate any area cleared outside the required areas with native plant species
- Carry out vegetation studies six months after construction
- Clearly mark out the areas to be cleared, with the clearing restricted to the marked areas for the new structures to be put in place.

It was rated as moderate with the application of the mitigation measures the residual impact will be minor

6.2.5. Traditional occupations (farming) could be adversely affected;

Mitigation measures: Operators shall provide

- Alternative access to farmlands where applicable
- Limited land take to the minimum required
- Impact on traditional income shall be assessed and adequate compensatory measures taken, where necessary

These measures will reduce the impact from moderate to minor

6.2.6 Nuisance (noise, emissions, vibrations) from heavy machinery;

Mitigation measures: Operators shall:

- Use machinery with noise level within acceptable limits (85 dB (A))
- Carry out site construction within the shortest possible time;
- Provide acoustic mufflers for heavy engines with noise level above acceptable limits;
- Avoid low over flights, where practicable;
- Ensure high sound energy equipment are enclosed in noise insulators in line with Environmental Management Policy;
- Apply HSE policy of wearing ear muffs/ plugs in all construction sites;
- Ensure the provision of sufficient separation distances for sources of high-energy sound to reduce noise levels.
- Deploy workers without existing hearing impairment to site;
- Ensure construction equipment are maintained regularly;
- Ensure air quality/noise level is monitored in line with ISO requirement (CO_x, SO_x, NO_x, SPM etc)

These measures will reduce the impact from moderate to minor

6.2.7 Pressure on existing roads and their users with the possibility of increased accidents

Mitigation measures: Operator shall:

- Create awareness on the potential of increased traffic accident on land and for road users and community members

- Ensure that the policy on road traffic journey Management is adhered to (all journey must be approved, no night journeys, speed limits on land).
- Undertake the upgrade of existing roads to suite the proposed project activities with additional access roads provided, where necessary. Road network within the project area shall be maintain regularly
- Ensure the provision of traffic signs on all the approved routes for the project during the construction phase.

These measures will reduce the impact from moderate to minor.

6.2.8 Increased social vices

Mitigation measures: Operators shall:

- Carry out awareness campaign to enlighten the communities/field workers on the implications of drug and alcohol abuse, unprotected sex, prostitution and the need to sustain cultural values
- Restrict the movement of field workers to camp/work sites
- Insist that sub contractors provide alternative recreational facilities at camp sites
- Implement Alcohol and drug/HIV/AIDS policies to encourage healthy lifestyle for workers

These measures will reduce the impact from major to moderate.

6.2.9 Impairment of air quality leading to increase upper respiratory tract diseases

Mitigation measures: Operators shall

- Support provision of drugs, upgrading of facilities and staff training of existing health facilities.
- Ensure appropriate dust masks/respirators are provided for workers
- Provide health and recreational facilities for workers to reduce stress and health vulnerabilities
- Ensure Water tankers are used to sprinkle water on exposed dusty soil surface

These measures will reduce the impact from moderate to minor.

6.2.10 Impairment of health of aquatic life

Mitigation measures: Operator shall:

- Ensure hazardous discharges from construction/drilling activities are treated prior to disposal

This measure will reduce the impact from moderate to minor.

6.2.11 Contamination of surface/groundwater and impairment of health of aquatic life

Mitigation measure: Operators shall:

- Segregate generated solid waste at source by the provision of color coded bins for different types of waste and dispose of according to company's waste Management guidelines
- Shred paper waste and sell to approved paper re-cycling vendors
- Collect de-contaminated scrap metals/drums and take to approved re-cycling vendors
- Take spent batteries to approved re-cycling vendors

These measures will reduce the impact from moderate to minor.

6.2.12 Increase accidents and injuries

Mitigation measures: Operators shall:

- Provide health and recreational facilities for workers to reduce stress and health vulnerabilities
- Ensure all contractors personnel are medically certified fit for their different activities and medical reports submitted for evaluation.
- Ensure all contractors provide retainership clinics and site medical facilities such as first aid.
- Carry out Health Risk Assessment (HRA) for all jobs to manage/control the potential health hazards associated with the activities.
- Provide adequate training on basic life saving techniques such as first aid, resuscitation, care of the unconscious and control of bleeding in line with contingency medical emergency response procedures.

- Ensure all contractor personnel are adequately trained to acquire the pre-requisite competence for the different jobs.
- Enforce and ensure all operations personnel are provided with appropriate Personnel Protective Equipment (PPE), and are worn.

6.2.13 Contamination of surface/groundwater/decreased availability of household water

Mitigation measures: Operators shall**:**

- Ensure that sanitary wastes are treated biologically by sewage treatment plant on site
- Provide emergency response prevention/control equipment at site
- Enforce the provision of bund for storage tank (diesel, lub oil and other chemicals) which are adequately lined with concrete to reduce seepage
- Drill monitoring boreholes to monitor ground water quality (toxic chemicals and faecal microorganisms) in line with regulatory requirement
- Register all discharge point sources with the state ministry of Environment and ensure that effluents from project sites are monitored and treated to comply with regulatory limits before disposal

These measures will reduce the impact from moderate to minor.

6.2.14 Contamination of surface, ground water quality and Soil quality

Mitigation measures: Operators shall:

- Implement emergency response plans when the need arises
- Drill monitoring boreholes to monitor ground water quality (toxic chemicals and faecal microorganisms) in line with regulatory requirement
- Characterized all wastewaters prior to disposal.
- Channel waste water from equipment washing to a concreted holding basin (impermeable receptacle) for treatment
- Treat wastewater to acceptable regulatory limit before disposal.
- Enforce the supervision of the disposal of generated wastewater by State or Federal DEP

These measures will reduce the impact from moderate to minor.

6.2.15 Effects on corporate reputation of Operators

Mitigation Measures: Operators shall:

- Identity the relevant stakeholders/legacy issues
- Undertake regular consultation with stakeholders (Appropriate Govt. Agencies Community, NGOs, etc.) and make adequate and prompt compensation, where applicable

These measures will reduce the impact from major to minor.

6.3.0 Measuring Safety and Compliance in the U.S. Gas Industry

Periodic inspections are mandated for all operators in the U.S. gas industry, overseen by the inspection program put in place by the Minerals Management Services (MMS). There are over 600 violations called the potential incidents of non compliance (PINC's) regulated by the MMS and if operators do not meet the stipulated requirements for operation, the operators are issued incident of non compliance (INC) by the MMS. Since there are so many operations and operators in the gas industry, which makes inspecting every expect of operations tedious, the MMS have made the requirement for inspection a standard nationally with a list of PINC's and placed into ten different categories as follows;

- Measurement
- Drilling
- Completions
- Production
- Workovers
- Pipelines
- Hydrogen Sulfide
- Environmental
- Abandonment
- General

The incident of non-compliance issued by the MMS comes with some enforcement actions denoted by the following;

- (W) represents mere warning
- (C) represents component shut- in
- (S) represents entire facility shut-in

require instant corrective actions

Depending on the level of severity of the INC, it may be considered for civil penalty if it is of considerable health risk to humans, terrestrial and marine environments. Criminal charges may be filed against any operator who intentionally commit these violations and threatens human health significantly.

6.3.1 Measuring Safety in Operations

Mineral Management Services (MMS) developed a formula that presents the situation involving operators and each accident that occur in their operations. This is done so that relative comparisons can be made between operators based on safety performance in their operations. The size and complexity of operations vary widely amongst operators; due to this fact MMS usually normalizes accident and compliance data with respect to inspected components and the number of available components. Weighting criteria was developed by the Mineral Management Services for the values of Incident of Non Compliance (INC) severity carried out by the enforcement actions. This gives a clear view of the safety level of operators in the industry, and the following formula is used to calculate the Operator's Safety Index (OSI).

$$\boldsymbol{OSI} = \frac{[\boldsymbol{W}(\mathbf{1}) + \boldsymbol{C}(\mathbf{2}) + \ \boldsymbol{S}(\mathbf{4}) + \ \boldsymbol{CP}(\mathbf{8})]}{[(\boldsymbol{CI}) + \left\{\frac{\boldsymbol{AS}}{\boldsymbol{CA}}\right\}]}$$

The enforcement action's notations are as follows;

- (W) mere warning
- (C) component shut- in
- (S) entire facility shut-in
- (CP) INC's referred for civil penalty
- (CI) total number of inspected components
- (AS) total accident severity from accident table
- (CA) total number of available components

The enforcement actions listed above are effective in determining the Operator's Safety Index and assessing the operator's level of regulation compliance.

Assuming there is an operator that has a fairly complex operation in the Marcellus Shale gas development and it is an average sized company with 25 horizontal wells and 5 vertical wells in the area. If the enforcement actions against the company in 2010 were as follows;

- (W) mere warning = 18
- (C) component shut- in = 14
- (S) entire facility shut-in = 3
- (CP) INC's referred for civil penalty = 0
- (CI) total number of inspected components = 1490
- (AS) total accident severity from accident table = 0
- (CA) total number of available components = 1651

The company's OSI for 2010 would be;

$$\boldsymbol{OSI} = \frac{[\boldsymbol{W}(\mathbf{1}) + \boldsymbol{C}(\mathbf{2}) + \ \boldsymbol{S}(\mathbf{4}) + \ \boldsymbol{CP}(\mathbf{8})]}{[(\boldsymbol{CI}) + \left\{\frac{\boldsymbol{AS}}{\boldsymbol{CA}}\right\}]}$$

$$\boldsymbol{OSI} = \frac{[\mathbf{18}(\mathbf{1}) + \mathbf{14}(\mathbf{2}) + \ \mathbf{3}(\mathbf{4}) + \ \mathbf{0}(\mathbf{8})]}{[(\mathbf{1490}) + \left\{\frac{\mathbf{0}}{\mathbf{1651}}\right\}]}$$

$$\boldsymbol{OSI} = \frac{\mathbf{58}}{\mathbf{1490}} \ = \mathbf{0.0389}$$

$$\boldsymbol{OSI} \approx \mathbf{0.04}$$

The safety performance of companies can be evaluated from this index. Operators with OSI of 1.0 and higher falls under the unacceptable operations category, otherwise, they fall in the acceptable operations category.

6.3.2 Incident rate and violations

Incident rate is the measure of the frequency of occurrence of incidences, and the value of the accident severity is additive by the different category of events. The importance of the OSI is to identify safety compromise by operators and also underscore operators with pertinent safety issues. Using the weighting method, it is easier to identify the operators with severe problems with non-compliance. The incident non-compliance (INC) weighting system uses a simple geometric progression such as 1, 2, 4, 6, and 8 which enables the MMS to statistically analyze the level of no compliance in the industry to form a correlation between INC and future occurrence.

6.3.3 Operator Disqualification

The MMS uses all the tools at its disposal to enforce proper safety compliance which all operators in the Marcellus Shale development must follow. If a designated operator who carries out operations on a permitted lease is found to be perpetually no compliant, either personally or on contracted operations, such operator would be made to undergo the process of operator's disqualification. Once there is a safety concern of any sort identified, the MMS calls for a meeting with the operator, and enforcement actions are given to such operator, with the use of the OSI, all operators are classified into two different categories, the acceptable operations category and the unacceptable operations category. Annually, in the gas industry about 97% of operators have OSI below 1.0 and they fall under the acceptable operations category. The remaining 3% have OSI above 1.0 and there operations are non-acceptable. They are subjected to a wide range of enforcement action depending on the severity of the violation, level of compliance and accident records. Some of the actions that may be taken against the operators include;

- Probationary conditions obliging the operator to submit a performance improvement plan
- Suspension of operators operations at active facilities
- Operator's disqualification to operate in specific district
- Operator's disqualification to operate a specific facility
- Operator's disqualification to operate regionally
- Operator's illegibility to acquire new facilities

These are just some of the actions that could be taken against any operator that falls in the unacceptable operations category as suggested by the high level of OSI. Although the OSI is not a broad tool to measure operator's performance at all fronts, but it is effective in identifying the level of compliance by operator to stipulated regulations. The OSI also provides a lead in strategic inspection planning through the Mineral Management Services risk based inspection program for OCS facilities.

6.4.0 SUMMARY OF ENVIRONMENTAL ISSUES & POLLUTION PREVENTION PRACTICES

As discussed in the previous sections, most of the causes of pollution in the Marcellus Shale play as a result of gas development come from a wide range of sources that have both short lived effects and chronic effects, depending on the level of exposure and potency of the pollutants. Some of the pollution sources are summarized below;

- solid wastes disposal; such as drilling cuttings, drilling fluids and workover operations
- produced water contaminations
- well stimulation additives such as; acids, corrosion inhibitors, surfactants, viscosifiers, biocides, etc
- heavy metals and organic from formation
- naturally occurring radioactive materials in some areas
- discharge of contaminants from improperly lined pit and the pit closure requirement
- air emissions
- volatile organic compounds (VOCs) and "non-VOCs", majorly methane directly from leaks, also from venting of excess pressure
- gas flaring of associated gases such as methane; carbon oxide, hydrogen sulfide; and nitrogen oxides emanating from combustion)
- transportation and storage of natural gas and waste materials and related accidents
- intentional discharges
- reinjection
- separated water discharge into percolation pits
- reuse processes such as irrigation and livestock, road dust control)
- underground migration of pollutants through improperly installed casings into the aquifers
- drilling in ecologically sensitive regions
- idle wells that are plugged but not producing
- from orphan wells; wells that have been abandoned, or the owner is unknown.

6.4.1 MINIMIZING POLLUTION & IMPROVING OVERALL PROJECT ECONOMICS

The aim of any pollution prevention program should be in reducing the amount of contaminant release and also minimizing the effects of the sources of these pollutions which would create economic feasibility of the project, reducing the impact of the gas development on the environment and also pose lesser threat to the health quality of residents with the use of advanced technologies. The following are examples of process changes according World Bank, (1998).

- Optimum use of freshwater gel-based mud systems.
- Reuse diesel based mud but ultimately eliminate its usage
- Effectively recycle drilling mud decant water.
- Prevent the degradation of sweet wells with the use of hydrogen sulfide scavengers-sulfate reducing bacteria.
- Use of less toxic additives such as corrosion inhibitors, biocides, etc
- Reduce the occurrence of gas flaring.
- Reduce and control leaks from pipelines and tanks.
- Ensure corrosion prevention is done on all facilities.
- Ensure the removal of sulfur compounds from sour gases before flaring
- Prevent condensate emissions discharges with the use of knockout drums on gas flares
- Regenerate used solvents, or take for recovery offsite.
- Make use of low-nitrogen oxide burners in process heaters.
- Provide spill prevention and mitigation measures such as pressure relief valves and high alarm systems.
- Recover oil present in wastewaters effectively.
- Ensure the separation of storm water from process water.
- Employ leak recognition and also repair programs.
- Ensure all maintenance programs are routinely updated and they are operational such as reclamation, remediation, contingency and closure plans

These plans should be effective in addressing all issues that may lead to environmental disasters arising from the gas development activities. Such issues include; waste removal and disposal in an environmentally responsive approach, remediation and site restoration.

6.5.0 USE OF ADVANCED TECHNOLOGY FOR POLLUTION PREVENTION/ CONTROL

There are several developments in technology that tackle the problem of pollution and also reduce the impacts associated with gas development on the environment. Although these novel technologies exist, they are applicable to specific drilling operations not all operations. It is required of all operators to follow stipulated pollution minimization guidelines in an attempt to reduce the footprint of gas development operations and also to incur cost saving measures in the implementation of significant environmental remediation programs. The United State Department of Energy publication in 1999 highlighted the areas of pollution prevention as follows;

- Drilling waste management
- Low-impact operations in sensitive environments
- Produced water management
- Production waste management
- Spill prevention & Remediation
- Air emissions control
- Underground injection
- Data management
- Risk management planning
- Toxics discharges observation and reporting to regulators

The advent of these technological improvements have made gas exploration, gas development, gas production and processing, transportation and distribution of gas a lot more economically feasible, increased efficiency, sustainability and overall protection of the environment. An example of where this technological improvement is applicable is for deviated wells, such as horizontal wells, the technology provides accurate interactive information that suggests where to deviate the well and how far to go; this is made possible by the advances in 3-D seismic technology. Other technologies employed during drilling include;

- Measurement-while-drilling (MWD) technology,
- Developments in fiber optics,
- Advanced sensors, and mud pulse telemetry,

These technologies are effective in ensuring so many possibilities such as assisting during drilling processes by providing flexibility for instance steering the well to the desired target.

6.5.1 TECHNOLOGY SOLUTIONS - ENVIRONMENTAL SUSTAINABILITY AND PROFITABILITY

Several pollution prevention technologies have been developed geared at reducing or eliminating environmental pollutions effectively in the Oil and Gas exploration and production industry. Newly developed engineering and operational techniques in exploration and production have emphasized the following,

Smarter Intelligent and fast computing, this is referred to as "smart wells"
Farther Deviated wells, such as horizontal wells or multiple laterals that are laterally extensive
Deeper wells: Deep subsalt exploration and production
Cleaner operations: Down hole separation technology, , Gas-to-liquids conversion,
Smaller Footprint, minimal effect on the environmental impact, use of micro hole technology

Due to this advancement, fewer wells are drilled, smaller well pads used, and less roads impact while more gas is produced resulting to fewer waste generated. These novel extraction techniques are changing the landscape of drilling and they have lesser impacts to the ecosystem than the conventional techniques employed before now. The economic importance of this advancement is huge, since wildlife, aquifer life, vegetation, surface and underground water sources and air quality are minimally impacted during developmental activities.

6.5.1.1 Available Technologies and their Impact on Environmental Protection

Geologist

- Advancement in satellite imagery and remote sensing technologies coupled with gravity and aeromagnetic accurately identifies the location of oil and gas in the subsurface with minimal incurred cost and reduced impact on the environment compared to ground surveys. After the reconnaissance survey is completed, a detailed survey is carried out on the ground with the use of three dimensional seismic techniques alongside other visualization techniques that gives the geologists a better perspective of the target.

Drilling Engineer

- The drilling job has been greatly improved with the development of several computing technologies such as the fiber optic sensor technology that enables the driller to be constantly aware of the prevalent conditions in the well down to the bottom of the hole. This fiber optic equipment make measurements of the subsurface characteristics and allows also for the flexibility of controlling as many as 30 horizontal wells from a single well drilling pad. This creates for better environmental conservation, improves safety and ensures optimum productivity
- Slim hole drilling is another technology that is very promising, this involves drilling a hole of 6 inches or even less during the early stages of exploration and also for mature fields. This technique is cost effect, environmentally friendly, reduces waste, and all other associated environmental impacts that are related to gas development operations.
- Another form of the slim hole drilling is the use of micro-hole coiled tubing drilling technology, this involves the use of microelectronics for manipulation, control and formation evaluation in the well at a borehole diameter of 2 inches, it can penetrate up to 7,000 feet from the surface (fossil.energy.gov/programs/oilgas/microhole). This method is more economical than the slim hole mentioned above and produces even lesser environmental impacts at all stages.

Petro-technical

- The popularity of fiber optics technology is increasing in the oil and gas industry due to its applicability for production optimization. This is applied for smart wells where reservoir property data are collected down hole and this can be used from monitoring stations in around the world through internet connectivity. Also the efficient use of energy is important, for field equipment by installing automatic timers during off peak hours, according to the US DOE, could reduce cost of power generation by 25% while production is not altered.

6.5.2 Technological Impacts on Pollution Sources

Best Management practices (BMP) and technology changes, if properly implemented are useful tools in ensuring that major sources of pollution such as drilling wastes and air pollution are reduced to the barest minimum. The following section describes the impact in details

Air Emissions:

- There are several inventions proffered into the industry with the aim of emission reduction from all power generations associated with combustion processes during well development, some of which include; recovery of waste heat, efficient fuel use, maximization of compressors and pumps and the use of energy conservation procedures. In the light of this, air emissions are reasonably reduced, but even more reduced when other technologies are incorporated for an enhanced combustion performance to reduce nitrogen oxide emissions, such as; selective catalyst reduction technology (SCR), dry low nitrogen oxide combustion technology, and steam and water injection.

Produced Water

- Novel technology such as the water shut-off technology which uses diverting gels in the provision of resourceful ways in the reduction in waste water quantities that requires treatment. The use of disposal wells where available into compatible formations provides a good means of getting rid of this waste water effectively. Dispersed oil in the produced water can be separated with the use of new technologies such as mechanical centrifugation, gas stripping and gas floatation. According to the US DOE in 2005, the treatment of this produce water can also be done using the following methods, evaporation, bio-oxidation, activated carbon filtration, reverse osmosis, ozonation, wet oxidation and forward osmosis.

Solid Waste

- Extensive research has been done to identify the best drilling fluid for gas development with the lowest toxic constituent. Mud and other additives are carefully chosen to ensure they do not contain heavy metals or toxic compounds. The 4 R’s technique is useful in ensuring that cost savings are incurred while optimizing productivity without negatively affecting the environment of operations. The 4R’s are reduce, recover, recycle and reuse of waste materials. The cuttings during drilling can be used in the brick manufacturing industry and road constructions, while other waste such as heavy hydrocarbons, emulsions and tank bottoms can also be used for road construction jobs. The novel technologies applied in solid waste treatment are also making a difference, such as the composting, tank based reactors, land spreading, detoxification, extraction, neutralization, centrifugation, gravity separation, filtration etc. In the future, the advancement of the downhole separation of waste will greatly enhance the effort of reducing the impact on the surface.

6.6.0 REGULATION AND POLICY OF PENNSYLVANIA STATE ON UTILIZATION

Several policies abound that are used to protect humans and the environment, these policies centralizes on the protection of the environment in the light of technological advancement and clean energy usage.

6.6.1. Overview of Regulation History for Gas Industry

Regulations are initiated by the Federal and State governments to guide petroleum extraction processes. The Federal government started with the regulations amongst different municipalities as gas producers started the sale of gas locally before expanding the market to outside states. With advancement in technology and industrial growth, so did the regulations, which became very complicated and conflicting. Due to numerous regulations that ensued, the Federal regulation was important to resolving the issues encountered.

Since 1977, the major regulatory agency in charge of the gas industry’s activities has been the government regulatory body, the Federal Energy Regulatory Commission (FERC), which has been effectively managed by the Department of Energy Organization Act of1977, with regulations and deregulations. Some of the issued orders are;

- FERC Order No.436, this pertains to interstate pipelines,
- FERC Order No.636 this is for pipeline unbundling services.
- Wellhead Decontrol Act of 1989 this is for deregulation of the wellheads in Natural Gas

6.6.2. CURRENT REGULATION AND DEREGULATION

Both the pipelines facilities and the local distribution corporations are directly regulated based on their provided services, whereas the markers and the gas producers are not directly regulated under current situation. The natural gas producers and marketers are however regulated by environmental regulations and the Local Act (Naturalgas.org, 2009). It is the duty of the State Utility Commissions to regulate the local distributions of the product by companies, construction problems as they emerge and ensure that appropriate levies are imposed with a view of ensuring that there is an adequate flow of products to consumers (Naturalgas.org, 2009).

Naturalgas.org (2009) reiterated that the Federal Energy Regulatory Commission (FERC) regulates gas companies to ensure that there is no recordable incidence of misuse of monopoly by such operators that are considerably powerful in the market and FERC have established its regulations with the following aims and objectives;

- As part of its priorities, FERC ensures a level playing field for all players by mitigating market power through the monitoring of energy market variations and dynamics, thereby servicing the sole aim of protecting market participants but ultimately, protecting the customers.
- In instances where there are no competitions, it serves as substitute
- Guarantee of superior service
- Prohibit the improvident replication of facilities
- Preclude inequitable or privileged service offered as a bias
- Guide against wasteful investment and inequitable pricing
- Encourage with the use of dependable policy, energy infrastructure that is environmentally safe, effective, high-quality, and standard
- Substituting conventional regulation for effective competitive market

There exist a number of regulations and orders implemented by the Federal Energy Regulation Commission, in the gas industry, among whom are;

- FERC Order 636 of 1992, entails interstate pipeline restructuring
- FERC Order 637 of 2000, outlines short term pipeline services
- FERC Order 639 of 1999, entails gas movement in the US (OCS)

6.6.3. POLICY FOR GAS INDUSTRY

The regulations discussed above as pertained to the natural gas sector in the United States are basically the federal regulations currently available. On the State level, regulations exist also and in the state of Pennsylvania there are a list of regulations that aims at increasing energy efficiency and minimizing the consumption of gas. This is achievable by allocating funds for advancement in technology and by tax breaks for energy usage in the State. The Pennsylvania State energy policies and climate considerations are listed below;

- Alternative Energy Portfolio Standards Act (2004): This was used in August 2006 in Pennsylvania State for the adoption of the interconnection standards which overs four distinct tiers of up to 2MW in size of clean Distributed Generation (DG) alongside the CHP. Each of this level expresses detailed timelines and technical monitors.

- Vehicle Policy: The California State Low-Emission Vehicle Program was adopted in 2006 by the State of Pennsylvania, making a 14 year commitment plan to reduce the average emissions of the GHG in new vehicles by 30% from 2002 to 2016

- **Smart Growth Policies:** In 2000, the State of Pennsylvania enacted the Growing Greener and Growing Smarter Acts; this was a revolution in the energy industry which boosted urban developments and was intended to control the issue of climate change. Seven years later the State came up with a climate change roadmap with current situation in mind, there was a projection of 10% increase in greenhouse gases emission in the state per ten years. If this policies and hybrid policies from other states are properly implemented, there could be a huge reduction in the emissions from greenhouse gases in the near future (Council PA Environment, 2009). This will consequently improve how business is done in the energy industry and provide new opportunities for investors interested in the production of clean energy

- **Electric Utility Sector Policies:** Alternative Energy Investment Act took effect in July 2008 with an energy fund of $650 million, this provide loans to homeowners for investing in efficient energy in their homes. This fund would enhance energy efficiency of existing homes, small businesses, and buildings while improving the technology

CHAPTER SEVEN: ANALYSIS, RESULT AND DISCUSSION

7.1 PROJECT DESCRIPTION

Marcellus Shale Violations:

The Borda count as described by Saari D.G. (1985) is an iteration process tool, which is very useful in decision making, was used in a public voting system around 1782-1784. Data from the Pennsylvania Department of Environmental Protection (DEP) on Operators violations in the Marcellus Shale from 2008 to 2010 was analyzed. The Borda count technique was employed for ranking of the different violations and assigning weights to them based on priority and category. All violations in the Marcellus Shale were categorized based on severity and potential impact to the environment.

The table below shows the ranking, violation descriptions (adapted from Pennsylvania DEP) and the total of violations under this ranked group for all operations in a three year period (2008 – 2010).

Table 9: Violation ranking (2008-2010) based on the Borda Count (Saari DG, 1985)

Rank	Violation Description	Total
1.	❑ Failure to post permit number, operator name, address, telephone number in a conspicuous manner at the site during drilling ❑ Failure to install, in a permanent manner, the permit number on a completed well ❑ Failure to post pit approval number ❑ Failure to notify DEP, landowner, political subdivision, or coal owner 24 hrs prior to commencement of drilling ❑ Drillers Log not on site ❑ Administrative Code General ❑ Encroachment without Permit or Waiver ❑ Failure to mark plugged well ❑ Failure to submit annual production report	317
2.	❑ No E&S plan developed, plan not on site ❑ Failure to have permit on site during drilling ❑ E&S Plan not adequate ❑ Encroachment –General	201

Rank	Violation Description	Total
	❑ Person constructed, operated, maintained, modified, enlarged or abandoned a water obstruction or encroachment but failed to obtain Chapter 105 permit ❑ Failure to affix, in a permanent manner, a registration number on a well within 60days of registration. ❑ Oil and Gas Conservation Law- General	
3.	❑ Impoundment not structurally sound, impermeable, 3rd party protected, greater than 20" of seasonal high ground water table ❑ Failure to maintain 2' freeboard in an impoundment ❑ Rat hole not filled, Rat hole was not filled before drilling equipment was moved off of location. A drill hole or bore hole used to facilitate the drilling of a well shall be filled with cement, soil, drill cuttings or other earthen material before moving the drilling equipment from the well site. ❑ Adequate impoundment freeboard was not maintained. ❑ Failure to submit well record within 30 days of completion of drilling ❑ Failure to submit plugging certificate 30days after well plugged ❑ Clean Streams Law-General. Used only when a specific CLS code cannot be used	439
4.	❑ Improperly lined pit ❑ Failure to report defective, insufficient, or improperly cemented casing w/in 24 hrs or submit plan to correct w/in 30 days ❑ Inadequate, insufficient, and/or improperly installed cement ❑ Failure of storage operator to maintain and/or submit required information, such as maps, well records, integrity testing information, pressure data	91
5.	❑ Industrial waste was discharged without permission ❑ O&G Act 223-General. Used only when a specific O&G Act code cannot be used, Discharge of drilling mud to the ground ❑ Pit and tanks not constructed with sufficient capacity to contain pollutional substances. ❑ Failure to minimize accelerated erosion, implement E&S plan, maintain E&S controls. ❑ Failure to stabilize site until total site restoration under OGA Sec 206(c)(d)	776
6.	❑ Failure to construct properly plug, frac, brine pits ❑ Improper encapsulation of waste ❑ Drilling w/in 100 ft of surface water or wetland w/o variance ❑ Failure to case and cement to prevent migrations into fresh groundwater ❑ Failure to case and cement properly through storage reservoir or storage horizon ❑ Failure to plug zones having borne gas, oil, or water ❑ Hazardous well venting ❑ Inadequate containment of oil tank	65
7.	❑ Failure to restore site w/in 9 months of completion of drilling or plugging	45

Rank	Violation Description	Total
	❑ Permittee has failed to perform work according to specifications as approved ❑ Leaking plug or failure to stop vertical flow of fluids	
8.	❑ There is a potential for polluting substance(s) reaching Waters of the Commonwealth and may require a permit. ❑ Site conditions present a potential for pollution to waters of the Commonwealth. ❑ Drilling, altering, or operating a well without a permit ❑ Failure to restore site w/in 9 months of plugging well ❑ Failure to take all necessary measures to prevent spill. Inadequate diking, potential pollution ❑ Improper casing to protect fresh ground water ❑ Improper coal protective casing and cementing procedures.	156
9.	❑ Failure to notify DEP of pollution incident. No phone call made forthwith ❑ Stream discharge of IW, includes drill cuttings, oil, brine and/or silt ❑ No Control and Disposal/PPC plan or failure to implement PPC plan ❑ Failure to plug a well upon abandonment ❑ Failure to comply with terms and conditions of permit ❑ Failure to properly store, transport, process or dispose of a residual waste. ❑ Failure to adopt pollution prevention measures required or prescribed by DEP by handling materials that create a danger of pollution.	257
10.	❑ Discharge of IW to ground ❑ Polluting substance(s) allowed to discharge into Waters of the Commonwealth. ❑ Inadequate or improperly installed BOP, other safety devices, or no certified BOP operator ❑ Tophole water discharged improperly ❑ Discharge of industrial waste to waters of Commonwealth without a permit.	254

Analyzed from Pennsylvania Department of Environmental Protection Data

The total number of violations for each year is summarized as shown in Table 10 below based on the ranking method.

Table 10: Total number of Violations in the Marcellus Shale for a three Year period

Year	Ranking										
	1	2	3	4	5	6	7	8	9	10	Total
2008	55	76	78	8	227	29	18	22	41	64	618
2009	57	60	120	21	277	4	3	30	32	35	639
2010	205	65	241	62	272	32	24	104	184	155	1344
Total	317	201	439	91	776	65	45	156	257	254	2601

Ranking based on the Border Count

The Table 10 above shows the different violations by all operators in the Marcellus Shale for a period of three years, 200-2010. The violations were grouped according to the severity and how it directly affects the environment. A number rank is given to each group to represent how serious the risk it poses to the environment can be interpreted. One is interpreted as being the least risky or less hazardous incidence, and 5 being the intermediate risk level. From left to right, the risk level increase until it reaches 10 which is the most risky/deadly and unsafe violation. There is a 342% increase in the incidence of potentially risky/deadly violations from 2009 to 2010, compared to the total violations committed between 2009 and 2010; there was a 110% increase. This trend will be analyzed further and interactions between the different violations as they occur annually be checked statistically to indicate their level of significance.

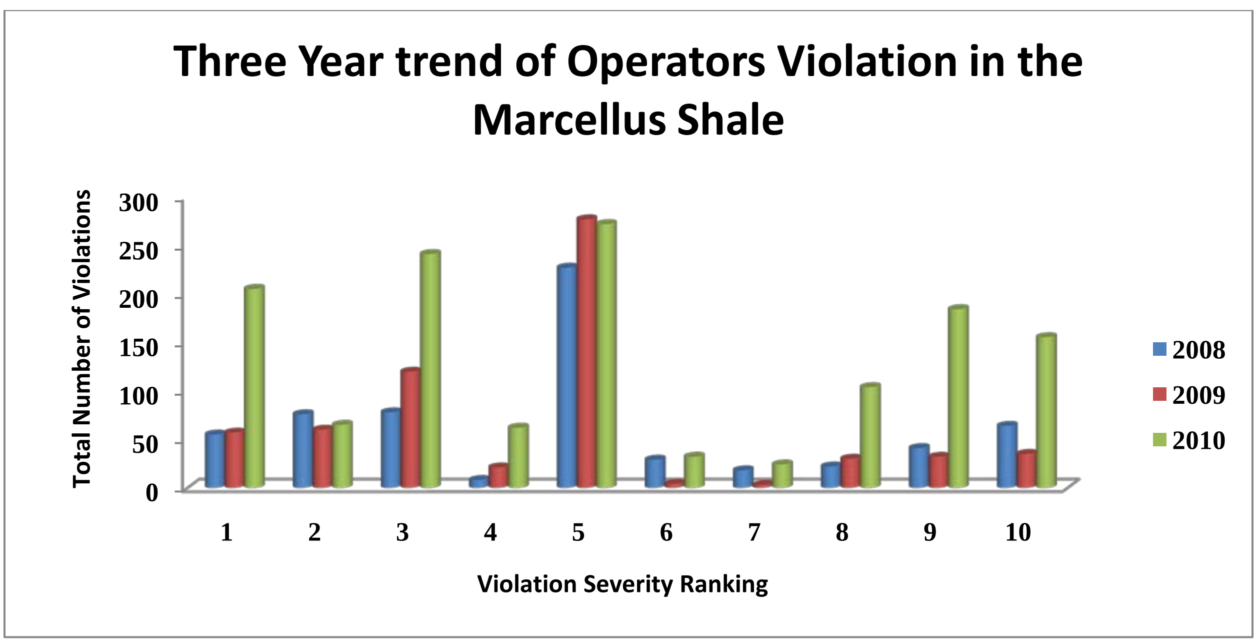


Figure 22: Ranking of Violations by Operators in the Marcellus Shale from 2008- 2010

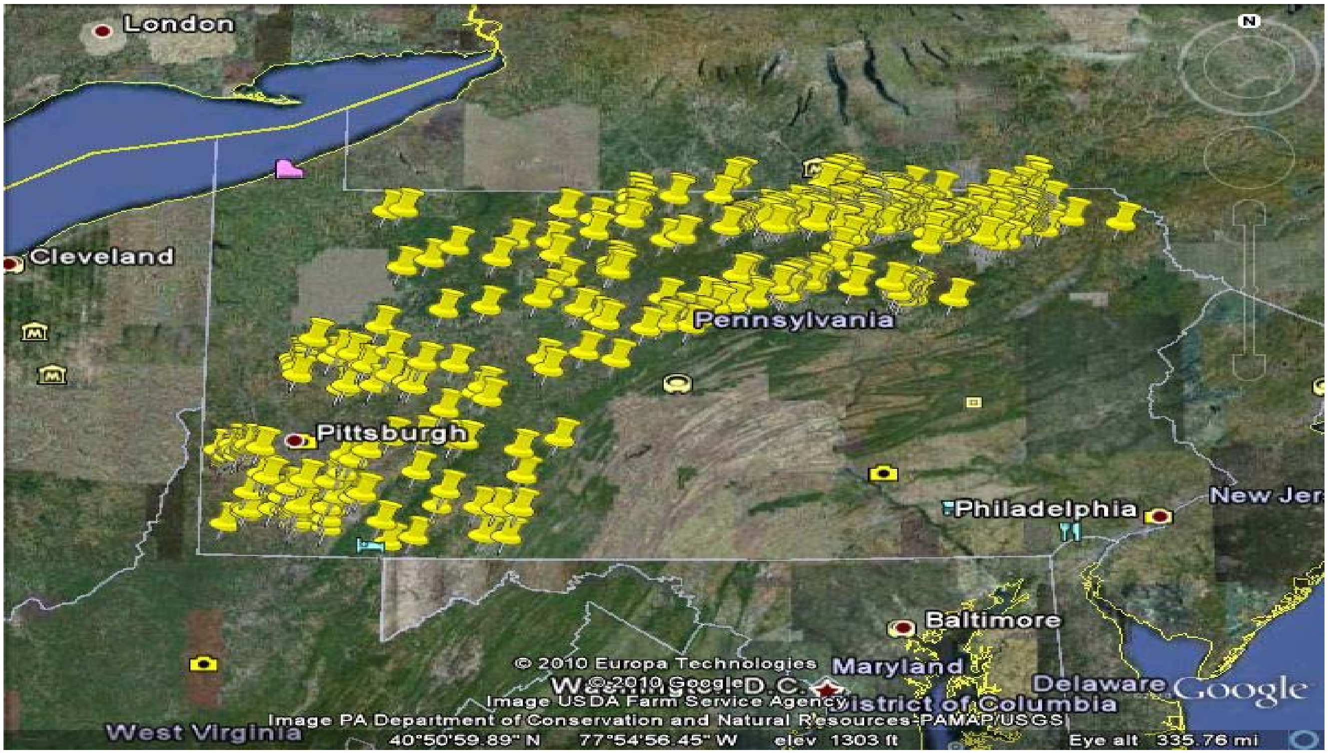


Figure 23 : Marcellus Shale Violation locations: Courtesy USDA 2010

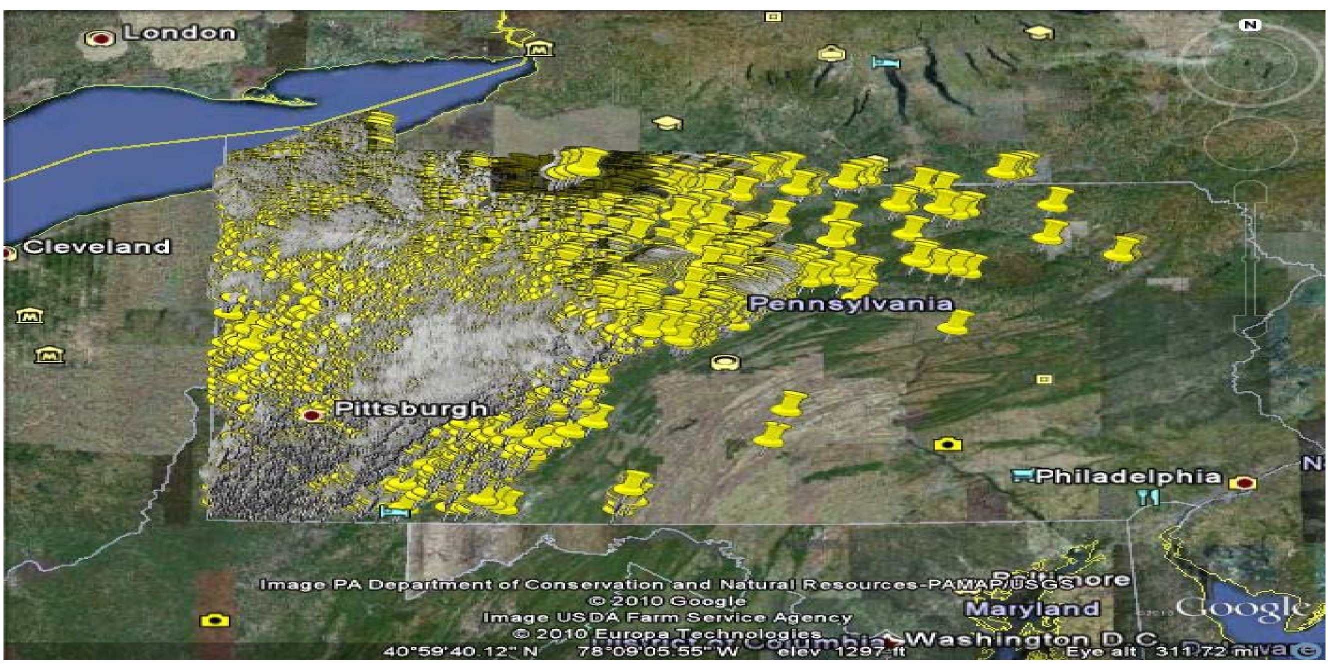


Figure 24: Marcellus Shale Well Locations: Courtesy USDA 2010

The Pennsylvania Department of Environmental Protection, confirmed that there are 1450 horizontal wells in the Marcellus Shale play and a total of 551 vertical wells, making the total number of spudded wells in Pennsylvania Marcellus play to be 2,001 wells. The locations are shown in Figure 24 above.

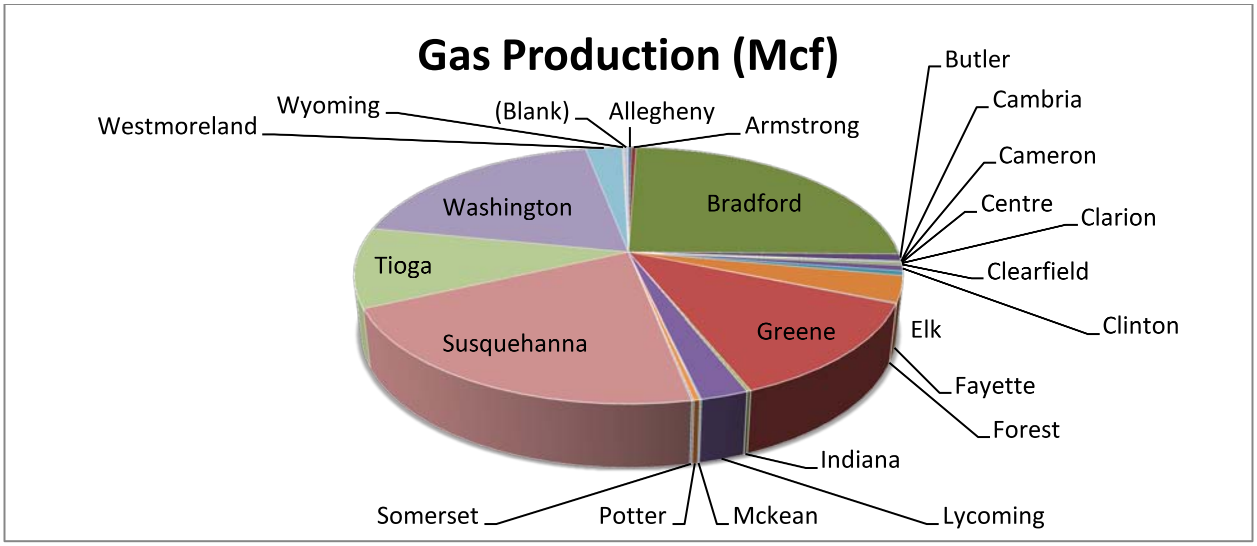


Figure 25: Marcellus Shale Gas Productions in Pennsylvania by County, July 1, 2009 through June 30, 2010.

It was identified from the data made available by the Pennsylvania DEP that operators in the Marcellus Shale violated state's oil and gas rules and regulations a total number of 2,601 times from January 1, 2008 to November 30, 2010. Out of which a total of 2,083 violations or 80% of the total violations committed are potential threats to the environment. Figure 26 illustrates the increase in particular violations within a three year period, and most of the increase possess imminent threat and risk to the environment. The most productive of the counties are Bradford, Susquehanna, Washington, Greene and Tioga, they account for a total of 87.27% of all Marcellus Shale production from July 2009 to June 2010. Figure 27.

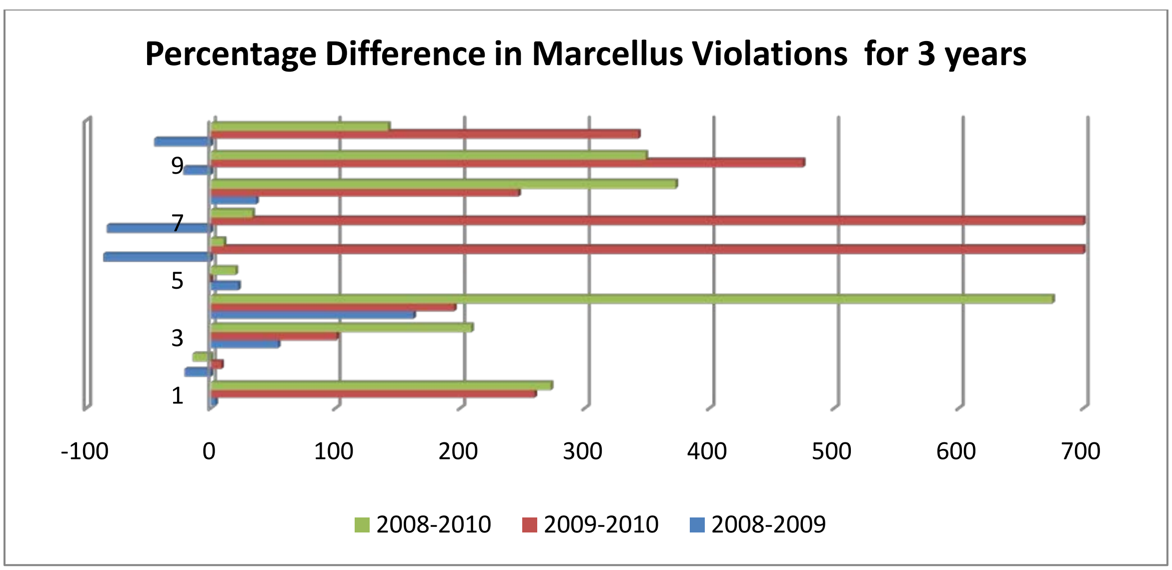


Figure 26: Percentage difference of Marcellus Shale Violations from 2008-2010

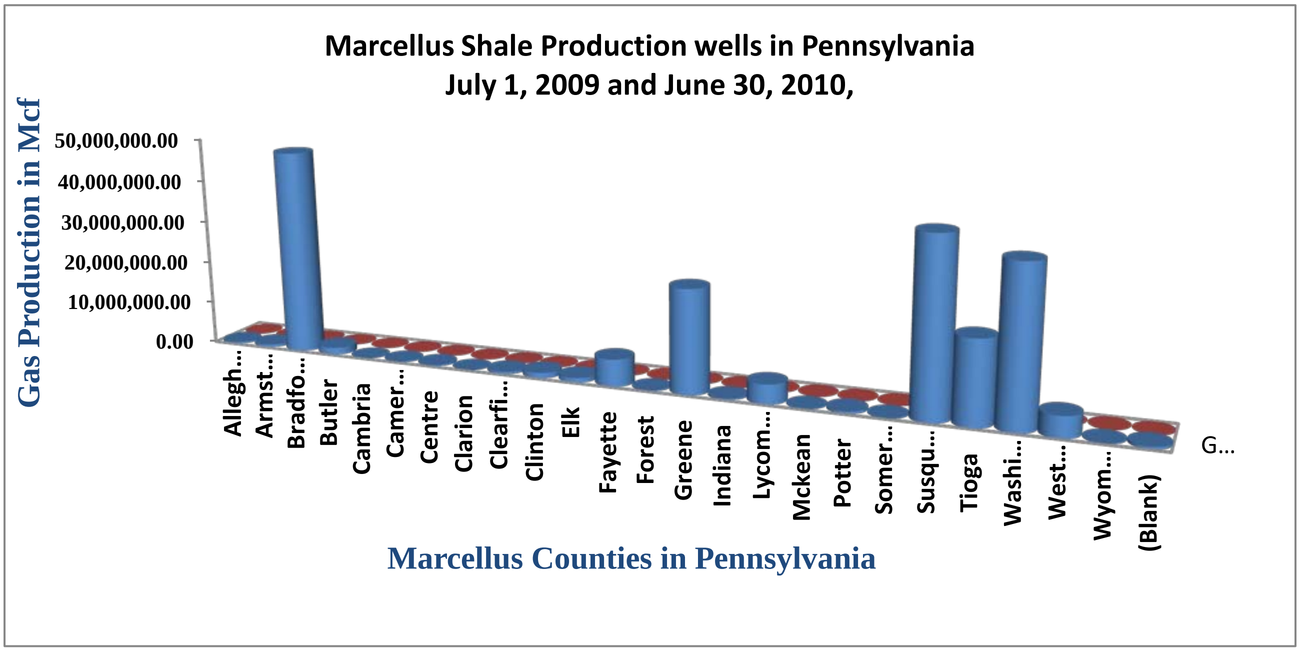


Figure 27: Marcellus Shale total Production by Counties in Pennsylvania

Production from Marcellus Shale wells between July 2009 and June 2010 was over 195 billion cu. feet (Bcf) of natural gas. This is part of the production from the 129,000 oil and gas locations identified by the DEP website and this suggests that heavy activities are ongoing in the region.

7.2 Statistical Objectives of study:

- Check for interaction between violations in the three years and forecast the future number of violations for the next three to five years.
- Develop a statistical code using the Statistical Analysis Software (SAS) by employing the analysis of covariance (ANCOVA) for predictive modeling and real visualization of the risk and safety evaluations in the Marcellus Shale gas play.
- Classify operators based to incident rate (i.e. severity of the violations based on significant values.

Incident rate was taken to be the total number of violations per level of severity, in other studies, violation per well was used, but that did not account for the magnitude of impact the incidences have on the Marcellus environment. In some cases, operators were found to have violated several numbers of times but the violations were neutral to the Marcellus Environment, but if the severity is not taken into consideration, there will always be a misconception that every operator that violates negatively affects the Marcellus Shale Environment. This research work is taking into account the contribution of each company's environmental footprint based on the number of violations committed in a three year period.

7.2.1 Main Variables:

The original data was processed and grouped by year of incidence (2008-2010) (Appendix B). And each year has thirteen variables. The first variable is "Operators in the Marcellus Shale". In the code, it is referred to as "company" to be an ID. The second to eleventh variables are called "Severity of Violations", which are the number of violations in each rank (1-10). These are denoted by "r1-r10" in the SAS code. They are also called "category" in the created model or factor determination. The last two variables in data are "Total" and "Weight". These are recalculated using the SAS code.

7.2.2 Weighted Average of Violations

The Violation averages were calculated using the weights which are ranked 1-10 in order to separate the companies to 4 groups. The reason for using the average of violations and not the sum of violations is that the severity of different violations should be taken into account. For example, 10 violations with ranking number 1 are different from 1 violation with ranking number 10. The weighted averages were calculated using SAS as follows;

$$\frac{= (\mathrm{r1} + \mathbf{2} * \mathrm{r2} + \mathbf{3} * \mathrm{r3} + \mathbf{4} * \mathrm{r4} + \mathbf{5} * \mathrm{r5} + \mathbf{6} * \mathrm{r6} + \mathbf{7} * \mathrm{r7} + \mathbf{8} * \mathrm{r8} + \mathbf{9} * \mathrm{r9} + \mathbf{10} * \mathrm{r10})}{\mathrm{violation}}$$

7.2.3 Data Preparation and Execution

The data files were converted into text format and saved as .txt file. The data were separated into three .txt files by year, and named "year2008", "year2009", "year2010" respectively. These were then loaded into SAS.

SAS Code can be found in the Appendix C

7.3 Exploratory Data Analysis (EDA)

This is an approach to analyzing data with the aim of formulating hypotheses that are to be tested. The objectives of **Exploratory Data Analysis (EDA)** include;

- Suggesting hypotheses as it relates to the sources of observed occurrences
- Evaluate assumptions on which statistical extrapolations will be based
- Bolster the choice of applicable statistical tools and procedures
- Used in data mining and it also provides the fundamentals for further data gathering through further studies or experimentations.

For the violation data, the first step is to calculate the weighted average of the ranking of violations for each company, in order to separate the companies into 4 groups. We use 2008 as an example, and you can do the same with 2009 and 2010. This can be found in the Appendix (**SAS Code).**

A means of distinguishing a distribution (such as the data) of one variable from a distribution of several variables, the **procunivariate** procedure was applied to find Quantiles of the dataset. The quantiles divide the data into fourths (0-25%, 25%-50%, 50%-75%, 75%-100%).

From the output, in 2008, it was observed that the smallest 25% of the data lies below average weight of 4, while the next 25% lies between 4 and 5, the third 25% are between 5 and 5.82353, and the largest 25% lies above 5.82353. So the data for year2008 are grouped using the following codes Appendix Figure 30.
The output of the desired result is shown in figure 31 below, with companies separated into 4 groups as in figure 31:

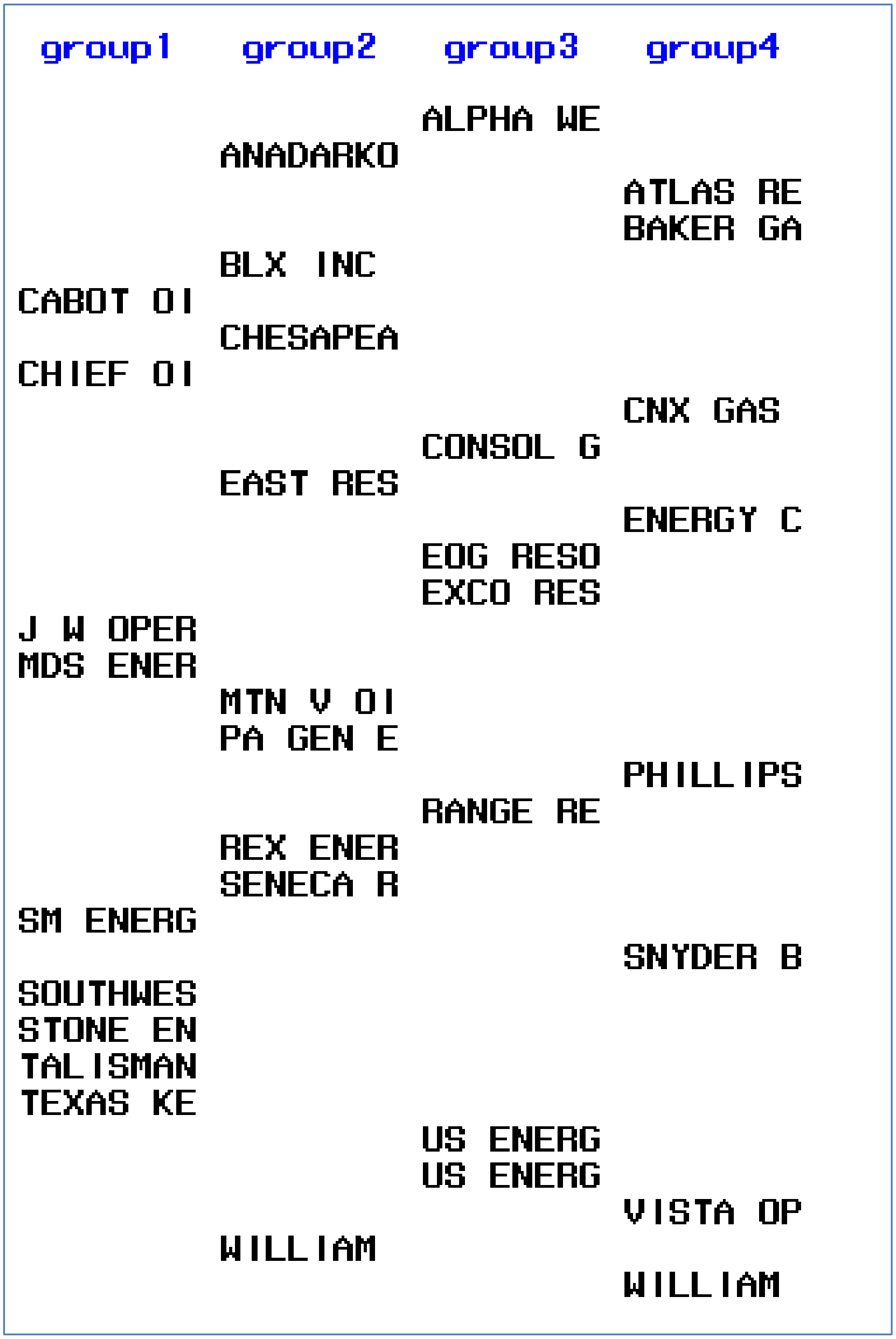


Figure 31: Company grouping based on Severity Rate calculated from the weighted average

Table 11: Categories of operators in 2008

Category	Operator	Environmental Effect
Group 1	CABOT OIL & GAS CORP; CHIEF OIL & GAS LLC; J W OPERATING CO; MDS ENERGY LTD; SM ENERGY CO; SOUTHWESTERN ENERGY PROD CO; STONE ENERGY CORP; TALISMAN ENERGY USA INC; TEXAS KEYSTONE INC	Low
Group 2	ANADARKO E&P CO LP; BLX INC; CHESAPEAKE APPALACHIA LLC; EAST RESOURCES INC; MTN V OIL & GAS INC; PA GEN ENERGY CO LLC; REX ENERGY OPERATING CORP; SENECA RESOURCES CORP; WILLIAM MCINTIRE COAL OIL & GAS;	Moderate
Group 3	ALPHA WELLS INC.; CONSOL GAS CO; EOG RESOURCES INC; EXCO RESOURCES PA INC; RANGE RESOURCES APPALACHIA LLC; US ENERGY; US ENERGY EXPLORATION;	High
Group 4	**ATLAS RESOURCES LLC;** **BAKER GAS INC;** **CNX GAS CO LLC;** **ENERGY CORP OF AMER;** **PHILLIPS EXPLORATION INC;** **SNYDER BROS INC;** **VISTA OPR INC;** **WILLIAM S BURKLAND;**	**Severe**

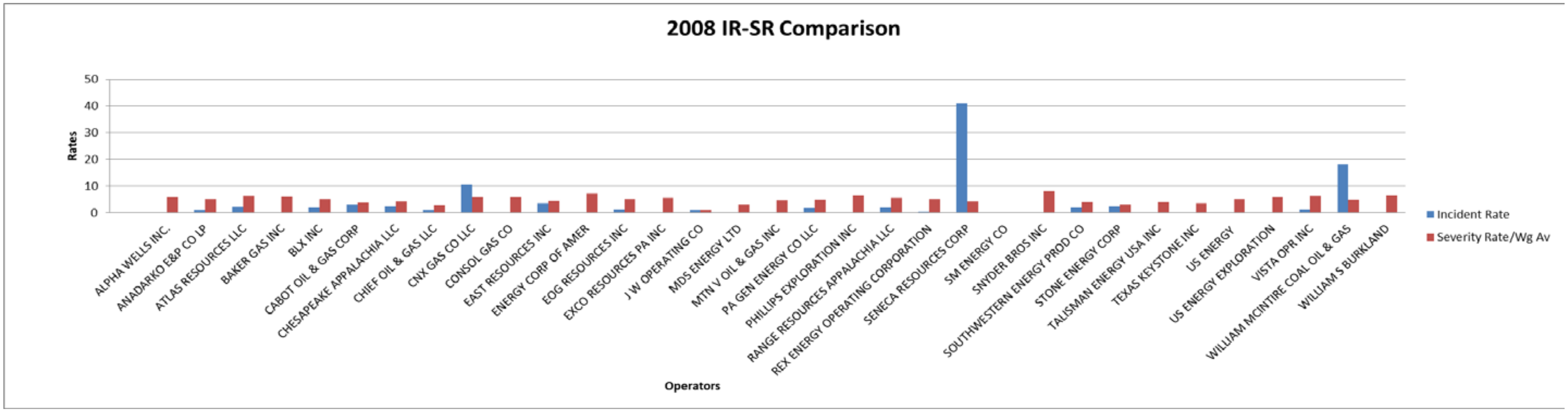


Figure 32: Incident Rate compared to Severity Rate in 2008

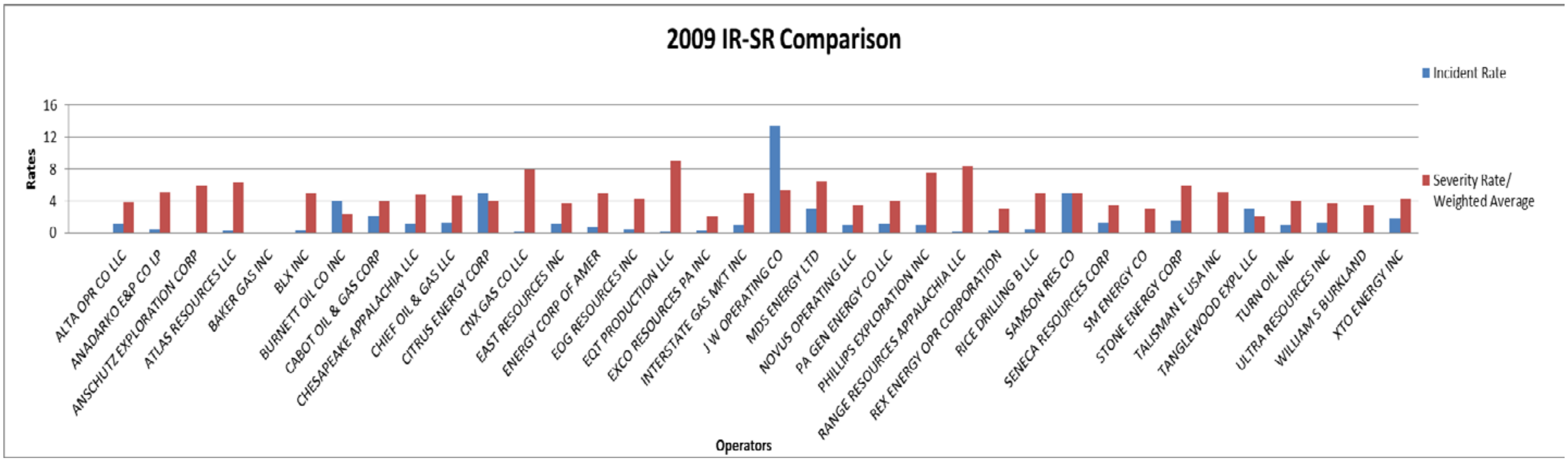


Figure 33: Incident Rate compared to Severity Rate in 2009

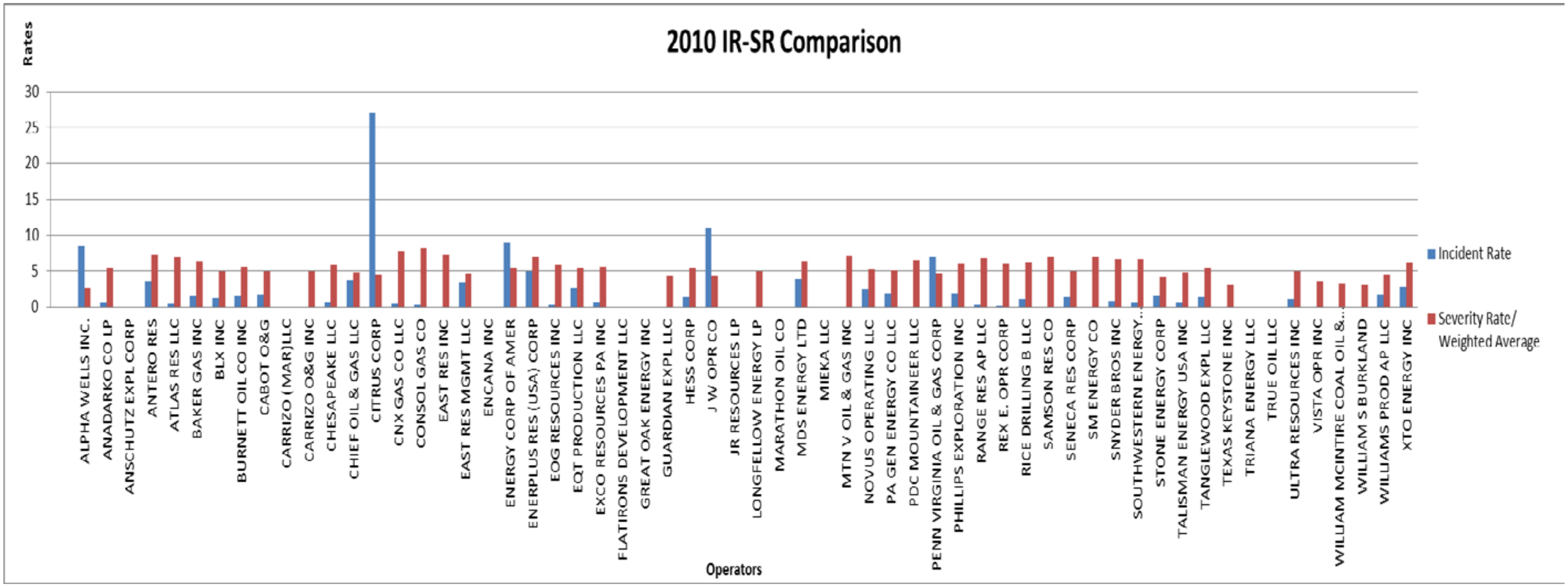


Figure 34: Incident Rate compared to Severity Rate in 2010

7.4 Symbolic scatter plot

To investigate the behavior of the violations over time, another dataset that contains the number of violations for each company and for each level in each year were prepared, so it should have 4 variables: one called “subjects” is company name, one called “violations” is number of violations, one called “category” is the violation ranking from 1 to 10, and the last variable called “year” is the year from 2008 to 2010. Example is shown below and outputs for all operators are in the Appendix figure 31b;

The attempt to forecast the trend and behavior of operators in the Marcellus Shale based on yearly violations was not productive due to limited data constraint. But the linear trend of all the data available (3 years) can be analyzed.

For the various years the code to correlate the relationship or dependency are in Appendix figure 35;

Using the output, the following dataset are created.

SAS Code

```
data scatter;
input r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 year;
cards;
        1.6666667   2.3030303   2.3636364   0.2424242   6.8787879
0.8787879   0.5454545   0.6666667   1.2424242   1.9393939   2008
        1.5833333   1.6666667   3.3333333   0.5833333   7.6944444
0.1111111   0.0833333   0.8333333   0.8888889   0.9722222   2009
        3.4166667   1.0833333   4.0166667   1.0333333   4.5333333
0.5333333   0.4   1.7333333   3.0666667   2.5833333   2010
        ;
run;
```

Finally, a plot was made to check for a linear trend in time for the number of violations in each category (Appendix) Figure 37.

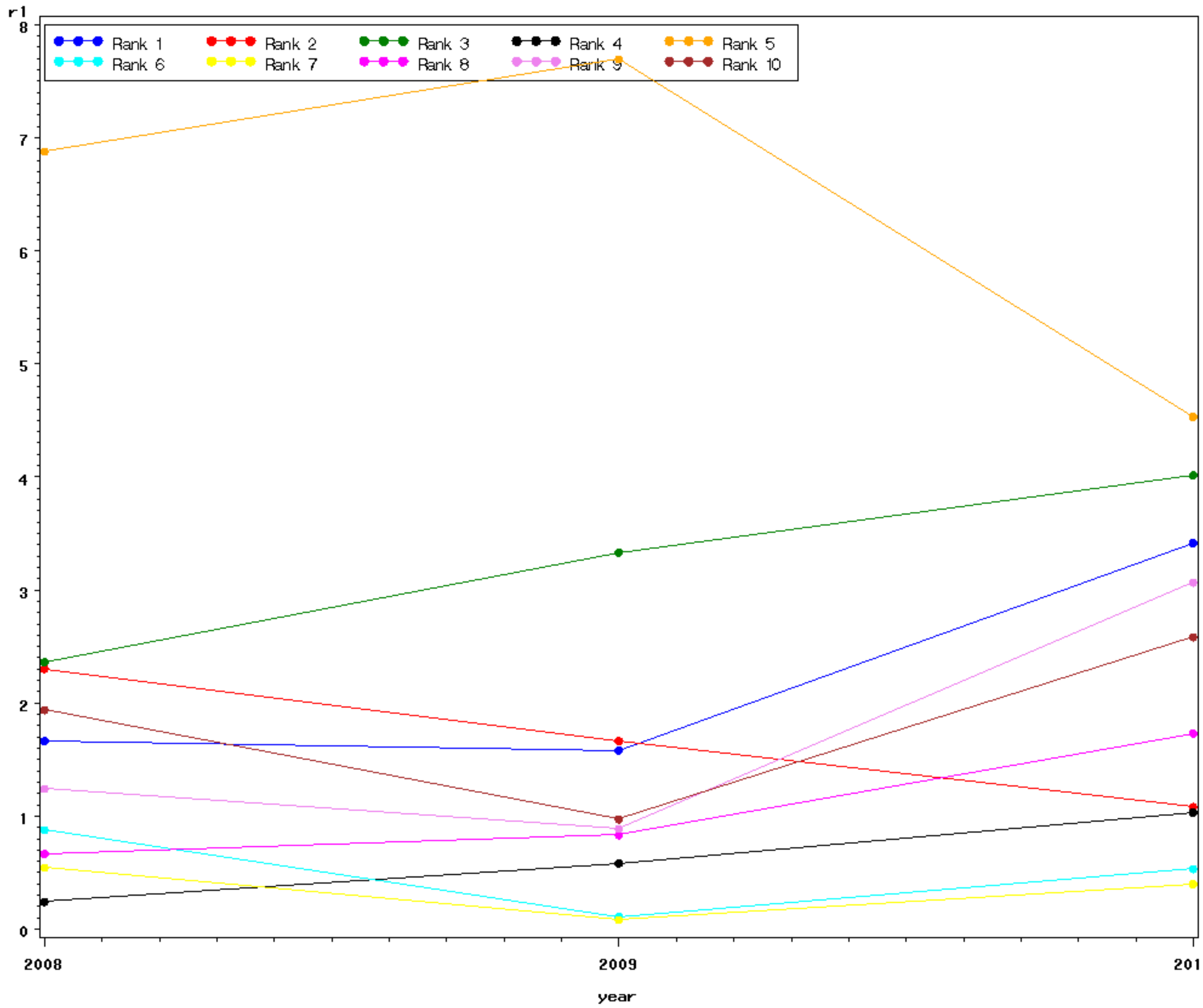


Figure 38: Ranking Interactions

From Figure 38, it is clearly evident that is not enough data to conclude if there is a linear trend. So forecasting cannot be made in this case. But the data can be analyzed further using the model below.

7.5 Doubly repeated measure ANCOVA

ANOVA make available a statistical test that compares the means of several groups and check if they are equal, and consequently specifies t-test to more than two groups. ANOVA are useful for statistical models because they possess an advantage over a two-sample t-test. And also, F-test is usually employed for checking the contrasts in components of the total deviation.

ANOVA assumptions:

- the distributions of samples/ the residuals follow normality;
- the population variances are equal;
- samples are independent.

7.5.1 Analysis of covariance (ANCOVA)

This is a universal linear model which presents a continuous result or outcome variable and multiple predictor variables, in a case where one of the variables is continuous and then however one is nominal, i.e. categorical. It is a general term used for covariates when analyzing experimental data and which is a fusion of the Analysis of Variance (ANOVA) and regression analysis for continuous (Quantitative) variables. ANCOVA is useful in testing if certain factors affect the resultant variable after eliminating the variance that determines the covariance (quantitative predictors).

The presence of covariates could enhance statistical power since it would take into considerations the variability.

The purpose of including covariates is two-fold:

- To reduce within-group error variance: The error variance is minimized, allowing for more precisely assess the impact of the experimental operation.
- Removal of Confounds: Variables are identified as a major influencing factor to the measured dependent variable, and then ANCOVA is preferably employed to eliminate the predisposition of these variables.

Since the analysis of doubly repeated measure ANCOVA is to be employed in this data analysis, renaming and copying of “year” to have a new variable called “year1” to be covariate is imperative.

SAS Code

```
Data long;
        /* Read the dataset*/
Infile'C:\Documents and Settings\rzo5017\My Documents\Downloads\Draft
Analysis\violations.txt'firstobs=2dlm='09'x;
Input company $ violations category year;
year1=year;
run;
```

7.6 Statistics Model:

Response Variable: Number of Violations of each company each year.

Factor: Category (rank 1-10)

Covariate: Year (year 2008-2010)

Repeated measure: Year, Category

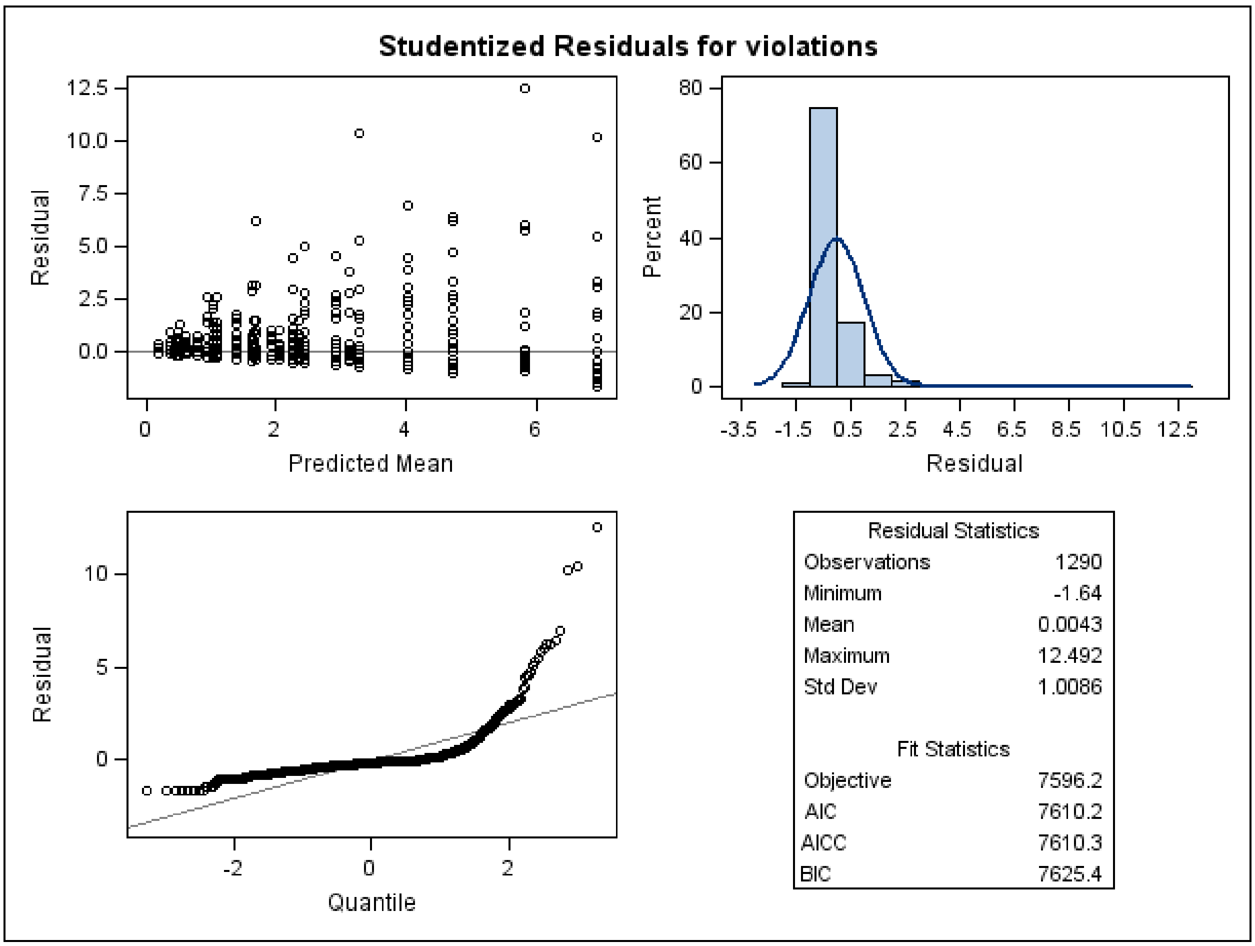
SAS Code

```
odsgraphicson;
proc mixed data=long;
        class category year1 company;
        model violations = category|year / residual;
        lsmeans category / adjust=tukey;
        repeated year1 category  / type=un@cs subject=company;
        run;
odsgraphicsoff;
```

Before the interpretation of the output from analysis of doubly repeated measure ANCOVA model is made, it is important to observe the residual plot to check if assumptions are correct.

Residual plot from Figure 39 below (upper left-hand corner), shows a trend between the variance of the error term and the mean, this is observed because the variance of the error terms increases with the mean.

Figure 39



This shows that the error variance is not quite constant, also noticed are numerous outliers in the output (great than 3). The best way to smoothing the output is by transforming the data to match the model.

Quantile plot (Q-Q plot) in the lower left-hand corner of Figure 39 of standardized residuals can reveal departures from normality. If the plot is quite straight, then there are no substantial departures from normality. In Figure 39, majority of the residuals are close to the line, but the upper-tail of the residuals deviate a lot.

7.7 Apply a transformation

When the variance of the error terms changes with the mean, a transformation can be applied, so that the response becomes g(Y) rather than Y. In applying a power transformation, the following equation can be employed;

$$g(Y) = (a + Y)^{\alpha}$$

This is applicable in transforming the output with the accurate choice of “α” and constants “a”.

Note that α is the important parameter; the choice of “a” is arbitrary.

Several simulations were ran to choose the best fit value for the unknowns, after several trials, using the value of (-3) – 3 for α, and (-3) – 3 for “a” the power transformation for the data: was found to be α=-0.6 and a = 1.57. In transforming the data, the following code was implemented;

SAS Code

```
/* Transform the dataset*/
Data translong;
	set long;
	transviolations=(violations+1.57)**(-.6);
	run;
```

In observing the residual, the same procedure as above is used

.SAS Code

```
odsgraphicson;
procmixeddata=long;
	class category year1 company;
	model violations = category|year / residual;
	lsmeans category / adjust=tukey;
```

```
            repeated year1 category  / type=un@cs subject=company;
            run;
      ods graphicsoff;
```

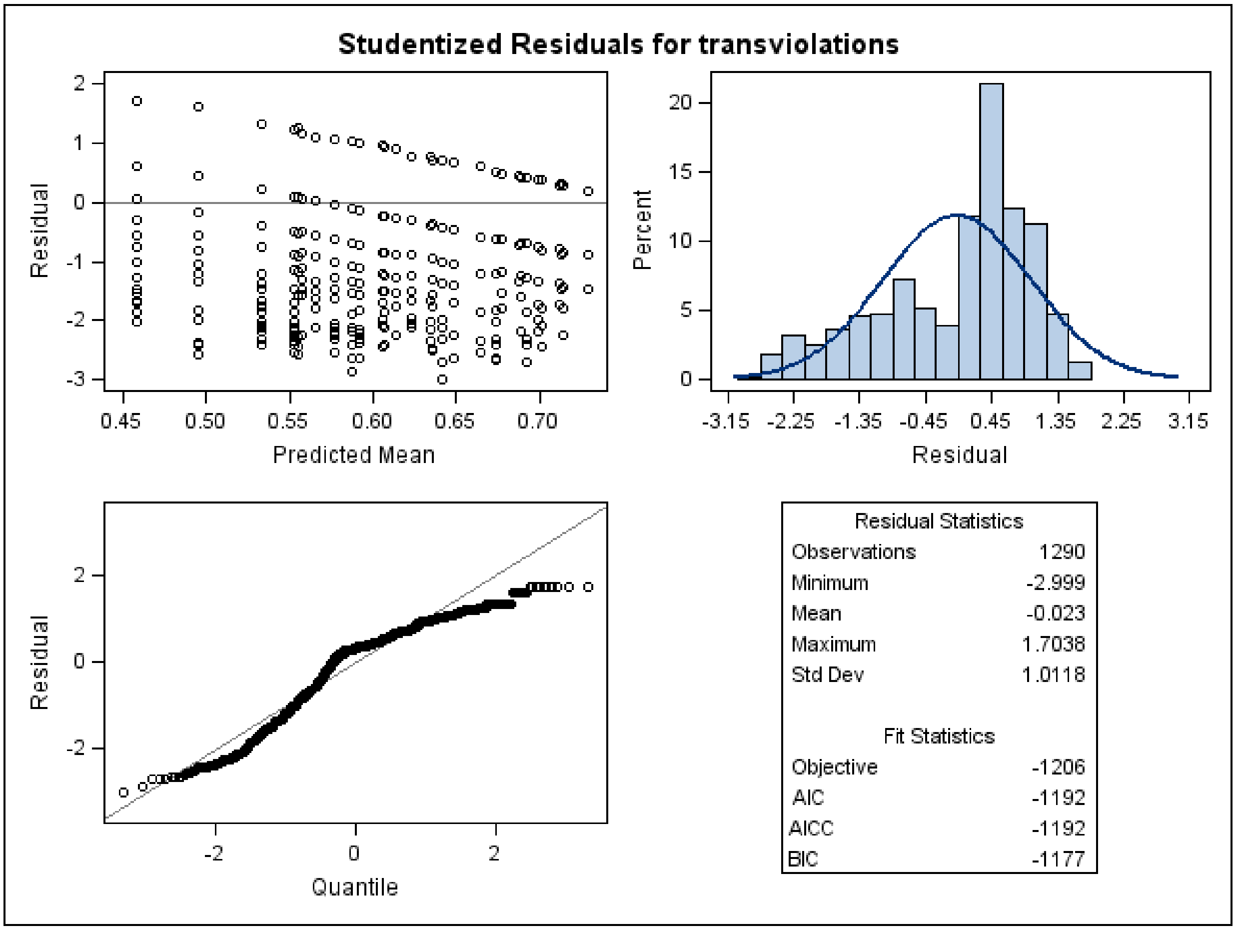


Figure 40: Transformed Studentized Residual Plot

The residual plot from Figure 40 (upper left-hand corner), shows the output and the variance of the error term appear different from the former. Although it still has some trend, but we can see that studentized residuals are between -3 and 3. Generally, power transformation procedure attempts to correct for skewness in the residuals rather than non-constancy of variance, therefore the data transformation is correct and useful for the model.

Observing the quantile plot (Q-Q plot) in the lower left-hand corner of Figure 40 of standardized residuals, it can be seen that the majority of the residuals become closer to the line. Even though there are still some outliers in the upper tail skewness, but it is much better than the original data. Then, it can be inferred that the assumption holds after the transformation of the data.

The interpretation of the output of analysis of doubly repeated measure ANCOVA model from **proc mixed** procedure can now be done easily. The part of output is shown in Figure 41:

The Mixed Procedure

Fit Statistics

-2 Res Log Likelihood	-1206.2
AIC (smaller is better)	-1192.2
AICC (smaller is better)	-1192.1
BIC (smaller is better)	-1177.0

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
category	9	576	4.62	<.0001
year	1	1206	0.22	0.6409
year*category	9	1206	4.61	<.0001

Model Validation

The **coefficient of determination R^2** is used in the framework of statistical models with the aim of future events forecast based on available information. It represents the proportionality of variance in a data set taking into consideration by the statistical model, while it also gives information on the suitability and the fit integrity of a model. In regression R^2 of 1.0 signifies that the regression line perfectly fits the data, if R^2 falls outside the range of 0 to 1 then there is a mismatch in the model, when this happens it is used to measure the agreement between observed and modeled values. But for this model characterization, forecasting cannot readily be done; the multiple comparison interaction technique is employed to show level of significance.

Post-hoc testing of ANCOVA Model

Multiple comparison measures are generally employed in an analysis of variance after acquiring a significant collection test outcome, such as the ANOVA F-test. The significant ANOVA outcome recommends rebuffing the general null hypothesis H_0 that states that the means are similar amongst the different groups compared. These comparison techniques are utilized in the determination of means difference. Some of the methods available for this procedure include;

Single-step procedures

- Tukey–Kramer method (Tukey's HSD) (1951)
- Scheffe method (1953)

The Tukey method was used for this analysis. In the section of "Type 3 Tests of Fixed Effects", category effect and interaction effect in the model are significant (p-value is less than 0.05). Even though one of the main effects--year is not significant, we still can't say that the year does not have any effect whatsoever. Since the interaction of category and year is significant, I suggest I should keep the factor "year" in my model.

Observing the section of "Differences of Least Squares Means", which used a method called Turkey comparisons, because we want to look at the difference between each two categories. We can see that most of the comparisons are significantly different (p-value is less than 0.05). By looking at the output, we can see that the developed model analyze the data correctly. The difference of least squares means table can be found at the Appendix Figure 41.

CHAPTER EIGHT: ENVIRONMENTAL MANAGEMENT PLAN

8.0 Drilling Hazard Management (DHM) for Marcellus Shale

Drilling hazard occurs due to any significant departure from plan in well drilling activities, which could result to uncontrollable well, and wellbore failure or other unwanted risk such as fluid loss, equipment mal function, and loss of productive time. There is risk associated with every gas drilling activity, having a fore knowledge of the vagueness of the drilling periphery and ways to drastically curtail the associated risk is elemental to drilling hazard management. Such that there could be a safety net application of the Equivalent Circulating Density (ECD) involving the fracture gradient and stress systems consequent upon the effect overburden poses at TVD. Although there is no perfect situation on earth, so also are predictions, but during the well design processes, it is important to incorporate risk mitigating technologies and appropriate BMP for drilling, completion and abandonment operations.

Having detailed and appropriate planning for risk opportunities in drilling and well operations is very vital. For instance an expected challenge when drilling into deeper formations is the issue of High Pressure High Temperature that has the potential to increase the mud weight in the formation. In this case, the DHM plan should be adopted through the performance of a leak off test in determining a safe and tolerable ECD for subsequent hole sections, employing equal mud weight level used for the casing to punch out the casing shoe, after which the head raising mud weight is drilled with regards the prevalent conditions in the system. An effective implementation of DHM minimizes and manages the risk or any opportunity of hazards when real time data is appropriately used in the consideration of the principle of well listening during the well drilling operations.

CHAPTER NINE: CONCLUSION

9.1 Analytical Summary

The total number of violations for the three years analyzed was 2,601. From the analysis, the response variable are the number of violations of operators each year and the factor is the category (rank 1- 10), the covariate are the years (year 2008 – 2010) and the ANCOVA repeated measure was used for 'year' and 'category'. There are 65 independent companies for the three years, in category (rank 1 – 10). Using the mixed procedure, the total number of observation read and used was 1290, the convergence criteria was met after the forth iteration. Covariance parameter estimate with subject (company) for; year (1,1) was 0.03284, year (2,1) was 0.006101, year (2,2) was 0.02786, year (3,1) was 0.001727, year (3,2) was 0.006504, year (3,3) was 0.03048, and category correlation with company covariance parameter estimate was 0.4260. The model came up with a fit statistics -2 Res. Log Likehood of -1206.2. The null model likelihood ratio test came up with 6 degrees of freedom, chi- square of 490.85 and Pr > chi square value of < 0.0001. After the power transformation, the F- test statistic value was found to be 4.62 for the significant factors and interactions, while 4.61was found for the main effects of category and year interactions.

Both analyses with a degree of freedom of 9 show a p-value of less than 0.0001, which highlights the level of significance of the safety violation model. Category (rank 1-10), together with the factor interactions (1~4), (1~5), (1~6), (1~7), (1~8), (2~3), (2~4), (2~5), (2~6), (2~7), (3~4), (3~6), (3~7), (3~8), (3~9), (4~5), (4~10), (5~6), (5~7), (5~8), (5~9), (5~10), (6~9), (6~10), (7~9) and (7,10) are shown to be the significant model terms.

The t-values for Category rank 7 (42.50), Category rank 4 (41.48) and Category rank 6 (41.14) are higher when compared to those of Category rank 1 (35.86),Category rank 2 (36.69), Category rank 3 (33.06),Category rank 5 (30.00), Category rank 8 (39.34), Category rank 9 (37.10),and Category rank 10 (36.34), as shown in Figure 38

This shows that Category rank 4,6, and 7, are very significant factors. But in the interaction analysis, Category rank (4~5) has the highest t-values of 10.71, compared to other higher significant interactions such as Category rank (7~10) t-values of 5.75, Category rank (2~5) t-values of 6.25, Category rank (1~5) t-values of 5.47, Category rank (7~9) t-values of 5.04 and

Category rank (6~10) t-values of 4.48. Due to the high t-values of these Categories, it is therefore imperative for more attention to be paid to these contributing effects as shown in the level of significance in the violations by operators in a three year period. In a broader perspective, the economic importance of adequate intervention in these categories is quintessential. If these highly significant categories are effectively taken care of, this would certainly enhance the usefulness of the safety model developed and consequently minimizing the environmental footprints from gas developmental activities in the Marcellus Shale area.

The high level of significance of these factors in the categories is an indication that it is possible to make predictions and accomplish appropriate severity rates if risk and safety measures are precisely carried out by health, safety and environmental (HSE) personnel in the quest to finding the most suitable mitigation and control methods.

9.2 Recommendations and Applications

My research work demonstrates how statistical techniques such as doubly repeated ANCOVA is effective in the determination of near-optimum rates for impact severity and incidence based on the comparative responses (incidence, as suggested by violations in this case) of the significant categories. My thesis also indicates quantitatively the extent of violation contributions to environmental damage and identification of severity rates due to gas development activities in the Marcellus Shale area. The Department of Environmental Protection could use this model to validate claims by several interest groups on the extent of degradation in these active areas. If the most significant incidents (rank 3,5,9,10) which account for 67% of all violations are taken care of by appropriate mitigation and control measures, there would be a huge effect on the minimization of exploration and production footprint in the Marcellus Shale play. This would create larger cost benefits, safe and responsible operations, minimal risk outcome, and positive social license to operate.

The use of a forecasting technique (double repeated measures) for the model validation indicates that by employing the appropriate forecasting procedure, the severity/ incident rates could be predicted for the long term effects and contingency mitigation plans could be put in place. The prediction technique is very vital in estimating the trend of footprint to the environment from all contributing activities. It is also important to calculate the total incident rates by taken into considerations the effect of other uncontrollable external factors such as blow outs, accidental spills and leaks.

Quantitative evaluations in the safety assessment of gas development operations in the Marcellus Shale should include carrying out investigative research for the purpose of examining the most significant factors and trend in environmental degradation due to the gas development in identifying regions of safety measures that requires improvements.

Adding to the benefits outlined above, the Department of Environmental Protection, Energy policy makers, safety personnel, administrative decision makers, supervisors and managers could employ the analysis derived in this research to create an operative safety monitoring program from the inception of the job till abandonment, which would ultimately provide enormous cost servings to operators, while the environment is greatly preserved. The statistical modeling of operational activities with regards to pollution control and mitigation would provide an efficient means of managing safety systems based on exploratory data methodology. The ability of stake holders such as the DEP, operators and environmental concern groups to employ quantitative appraisal, quantity and verification approaches to improve their existing safety plans would greatly help in creating adequate, effective and functioning safety culture which would consequently reduce incidents at workplace and minimize greatly the environmental foot prints from fossil fuel development. Several operational and administrative costs such as; pipeline repairs, remediation cost, equipment repair, liability, and downtime costs could be curtailed if there is an acute knowledge of the causes, effects and long term consequences of pollution related activities and there are appropriate interventions in place to reduce the severity of such. The social license to operate responsibly is quintessential in the overall interest of operators and the also for the world's economy that currently hugely depends on oil and gas for sustenance. A safety conscious operator improves its cooperate image, and preserves its reputation while doing business profitably with an increasing public trust evident in the dominant shareholder value of the firm.

9.3 Suggestions for Future Work

It would be important to further expand this work by taking into consideration not only the violations by operators, but all other uncontrollable causes of environmental pollution to the environment arising from shale gas development in the Marcellus area. This would further depict the contribution of gas development activities to environmental concerns in the area. Also by increasing the number of years from which data are available would make it possible to make effective predictions of incident rates in the gas play.

Another important aspect that could potential expand the scope of this research in order to propose standards for safety implementations by assigning universal weights to the contributing factors, such as each rank of violations and carrying out an Analytic Hierarchy Process (AHP) technique using pairwise comparison. This would proffer a more accurate value of the level of occurrence and also determine the extent of enthusiasm shown by each operator to safety intervention actions. The developed safety model would integrate numerical techniques and the inclination of the operators based on past occurrences to forecast efficient policies and aggressive mitigation practices which would largely minimize or eradicate existing intervention programs that are ineffective and create a platform for the development of better ones.

Finally, the developing of a graphical user interface (GUI) to show the interactive potential of the developed model using a computer program to analyze the developed safety intervention program by adapting to changes in incident rates over time would be very helpful. The interactive user interface would integrate qualitative and numerical methods to interlink past occurrences and predict effective mitigation strategies and also remediation which would consequently minimize the need for non effective intervention programs.

9.4 Conclusion of Research Work

The Marcellus Shale has become an economically important regions in the world due to the huge natural gas deposits sitting some 8,000 feet below its sub surface. Shale gas development have brought a lot of changes to the region, ranging from population increase, infrastructural development, increase in job opportunities and provision of substantial revenue. But the environmental hazards presented by this challenging situation of natural gas extraction from the Marcellus Shale area are overwhelming. A synergy is achievable between gas production in the Marcellus shale and keeping the environment safe from pollutions through the effective adoption of BMP; which aids in the minimization of dangerous environmental risks such as waster source contamination, blow outs, fracture fluids or waste water leakage, air emissions etc.

The total number of violations and percentage increase in violations from previous years by companies operating in the Marcellus Shale area suggests a massive neglect in the BMP which leaves the environment at the peril of degradation. If the active operators in the Marcellus Shale act responsibly with the environment as a primary concern, there still exist numerous environmental concerns to be considered even from the mere execution of drilling or high powered operations in the region. But in the case where a total number of 1344 violations were committed in 2010 alone, including direct discharge of poisonous substances into the free flowing clean open water bodies, this signals a bane to the overall sustainability of the health and safety of residents of these areas in the long run.

In view of the recent trends in the extraction of gas in the Marcellus Shale, it is imperative for operators to comply and readily adequately implement the BMP in accordance to all slated local and state regulations in the Marcellus Shale area. This fit will not only diminish the risk associated with natural resource exploration, but will also create a means of safety whereby the needed energy for human survival is available alongside a pristine environment. The economic importance of the Marcellus Shale drilling is huge and must be balanced out. Enormous attention is required in water management in this area, to avoid carrying out drilling and hydraulic fracturing for the benefits of today’s needs at the detriment of clean water sources in particular, and the entire environment in general. The following issues need to be specifically looked into in broader light;

The withdrawal of water from surface and sub-surface sources: This should be done responsibly, having in mind the consequence of excessive draw down and drought to the environment. Reuse of water will reduce the risk of exposure to drinking water sources and air emissions and also reduces the total volume of water required both for the fracture job and eventual treatment or disposal.

Waste Management: Handling of every component of the hydraulic fracture generated wastes must be of prime important, such as drill cuttings, waste water, hydraulic fracturing fluids, drilling fluids, dust etc. Due to fewer numbers of waste water treatment plants in the Marcellus Shale area, flow back water reuse may be encouraged once diluted and re injected into the reservoir. The waste/produced water could also be stored in steel cased tanks, to avoid leak of any kind, even as larger sized processing treatment technologies are being considered. Proper measures should be implemented to safeguard the source of water; this will eliminate the risk of soil and drinking water contamination, air pollution and wildlife threat. The equipment used for all operations should be regularly screened to avoid NORM, spills and malfunctioning during the process of injection or transportation of waste across from well sites or storage sites to treatment plants.

Environmental Impact Assessment (EIA) and Environmental Evaluation Studies (EES) should be carried out for all drilling activities for the Identification and assessment of environmental threats created by these operations in the Marcellus Shale area. This will guide in understanding the effect of drilling and hydraulic fracturing on human health and long term consequence to the environment. Also the establishment of buffer or exclusion zones for active well drilling sites, right of ways, compressors, tank batteries, residences, natural forests, and also abandonment sites are very necessary in keeping the Marcellus shale area safe from any unforeseen hazard that may arise from gas extraction activities.

Other regulatory recommendations include;

- Full disclosure of fracturing fluid constituents

- The need for policy makers to as a matter of urgency, include hydraulic fracturing to be a part of sub surface injection practice.

- The Safe Drinking Water Act that exempts hydraulic fracturing from sub surface injection through the Halliburton Loophole should be repealed since this is inconsistent with the reality of underground injection, by passing the Fracturing Responsibility and Awareness of Chemicals Act.

- Operators must commit to the restoration of the environment and bear full responsibility of any potential hazard their activities presents to the resident, communities and the environment in the Marcellus Shale.

- Finally there should be more over sight in the energy industry through the establishment of effective regulations that is based on zero tolerance to regulation violations and irresponsible operations in the Marcellus shale area.

APPENDIX A: NOMENCLATURE

Bcf =	billion cubic feet
BMP =	best management practices
DO =	Dissolve Oxygen
DOE=	Department of Energy
DNR=	Department of Natural Resources
EES=	Environmental Evaluation Studies
EIA =	Environmental Impact Assessment
EPA =	U.S. Environmental Protection Agency
FERC =	Federal Energy Regulation COmmission
HAP=	hazardous air pollutants
HCP=	habitat conservation plan
HIA =	Health Impact Assessment
HVHF=	High-volume hydraulic fracturing
INC's =	Incidence of Non-Compliance
IR =	Incident Rate
Km =	Kilometers
m^3=	cubic meters
MMcf =	million cubic feet
MSDS=	Material Safety Data Sheet
NEPA =	National Environmental Policy Act
NORM=	Naturally Occurring Radioactive Material
NRDC =	Natural Resource Defense Council
OGC=	Oil and Gas Commission
OSI =	Operator Severity Index
PAH =	Polycyclic Aromatic Hydrocarbon
PHMSA=	Pipeline and Hazardous Materials Safety Administration
RCRA =	Resource Conservation Recovery Act
RQ=	reportable quantity
SDWA=	Safe Drinking Water Act
SEPA=	state environmental policy act
SIA =	Social Impact Assessment
SPCC =	Spill prevention, control and countermeasure plans
SR =	Severity Rate
SWDA=	Solid Waste Disposal Act
TVD=	True vertical depth
Tcf =	trillion cubic feet
VOC =	Volatile Organic Compound

APPENDIX B RAW DATA

Violations in the Marcellus Shale Play in **2008**, group using the Borda count technique

Operators in the Marcellus Shale 2008	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Wg Av
	1	2	3	4	5	6	7	8	9	10					
ALPHA WELLS INC.	0	0	1	1	0	0	0	0	0	1	3	0.005	0	0	5.6667
ANADARKO E&P CO LP	0	0	0	0	1	0	0	0	0	0	1	0.002	1	1	5
ATLAS RESOURCES LLC	5	0	0	0	10	3	1	6	4	4	33	0.053	16	2.063	6.1818
BAKER GAS INC	0	0	0	0	0	1	0	0	0	0	1	0.002	0	0	6
BLX INC	0	1	0	0	2	0	0	1	0	0	4	0.006	2	2	5
CABOT OIL & GAS CORP	7	15	7	1	30	0	0	1	0	2	63	0.102	21	3	3.8095
CHESAPEAKE APPALACHIA LLC	0	0	3	0	4	0	0	0	0	0	7	0.011	3	2.333	4.1429
CHIEF OIL & GAS LLC	3	3	2	0	3	0	0	0	0	0	11	0.018	10	1.1	2.7273
CNX GAS CO LLC	9	6	6	0	20	3	3	0	12	15	74	0.12	7	10.57	5.8919
CONSOL GAS CO	1	1	1	0	0	2	2	2	0	1	10	0.016	0	0	5.8
EAST RESOURCES INC	8	5	4	2	15	0	0	1	2	4	41	0.066	12	3.417	4.3659
ENERGY CORP OF AMER	0	1	1	0	0	0	0	1	0	3	6	0.01	0	0	7.1667
EOG RESOURCES INC	0	1	2	2	5	0	0	0	0	2	12	0.019	10	1.2	5.0833
EXCO RESOURCES PA INC	0	0	5	0	0	2	0	0	1	2	10	0.016	0	0	5.6
J W OPERATING CO	3	0	0	0	0	0	0	0	0	0	3	0.005	3	1	1
MDS ENERGY LTD	2	1	2	0	1	1	0	0	0	0	7	0.011	0	0	3
MTN V OIL & GAS INC	4	7	3	1	14	3	0	0	7	0	39	0.063	0	0	4.6667
PA GEN ENERGY CO LLC	1	0	1	0	2	0	0	0	0	1	5	0.008	3	1.667	4.8

Operators in the Marcellus Shale 2008	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Wg Av
PHILLIPS EXPLORATION INC	0	1	1	0	4	0	1	3	1	2	13	0.021	0	0	6.5385
RANGE RESOURCES APPALACHIA LLC	2	7	3	1	21	1	3	0	8	5	51	0.083	27	1.889	5.549
REX ENERGY OPERATING CORPORATION	0	0	0	0	3	0	0	0	0	0	3	0.005	8	0.375	5
SENECA RESOURCES CORP	5	9	5	0	14	3	2	1	0	2	41	0.066	1	41	4.0976
SM ENERGY CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNYDER BROS INC	0	1	0	0	0	1	0	3	0	4	9	0.015	0	0	8
SOUTHWESTERN ENERGY PROD CO	1	0	2	0	5	0	0	0	0	0	8	0.013	4	2	4
STONE ENERGY CORP	1	2	2	0	2	0	0	0	0	0	7	0.011	3	2.333	3
TALISMAN ENERGY USA INC	0	2	1	0	5	0	0	0	0	0	8	0.013	0	0	4
TEXAS KEYSTONE INC	0	1	0	0	1	0	0	0	0	0	2	0.003	0	0	3.5
US ENERGY	1	9	21	0	50	4	0	1	1	14	101	0.163	0	0	5.0792
US ENERGY EXPLORATION	1	1	0	0	7	2	3	0	2	1	17	0.028	0	0	5.8235
VISTA OPR INC	0	1	0	0	1	0	1	1	1	0	5	0.008	4	1.25	6.2
WILLIAM MCINTIRE COAL OIL & GAS	0	1	5	0	7	1	2	1	1	0	18	0.029	1	18	4.9444
WILLIAM S BURKLAND	1	0	0	0	0	2	0	0	1	1	5	0.008	0	0	6.4
Total	55	76	78	8	227	29	18	22	41	64	618	1	136	4.544	

Violations in the Marcellus Shale Play in **2009**, group using the Borda count technique

Operators in the Marcellus Shale 2009	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Wg Av
	1	2	3	4	5	6	7	8	9	10					
ALTA OPR CO LLC	0	0	4	0	3	0	0	0	0	0	7	0.011	6	1.16667	3.85714
ANADARKO E&P CO LP	1	0	0	1	4	0	0	2	0	0	8	0.013	20	0.4	5.125
ANSCHUTZ EXPLO. CORP	0	0	1	0	0	0	0	0	1	0	2	0.003	0	0	6
ATLAS RESOURCES LLC	0	2	4	0	5	0	0	9	1	3	24	0.038	114	0.21053	6.33333
BAKER GAS INC												0	1	0	0
BLX INC	0	0	0	0	1	0	0	0	0	0	1	0.002	3	0.33333	5
BURNETT OIL CO INC	4	1	1	0	2	0	0	0	0	0	8	0.013	2	4	2.375
CABOT OIL & GAS CORP	8	4	29	4	19	0	0	0	1	5	70	0.110	32	2.1875	3.9
CHESAPEAKE APPALACHIA LLC	7	12	22	3	47	2	0	7	4	9	113	0.177	96	1.17708	4.76106
CHIEF OIL & GAS LLC	3	4	6	0	14	0	0	1	1	4	33	0.052	26	1.26923	4.72727
CITRUS ENERGY CORP	0	1	1	0	3	0	0	0	0	0	5	0.008	1	5	4
CNX GAS CO LLC	0	0	0	0	0	0	0	1	0	0	1	0.002	21	0.04762	8
EAST RESOURCES INC	13	8	16	6	45	0	1	0	0	0	89	0.140	77	1.15584	3.74157
ENERGY CORP OF AMER	0	1	3	0	6	0	2	0	0	1	13	0.020	16	0.8125	5

EOG RESOURCES INC	3	1	1	0	3	0	0	0	0	2	10	0.016	25	0.4	4.3
EQT PROD LLC	0	0	0	0	0	0	0	0	1	0	1	0.002	18	0.05556	9
EXCO RES PA INC	0	1	0	0	0	0	0	0	0	0	1	0.002	5	0.2	2
INTERSTATE GAS MKT INC	0	0	0	0	1	0	0	0	0	0	1	0.002	1	1	5
J W OPR CO	5	4	4	0	2	0	0	2	7	3	27	0.040	2	13.5	5.33333
MDS ENERGY LTD	0	1	0	0	1	0	0	4	0	0	6	0.010	2	3	6.5
NOVUS OPERATING LLC	0	1	0	0	1	0	0	0	0	0	2	0.003	2	1	3.5
PA GEN ENERGY CO LLC	1	4	4	0	5	0	0	1	0	1	16	0.025	13	1.23077	4
PHILLIPS EXPL INC	0	0	0	0	1	0	0	0	0	1	2	0.003	2	1	7.5
RANGE RES APPALACHIA LLC	0	0	0	0	2	0	0	0	6	2	10	0.016	121	0.08264	8.4
REX ENERGY OPR CORPORATION	1	0	1	0	1	0	0	0	0	0	3	0.005	11	0.27273	3
RICE DRILLING B LLC	0	0	0	0	1	0	0	0	0	0	1	0.002	2	0.5	5
SAMSON RES CO	2	0	1	0	0	0	0	0	0	2	5	0.008	1	5	5
SENECA RES CORP	5	6	4	0	2	1	0	0	1	2	21	0.033	16	1.3125	3.52381
SM ENERGY CO	0	0	1	0	0	0	0	0	0	0	1	0.002	0	0	3
STONE ENERGY CORP	0	0	0	0	2	0	0	1	0	0	3	0.005	2	1.5	6
TALISMAN E USA INC	2	2	2	4	91	0	0	0	9	0	110	0.172	0	0	5.12727

TANGLEWOOD EXPL LLC	1	1	1	0	0	0	0	0	0	0	3	0.005	1	3	2
TURN OIL INC	0	0	1	0	1	0	0	0	0	0	2	0.003	2	1	4
ULTRA RESOURCES INC	0	3	6	3	7	0	0	0	0	0	19	0.030	15	1.26667	3.73684
WILLIAM S BURKLAND	1	2	1	0	1	0	0	1	0	0	6	0.009	0	0	3.5
XTO ENERGY INC	0	1	6	0	6	1	0	1	0	0	15	0.023	8	1.875	4.26667
Total	57	60	120	21	277	4	3	30	32	35	639	1	664		

Violations in the Marcellus Shale Play in **2010**, group using the Borda count technique

Operators in the Marcellus Shale 2010	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Weighted Average
	1	2	3	4	5	6	7	8	9	10					
ALPHA WELLS INC.	11	1	1	1	0	0	1	0	2	0	17	0.0126	2	8.5	2.6471
ANADARKO CO LP	4	1	17	2	12	0	0	2	15	3	56	0.0417	92	0.6087	5.4643
ANSCHUTZ EXPL CORP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ANTERO RES	0	0	1	0	2	0	0	0	2	2	7	0.0052	2	3.5	7.2857
ATLAS RES LLC	0	0	1	0	6	1	5	1	1	4	19	0.0141	43	0.4419	6.8947
BAKER GAS INC	1	0	0	0	0	0	0	0	2	0	3	0.0022	2	1.5	6.3333
BLX INC	1	1	2	0	1	1	1	0	2	0	9	0.0067	7	1.2857	5
BURNETT OIL CO INC	1	0	0	0	0	0	0	2	0	0	3	0.0022	2	1.5	5.6667

Operators in the Marcellus Shale 2010	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Weighted
CABOT O&G	5	0	26	12	17	1	0	0	15	4	80	0.0595	47	1.7021	4.9625
CARRIZO (MAR)LLC	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
CARRIZO O&G INC	0	0	1	0	0	0	1	0	0	0	2	0.0015	0	0	5
CHESAPEAKE LLC	18	8	6	7	35	0	2	17	11	27	131	0.0975	181	0.7238	5.9084
CHIEF OIL & GAS LLC	29	8	38	11	36	1	0	9	25	14	171	0.1272	47	3.6383	4.8304
CITRUS CORP	4	1	10	1	5	0	0	0	3	3	27	0.0201	1	27	4.5185
CNX GAS CO LLC	0	0	2	0	0	0	0	2	0	4	8	0.006	18	0.4444	7.75
CONSOL GAS CO	0	0	0	0	0	1	0	2	1	1	5	0.0037	14	0.3571	8.2
EAST RES INC	0	0	1	0	0	0	0	0	1	1	3	0.0022	107	0.028	7.3333
EAST RES MGMT LLC	18	14	23	8	28	3	0	1	14	12	121	0.09	35	3.4571	4.6198
ENCANA INC	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
ENERGY CORP OF AMER	0	2	0	1	3	1	0	0	0	2	9	0.0067	1	9	5.4444
ENERPLUS RES (USA) CORP	0	0	1	0	1	0	0	0	3	0	5	0.0037	1	5	7
EOG RESOURCES INC	2	1	3	0	6	2	0	3	0	5	22	0.0164	59	0.3729	5.8636
EQT PROD LLC	3	1	4	0	0	1	0	0	6	1	16	0.0119	6	2.6667	5.4375
EXCO RES PA INC	3	0	4	1	2	0	0	2	5	1	18	0.0134	27	0.6667	5.5556
FLATIRONS DEV LLC	0	0	0	0	0	0	0	0	0	1	1	0.0007	0	0	0

Operators in the Marcellus Shale 2010	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Weighted
GREAT OAK ENERGY INC	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
GUARDIAN EXPL LLC	4	0	0	0	0	1	0	0	0	2	7	0.0052	0	0	4.2857
HESS CORP	0	0	1	0	2	0	0	0	1	0	4	0.003	3	1.3333	5.5
J W OPR CO	4	4	4	0	3	0	3	1	3	0	22	0.0164	2	11	4.3182
JR RESOURCES LP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LONGFELLOW ENERGY LP	0	0	0	0	1	0	0	0	0	0	1	0.0007	0	0	5
MARATHON OIL	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
MDS ENERGY LTD	0	1	2	0	1	0	0	0	2	2	8	0.006	2	4	6.375
MIEKA LLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MTN V OIL & GAS INC	0	0	0	0	2	0	1	2	0	1	6	0.0045	0	0	7.1667
NOVUS OPERATING LLC	1	1	2	0	3	0	0	0	2	1	10	0.0074	4	2.5	5.2
PA GEN ENERGY CO LLC	8	2	15	0	9	1	2	0	2	12	51	0.0379	27	1.8889	5.098
PDC MOUNTAINEER LLC	0	0	0	0	1	0	0	1	0	0	2	0.0015	0	0	6.5
PENN VIRGINIA OIL & GAS CORP	0	0	1	2	2	2	0	0	0	0	7	0.0052	1	7	4.7143
PHILLIPS EXPL INC	1	0	1	0	5	0	2	2	1	1	13	0.0097	7	1.8571	6
RANGE RES AP LLC	3	3	1	0	10	1	1	7	12	5	43	0.032	133	0.3233	6.7209
REX E. OPR CORP	0	0	1	1	1	0	0	0	2	0	5	0.0037	31	0.1613	6

Operators in the Marcellus Shale 2010	Severity of Violations										Total	Weight	Wells Drilled	Incident Rate	Severity Rate/ Weighted
RICE DRILLING B LLC	1	1	0	0	1	0	0	0	4	0	7	0.0052	6	1.1667	6.2857
SAMSON RES CO	0	0	0	0	0	0	2	0	0	0	2	0.0015	0	0	7
SENECA RES CORP	5	4	16	5	21	5	1	2	5	7	71	0.0528	54	1.3148	4.9859
SM ENERGY CO	0	0	1	0	0	0	0	1	0	1	3	0.0022	0	0	7
SNYDER BROS INC	2	1	1	0	1	0	1	2	5	2	15	0.0112	19	0.7895	6.6667
SOUTHWESTERN ENERGY PROD CO	0	0	3	1	2	0	0	3	1	3	13	0.0097	20	0.65	6.6154
STONE ENERGY CORP	1	0	0	2	0	2	0	0	0	0	5	0.0037	3	1.6667	4.2
TALISMAN ENERGY USA INC	54	2	19	4	18	2	0	32	15	16	162	0.1205	254	0.6378	4.8395
TANGLEWOOD EXPL LLC	1	0	1	0	0	0	0	1	0	1	4	0.003	3	1.3333	5.5
TEXAS KEYSTONE INC	1	0	0	0	1	0	0	0	0	0	2	0.0015	0	0	3
TRIANA ENERGY LLC	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
TRUE OIL LLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULTRA RES INC	2	2	8	2	15	4	0	0	2	4	39	0.029	34	1.1471	5
VISTA OPR INC	1	1	0	0	1	1	0	0	0	0	4	0.003	0	0	3.5
W. MCINTIRE	1	1	0	0	0	0	1	0	0	0	3	0.0022	0	0	3.3333
WILLIAM S BURKLAND	0	2	0	0	1	0	0	0	0	0	3	0.0022	0	0	3
WILLIAMS PROD	3	2	13	1	10	1	0	3	3	1	37	0.0275	21	1.7619	4.5135
XTO ENERGY INC	12	0	10	0	7	0	0	6	16	11	62	0.0461	22	2.8182	6.1129
Total	**205**	**65**	**241**	**62**	**272**	**32**	**24**	**104**	**184**	**155**	**1344**	**1**	**1352**	**0.9941**	

APPENDIX C VALIDATION SAS CODE

```
/****************************/
/* Exploratory Data Analysis */
/****************************/

/* Datasets */

Data year2008;
      /* Read the dataset*/
      Infile'V:\My Documents\My SAS Files\9.1\2008.txt'dlm='09'x;
      Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10;
      run;

Data year2009;
      /* Read the dataset*/
      Infile'V:\My Documents\My SAS Files\9.1\2009.txt'dlm='09'x;
      Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10;
      run;

Data year2010;
      /* Read the dataset*/
      Infile'V:\My Documents\My SAS Files\9.1\2010.txt'dlm='09'x;
      Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10;
      run;

data year2008;
      set year2008;
      viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
      if (viol>0) then
avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;
      else avgsev=0;
      run;

data year2009;
      set year2009;
      viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
      if (viol>0) then
avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;
      else avgsev=0;
      run;

data year2010;
      set year2010;
      viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
      if (viol>0) then
avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;
      else avgsev=0;
      run;



procprintdata=year2008;run;

procunivariatedata=year2008;
      var avgsev;
```

```
        run;

    procunivariatedata=year2008;
        var avgsev;

    procprintdata=year2009;run;

    procunivariatedata=year2009;
        var avgsev;
        run;

    procunivariatedata=year2009;
        var avgsev;


    procprintdata=year2010;run;

    procunivariatedata=year2010;
        var avgsev;
        run;

    procunivariatedata=year2010;
        var avgsev;

        outputout=result min=min_avgsev q1=q1_savgsev median=med_avgsev
q3=q3_savgsev max=max_savgsev;
        run;

    data group;
        set result year2008;
        if (avgsev<=4) then group1 = company;
        if (avgsev>4& avgsev<=5) then group2 = company;
        if (avgsev>5& avgsev<=5.82353) then group3 = company;
        if (avgsev>5.82353) then group4 = company;
        run;

    procprintdata=group ; run;

    data group;
        set result year2009;
        if (avgsev<=3.63033) then group1 = company;
        if (avgsev>3.63033& avgsev<=4.51364) then group2 = company;
        if (avgsev>4.51364& avgsev<=5.23030) then group3 = company;
        if (avgsev>5.23030) then group4 = company;
        run;

    procprintdata=group ; run;

    data group;
        set result year2010;
        if (avgsev<=4.24286) then group1 = company;
        if (avgsev>4.24286& avgsev<=5.14902) then group2 = company;
        if (avgsev>5.14902& avgsev<=6.35417) then group3 = company;
        if (avgsev>6.35417) then group4 = company;
        run;

    procprintdata=group ; run;
```

```
/***********************************/
/* Doubly Repeated Measures ANCOVA */
/***********************************/

Data long;
      /* Read the dataset*/
      Infile'V:\My Documents\My SAS
Files\9.1\violations.txt'firstobs=2dlm='09'x;
      Input company $ violations category year;
      year1=year;
      run;


/* Symbolic scatter plot: */
data cplot;
      set long;
      if (category=1&year=2008) then category1=violations;
      elseif (category=2&year1=2008) then category2 = violations;
      elseif (category=3&year1=2008) then category3 = violations;
      elseif (category=4&year1=2008) then category4 = violations;
      elseif (category=5&year1=2008) then category5 = violations;
      elseif (category=6&year1=2008) then category6 = violations;
      elseif (category=7&year1=2008) then category7 = violations;
      elseif (category=8&year1=2008) then category8 = violations;
      elseif (category=9&year1=2008) then category9 = violations;
      elseif (category=10&year1=2008) then category10 = violations;
      run;

procmeansdata=cplot;
      var category1 category2 category3 category4 category5 category6
category7 category8 category9 category10;
      outputout=cat2008 mean=m_2008;
      run;


data cplot;
      set long;
      if (category=1&year=2009) then category1=violations;
      elseif (category=2&year1=2009) then category2 = violations;
      elseif (category=3&year1=2009) then category3 = violations;
      elseif (category=4&year1=2009) then category4 = violations;
      elseif (category=5&year1=2009) then category5 = violations;
      elseif (category=6&year1=2009) then category6 = violations;
      elseif (category=7&year1=2009) then category7 = violations;
      elseif (category=8&year1=2009) then category8 = violations;
      elseif (category=9&year1=2009) then category9 = violations;
      elseif (category=10&year1=2009) then category10 = violations;
      run;

procmeansdata=cplot;
      var category1 category2 category3 category4 category5 category6
category7 category8 category9 category10;
      outputout=cat2009 mean=m_2009;
      run;


data cplot;
```

```
            set long;
            if (category=1&year=2010) then category1=violations;
            elseif (category=2&year1=2010) then category2 = violations;
            elseif (category=3&year1=2010) then category3 = violations;
            elseif (category=4&year1=2010) then category4 = violations;
            elseif (category=5&year1=2010) then category5 = violations;
            elseif (category=6&year1=2010) then category6 = violations;
            elseif (category=7&year1=2010) then category7 = violations;
            elseif (category=8&year1=2010) then category8 = violations;
            elseif (category=9&year1=2010) then category9 = violations;
            elseif (category=10&year1=2010) then category10 = violations;
            run;

      procmeansdata=cplot;
            var category1 category2 category3 category4 category5 category6
category7 category8 category9 category10;
            outputout=cat2010 mean=m_2010;
            run;

      data scatter;
      input r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 year;
      cards;
            1.6666667   2.3030303   2.3636364   0.2424242   6.8787879
      0.8787879   0.5454545   0.6666667   1.2424242   1.9393939   2008
            1.5833333   1.6666667   3.3333333   0.5833333   7.6944444
      0.1111111   0.0833333   0.8333333   0.8888889   0.9722222   2009
            3.4166667   1.0833333   4.0166667   1.0333333   4.5333333
      0.5333333   0.4   1.7333333   3.0666667   2.5833333   2010
            ;
      run;



      /* Symbolic scatter plot: */
      goptionsreset=all;
      symbol1c=blue    v=dot h=.8interpol=join;
      symbol2c=red     v=dot h=.8interpol=join;
      symbol3c=green   v=dot h=.8interpol=join;
      symbol4c=black   v=dot h=.8interpol=join;
      symbol5c=orange  v=dot h=.8interpol=join;
      symbol6c=cyan    v=dot h=.8interpol=join;
      symbol7c=yellow  v=dot h=.8interpol=join;
      symbol8c=magenta v=dot h=.8interpol=join;
      symbol9c=violet  v=dot h=.8interpol=join;
      symbol10c=brown   v=dot h=.8interpol=join;
      legend1label=none value=(height=1font=swiss 'Rank 1''Rank 2''Rank
3''Rank 4'
                  'Rank 5''Rank 6''Rank 7''Rank 8''Rank 9''Rank 10' )
                  position=(top left inside) mode=share cborder=black;
      procgplotdata=scatter;
      plot (r1 r2 r3 r4 r5 r6 r7 r8 r9 r10)*year/overlaylegend=legend1;
      run;


      /* First fit - untransformed data */

      Data long;
```

```
            /* Read the dataset*/
            infile'V:\My Documents\My SAS
Files\9.1\violations.txt'firstobs=2dlm='09'x;
            input company $ violations category year;
            year1=year;
            run;

      ods graphics on;
      procmixeddata=long;
            class category year1 company;
            model violations = category|year / residual;
            lsmeans category / adjust=tukey;
            repeated year1 category  / type=un@cs subject=company;
            run;
      ods graphics off;


      /* Second fit - transformed data */

      /* Transform the dataset*/
      Data translong;
            set long;
            transviolations=(violations+1.57)**(-.6);
            run;

      ods graphics on;
      procmixeddata=translong;
            class category year1 company;
            model transviolations = category|year / residual;
            lsmeans category / adjust=tukey;
            repeated year1 category  / type=un@cs subject=company;
            run;
      ods graphics off;
```

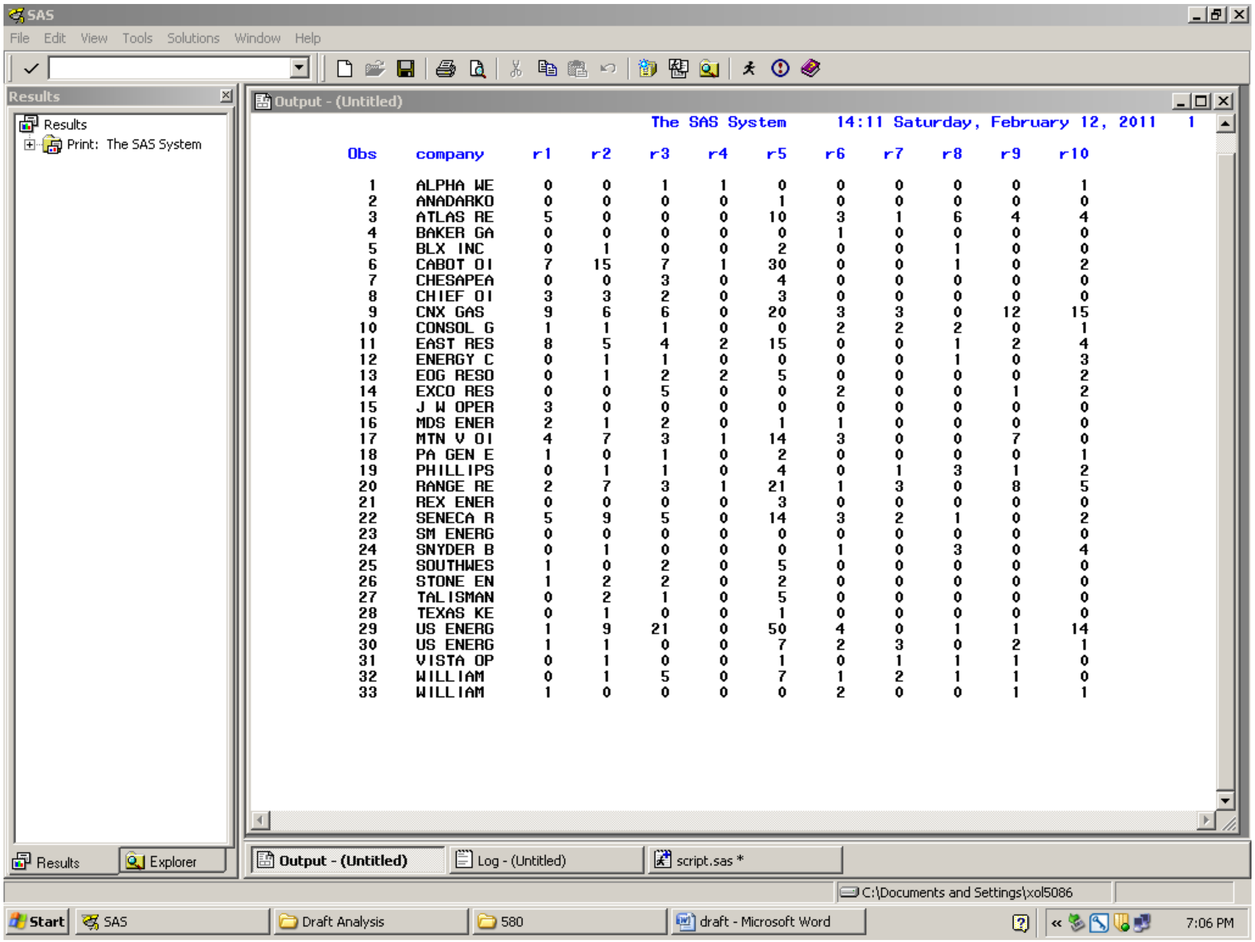
```
Raw Program data: /*To read the .txt file into sas*/

Data year2008;
        /* Read the dataset*/
Infile'C:\Documents and Settings\rzo5017\My Documents\Downloads\Draft Analysis\2008.txt'dlm='09'x;
Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 ;
run;

Data year2009;
        /* Read the dataset*/
Infile'C:\Documents and Settings\rzo5017\My Documents\Downloads\Draft Analysis\2009.txt'dlm='09'x;
Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 Total Weight;
run;

Data year2010;
        /* Read the dataset*/
Infile'C:\Documents and Settings\rzo5017\My Documents\Downloads\Draft Analysis\2010.txt'dlm='09'x;
Input company $ r1 r2 r3 r4 r5 r6 r7 r8 r9 r10 Total Weight;
run;
```

To print this SAS dataset, we use the procedure **procprint**.

```
procprintdata=year2008;
run;
procprintdata=year2009;
run;
procprintdata=year2010;
run;
```

Using **Proc Print**, you should get output that looks like Figure 28

```
data year2008;
        set year2008;
        viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
        if (viol>0) then
avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;
        else avgsev=0;
run;
```



The SAS System 14:11 Saturday, February 12, 2011 1

Obs	company	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10
1	ALPHA WE	0	0	1	1	0	0	0	0	0	1
2	ANADARKO	0	0	0	0	1	0	0	0	0	0
3	ATLAS RE	5	0	0	0	10	3	1	6	4	4
4	BAKER GA	0	0	0	0	0	1	0	0	0	0
5	BLX INC	0	1	0	0	2	0	0	1	0	0
6	CABOT OI	7	15	7	1	30	0	0	1	0	2
7	CHESAPEA	0	0	3	0	4	0	0	0	0	0
8	CHIEF OI	3	3	2	0	3	0	0	0	0	0
9	CNX GAS	9	6	6	0	20	3	3	0	12	15
10	CONSOL G	1	1	1	0	0	2	2	2	0	1
11	EAST RES	8	5	4	2	15	0	0	1	2	4
12	ENERGY C	0	1	1	0	0	0	0	1	0	3
13	EOG RESO	0	1	2	2	5	0	0	0	0	2
14	EXCO RES	0	0	5	0	0	2	0	0	1	2
15	J W OPER	3	0	0	0	0	0	0	0	0	0
16	MDS ENER	2	1	2	0	1	1	0	0	0	0
17	MTN V OI	4	7	3	1	14	3	0	0	7	0
18	PA GEN E	1	0	1	0	2	0	0	0	0	1
19	PHILLIPS	0	1	1	0	4	0	1	3	1	2
20	RANGE RE	2	7	3	1	21	1	3	0	8	5
21	REX ENER	0	0	0	0	3	0	0	0	0	0
22	SENECA R	5	9	5	0	14	3	2	1	0	2
23	SM ENERG	0	0	0	0	0	0	0	0	0	0
24	SNYDER B	0	1	0	0	0	1	0	3	0	4
25	SOUTHWES	1	0	2	0	5	0	0	0	0	0
26	STONE EN	1	2	2	0	2	0	0	0	0	0
27	TALISMAN	0	2	1	0	5	0	0	0	0	0
28	TEXAS KE	0	1	0	0	1	0	0	0	0	0
29	US ENERG	1	9	21	0	50	4	0	1	1	14
30	US ENERG	1	1	0	0	7	2	3	0	2	1
31	VISTA OP	0	1	0	0	1	0	1	1	1	0
32	WILLIAM	0	1	5	0	7	1	2	1	1	0
33	WILLIAM	1	0	0	0	0	2	0	0	1	1

Figure 28: Companies Display

```
data year2009;
    set year2009;
    viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
    if (viol>0) then
avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;
    else avgsev=0;
run;

data year2010;
    set year2010;
    viol=sum(r1,r2,r3,r4,r5,r6,r7,r8,r9,r10);
```

if (viol>0) then

avgsev=(r1+2*r2+3*r3+4*r4+5*r5+6*r6+7*r7+8*r8+9*r9+10*r10)/viol;

else avgsev=0;

run;

To print this SAS dataset, the **procprint** was used

procprintdata=year2008;

run;

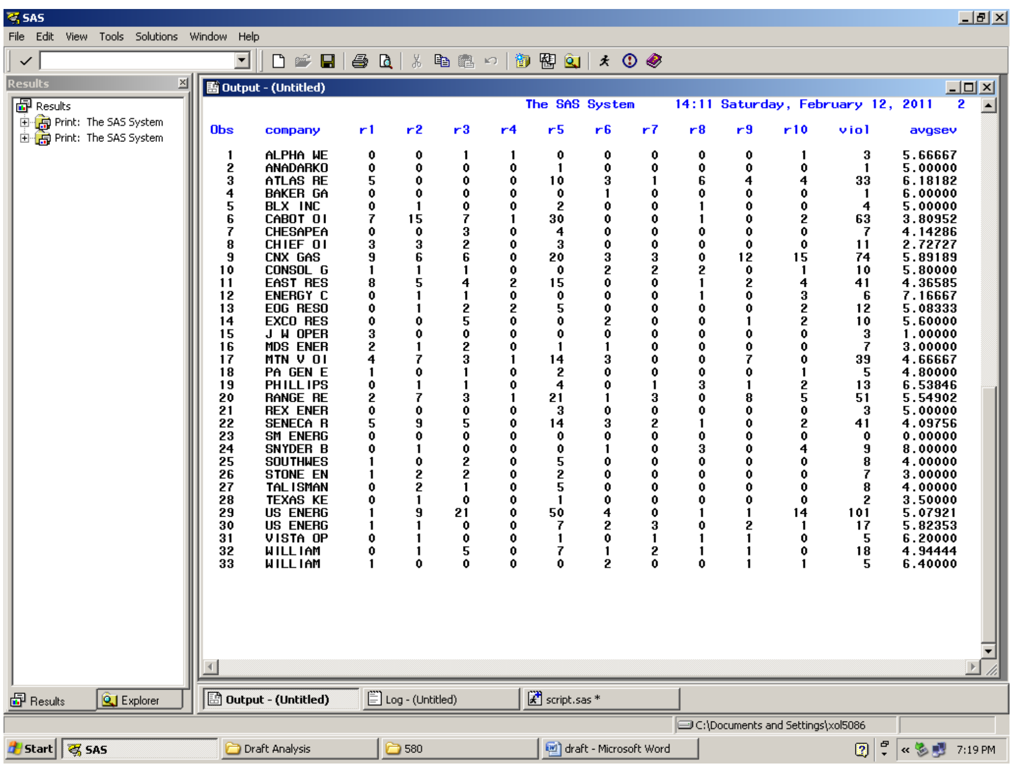
procprintdata=year2009;

run;

procprintdata=year2010;

run;

Using **procprint**, there are two need additional variables to the data, these variables are **viol** and **avgsev,** as shown in Figure 29:



The SAS System 14:11 Saturday, February 12, 2011 2

Obs	company	r1	r2	r3	r4	r5	r6	r7	r8	r9	r10	viol	avgsev
1	ALPHA WE	0	0	1	1	0	0	0	0	0	1	3	5.66667
2	ANADARKO	0	0	0	0	1	0	0	0	0	0	1	5.00000
3	ATLAS RE	5	0	0	0	10	3	1	6	4	4	33	6.18182
4	BAKER GA	0	0	0	0	0	1	0	0	0	0	1	6.00000
5	BLX INC	0	1	0	0	2	0	0	1	0	0	4	5.00000
6	CABOT OI	7	15	7	1	30	0	0	1	0	2	63	3.80952
7	CHESAPEA	0	0	3	0	4	0	0	0	0	0	7	4.14286
8	CHIEF OI	3	3	2	0	3	0	0	0	0	0	11	2.72727
9	CNX GAS	9	6	6	0	20	3	3	0	12	15	74	5.89189
10	CONSOL G	1	1	1	0	0	2	2	2	0	1	10	5.80000
11	EAST RES	8	5	4	2	15	0	0	1	2	4	41	4.36585
12	ENERGY C	0	1	1	0	0	0	0	1	0	3	6	7.16667
13	EOG RESO	0	1	2	2	5	0	0	0	0	2	12	5.08333
14	EXCO RES	0	0	5	0	0	2	0	0	1	2	10	5.60000
15	J W OPER	3	0	0	0	0	0	0	0	0	0	3	1.00000
16	MDS ENER	2	1	2	0	1	1	0	0	0	0	7	3.00000
17	MTN V OI	4	7	3	1	14	3	0	0	7	0	39	4.66667
18	PA GEN E	1	0	1	0	2	0	0	0	0	1	5	4.80000
19	PHILLIPS	0	1	1	0	4	0	1	3	1	2	13	6.53846
20	RANGE RE	2	7	3	1	21	1	3	0	8	5	51	5.54902
21	REX ENER	0	0	0	0	3	0	0	0	0	0	3	5.00000
22	SENECA R	5	9	5	0	14	3	2	1	0	2	41	4.09756
23	SM ENERG	0	0	0	0	0	0	0	0	0	0	0	0.00000
24	SNYDER B	0	1	0	0	0	1	0	3	0	4	9	8.00000
25	SOUTHWES	1	0	2	0	5	0	0	0	0	0	8	4.00000
26	STONE EN	1	2	2	0	2	0	0	0	0	0	7	3.00000
27	TALISMAN	0	2	1	0	5	0	0	0	0	0	8	4.00000
28	TEXAS KE	0	1	0	0	1	0	0	0	0	0	2	3.50000
29	US ENERG	1	9	21	0	50	4	0	1	1	14	101	5.07921
30	US ENERG	1	1	0	0	7	2	3	0	2	1	17	5.82353
31	VISTA OP	0	1	0	0	1	0	1	1	1	0	5	6.20000
32	WILLIAM	0	1	5	0	7	1	2	1	1	0	18	4.94444
33	WILLIAM	1	0	0	0	0	2	0	0	1	1	5	6.40000

Figure 29: Weighted Average Display

```
procunivariatedata=year2008;
var avgsev;
run;

procunivariatedata=year2009;
var avgsev;
run;

procunivariatedata=year2010;
var avgsev;
run;
```

The output should look like Figure 29:

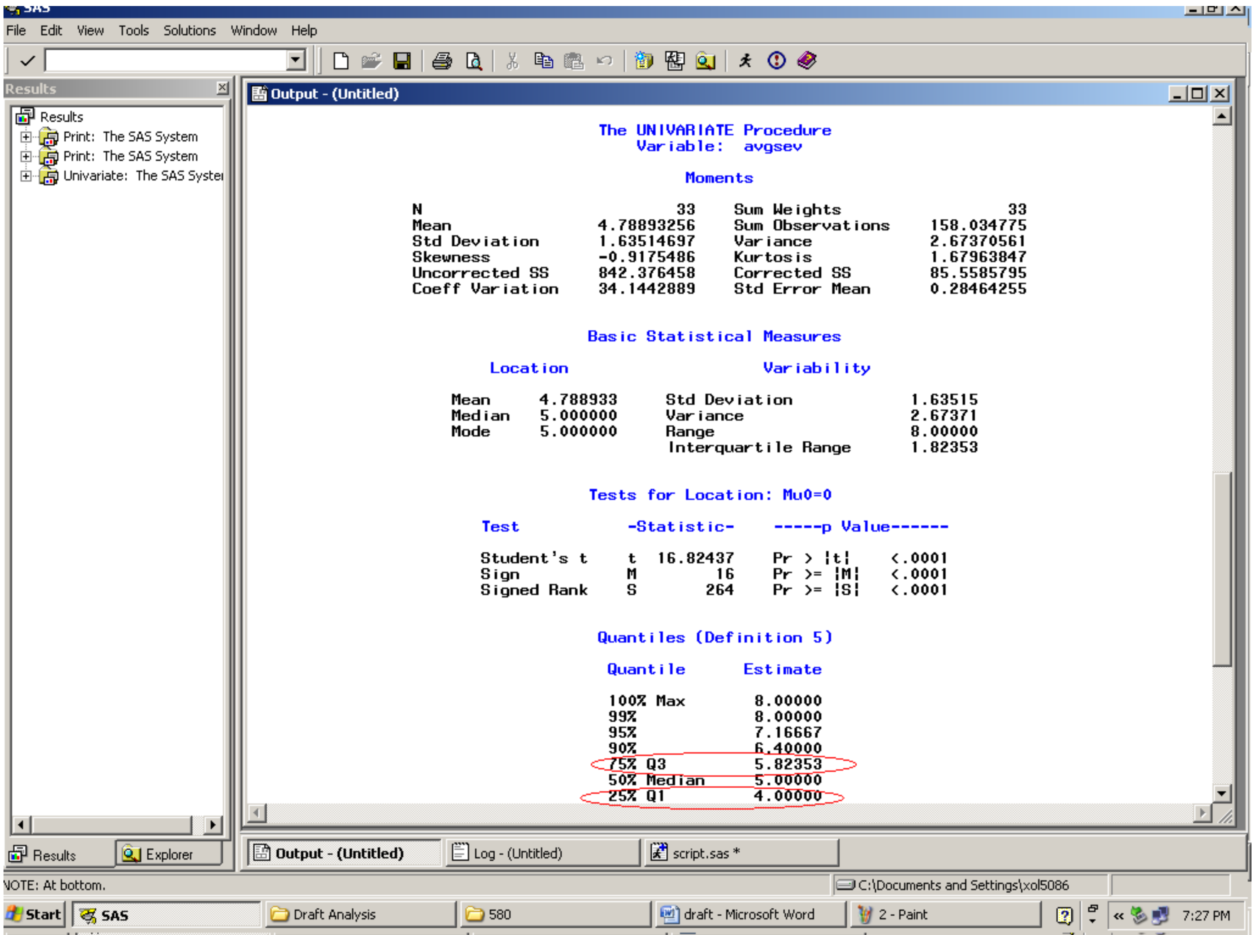


Figure 30: Univariate Procedure Display

.

For 2009,

```
data group;
      set result year2009;
      if (avgsev<=3.63033) then group1 = company;
      if (avgsev>3.63033& avgsev<=4.51364) then group2 = company;
      if (avgsev>4.51364& avgsev<=5.23030) then group3 = company;
      if (avgsev>5.23030) then group4 = company;
      run;

procprintdata=group ; run;
procprintdata=group ;
var group1 group2 group3 group4;
run;
```

For 2010

```
data group;
      set result year2010;
      if (avgsev<=4.24286) then group1 = company;
      if (avgsev>4.24286& avgsev<=5.14902) then group2 = company;
      if (avgsev>5.14902& avgsev<=6.35417) then group3 = company;
      if (avgsev>6.35417) then group4 = company;
      run;

procprintdata=group ; run;
procprintdata=group ;
var group1 group2 group3 group4;
run;
```

Fig 31b: Subjects	**violations**	**category**	**year**
ALPHA WELLS INC.	0	1	2008
ALPHA WELLS INC.	0	2	2008
ALPHA WELLS INC.	1	3	2008
ALPHA WELLS INC.	1	4	2008
ALPHA WELLS INC.	0	5	2008

ALPHA WELLS INC.	0	6	2008
ALPHA WELLS INC.	0	7	2008
ALPHA WELLS INC.	0	8	2008
ALPHA WELLS INC.	0	9	2008
ALPHA WELLS INC.	1	10	2008
ANADARKO E&P CO LP	0	1	2008
ANADARKO E&P CO LP	0	2	2008
ANADARKO E&P CO LP	0	3	2008
ANADARKO E&P CO LP	0	4	2008
ANADARKO E&P CO LP	1	5	2008
ANADARKO E&P CO LP	0	6	2008
ANADARKO E&P CO LP	0	7	2008
ANADARKO E&P CO LP	0	8	2008
ANADARKO E&P CO LP	0	9	2008
ANADARKO E&P CO LP	0	10	2008
ATLAS RESOURCES LLC	5	1	2008
ATLAS RESOURCES LLC	0	2	2008
ATLAS RESOURCES LLC	0	3	2008
ATLAS RESOURCES LLC	0	4	2008
ATLAS RESOURCES LLC	10	5	2008
ATLAS RESOURCES LLC	3	6	2008
ATLAS RESOURCES LLC	1	7	2008
ATLAS RESOURCES LLC	6	8	2008
ATLAS RESOURCES LLC	4	9	2008
ATLAS RESOURCES LLC	4	10	2008

Fig 31b: Example of Operators listing yearly and number of violations

SAS Code Figure 35

```
data cplot;
	set long;
	if (category=1&year=2008) then category1=violations;
	elseif (category=2&year1=2008) then category2 = violations;
	elseif (category=3&year1=2008) then category3 = violations;
	elseif (category=4&year1=2008) then category4 = violations;
	elseif (category=5&year1=2008) then category5 = violations;
	elseif (category=6&year1=2008) then category6 = violations;
	elseif (category=7&year1=2008) then category7 = violations;
	elseif (category=8&year1=2008) then category8 = violations;
	elseif (category=9&year1=2008) then category9 = violations;
	elseif (category=10&year1=2008) then category10 = violations;
	run;

procmeansdata=cplot;
	var category1 category2 category3 category4 category5 category6 category7 category8
category9 category10;
	outputout=cat2008 mean=m_2008;
	run;

data cplot;
	set long;
	if (category=1&year=2009) then category1=violations;
	elseif (category=2&year1=2009) then category2 = violations;
	elseif (category=3&year1=2009) then category3 = violations;
	elseif (category=4&year1=2009) then category4 = violations;
	elseif (category=5&year1=2009) then category5 = violations;
	elseif (category=6&year1=2009) then category6 = violations;
	elseif (category=7&year1=2009) then category7 = violations;
	elseif (category=8&year1=2009) then category8 = violations;
	elseif (category=9&year1=2009) then category9 = violations;
	elseif (category=10&year1=2009) then category10 = violations;
	run;
```

```
procmeansdata=cplot;
        var category1 category2 category3 category4 category5 category6 category7 category8
category9 category10;
        outputout=cat2009 mean=m_2009;
        run;


data cplot;
        set long;
        if (category=1&year=2010) then category1=violations;
        elseif (category=2&year1=2010) then category2 = violations;
        elseif (category=3&year1=2010) then category3 = violations;
        elseif (category=4&year1=2010) then category4 = violations;
        elseif (category=5&year1=2010) then category5 = violations;
        elseif (category=6&year1=2010) then category6 = violations;
        elseif (category=7&year1=2010) then category7 = violations;
elseif (category=8&year1=2010) then category8 = violations;
    elseif (category=9&year1=2010) then category9 = violations;
        elseif (category=10&year1=2010) then category10 = violations;
        run;

procmeansdata=cplot;
        var category1 category2 category3 category4 category5 category6 category7 category8
category9 category10;
        outputout=cat2010 mean=m_2010;
        run;
```

The output for year 2008-2010 is presented in Figure 35:

Figure 36: The MEANS Procedure (2008)

Variable	N	Mean	Std Dev	Minimum	Maximum
category1	33	1.6666667	2.5083195	0	9.0000000
category2	33	2.3030303	3.5309776	0	15.0000000
category3	33	2.3636364	3.8956561	0	21.0000000
category4	33	0.2424242	0.5607084	0	2.0000000
category5	33	6.8787879	10.6587921	0	50.0000000
category6	33	0.8787879	1.2185436	0	4.0000000
category7	33	0.5454545	1.0028369	0	3.0000000
category8	33	0.6666667	1.2665570	0	6.0000000
category9	33	1.2424242	2.7160438	0	12.0000000
category10	33	1.9393939	3.5526345	0	15.0000000

The MEANS Procedure (2009)

Variable	N	Mean	Std Dev	Minimum	Maximum
category1	36	1.5833333	2.8722813	0	13.0000000
category2	36	1.6666667	2.6076810	0	12.0000000
category3	36	3.3333333	6.3064593	0	29.0000000
category4	36	0.5833333	1.4614083	0	6.0000000
category5	36	7.6944444	17.8754731	0	91.0000000
category6	36	0.1111111	0.3984095	0	2.0000000
category7	36	0.0833333	0.3683942	0	2.0000000
category8	36	0.8333333	1.9639610	0	9.0000000
category9	36	0.8888889	2.1351183	0	9.0000000
category10	36	0.9722222	1.8896124	0	9.0000000

The MEANS Procedure (2010)

Variable	N	Mean	Std Dev	Minimum	Maximum

category1	60	3.4166667	8.4438156	0	54.0000000
category2	60	1.0833333	2.3670884	0	14.0000000
category3	60	4.0166667	7.5655142	0	38.0000000
category4	60	1.0333333	2.5309385	0	12.0000000
category5	60	4.5333333	8.2430591	0	36.0000000
category6	60	0.5333333	1.0162521	0	5.0000000
category7	60	0.4000000	0.9057257	0	5.0000000
category8	60	1.7333333	4.8147607	0	32.0000000
category9	60	3.0666667	5.3006769	0	25.0000000
category10	60	2.5833333	4.8896004	0	27.0000000

Figure 36: Means Procedure

Figure 37: SAS Code

```
/* Symbolic scatter plot: */
goptionsreset=all;
symbol1c=blue    v=dot h=.8interpol=join;
symbol2c=red     v=dot h=.8interpol=join;
symbol3c=green   v=dot h=.8interpol=join;
symbol4c=black   v=dot h=.8interpol=join;
symbol5c=orange  v=dot h=.8interpol=join;
symbol6c=cyan    v=dot h=.8interpol=join;
symbol7c=yellow  v=dot h=.8interpol=join;
symbol8c=magenta v=dot h=.8interpol=join;
symbol9c=violet  v=dot h=.8interpol=join;
symbol10c=brown   v=dot h=.8interpol=join;
legend1label=none value=(height=1font=swiss 'Rank 1''Rank 2''Rank 3''Rank 4'
                 'Rank 5''Rank 6''Rank 7''Rank 8''Rank 9''Rank 10' )
                 position=(top left inside) mode=share cborder=black;
procgplotdata=scatter;
plot (r1 r2 r3 r4 r5 r6 r7 r8 r9 r10)*year/overlaylegend=legend1;
run;
```

The output for year 2008-2010 should be as shown in figure 37:

Figure 41: Differences of Least Squares Means

Effect	category	_category	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	AdjP
category	1	2	-0.01384	0.01797	576	-0.77	0.4416	Tukey-Kramer	0.9989
category	1	3	0.04710	0.01797	576	2.62	0.0090	Tukey-Kramer	0.2100
category	1	4	-0.09415	0.01797	576	-5.24	<.0001	Tukey-Kramer	<.0001
category	1	5	0.09829	0.01797	576	5.47	<.0001	Tukey-Kramer	<.0001
category	1	6	-0.08852	0.01797	576	-4.93	<.0001	Tukey-Kramer	<.0001
category	1	7	-0.1112	0.01797	576	-6.19	<.0001	Tukey-Kramer	<.0001
category	1	8	-0.05836	0.01797	576	-3.25	0.0012	Tukey-Kramer	0.0403
category	1	9	-0.02071	0.01797	576	-1.15	0.2495	Tukey-Kramer	0.9788
category	1	10	-0.00795	0.01797	576	-0.44	0.6584	Tukey-Kramer	1.0000
category	2	3	0.06094	0.01797	576	3.39	0.0007	Tukey-Kramer	0.0256
category	2	4	-0.08031	0.01797	576	-4.47	<.0001	Tukey-Kramer	0.0004
category	2	5	0.1121	0.01797	576	6.24	<.0001	Tukey-Kramer	<.0001
category	2	6	-0.07469	0.01797	576	-4.16	<.0001	Tukey-Kramer	0.0015
category	2	7	-0.09739	0.01797	576	-5.42	<.0001	Tukey-Kramer	<.0001
category	2	8	-0.04452	0.01797	576	-2.48	0.0135	Tukey-Kramer	0.2828
category	2	9	-0.00688	0.01797	576	-0.38	0.7022	Tukey-Kramer	1.0000
category	2	10	0.005889	0.01797	576	0.33	0.7432	Tukey-Kramer	1.0000
category	3	4	-0.1413	0.01797	576	-7.86	<.0001	Tukey-Kramer	<.0001
category	3	5	0.05118	0.01797	576	2.85	0.0046	Tukey-Kramer	0.1231
category	3	6	-0.1356	0.01797	576	-7.55	<.0001	Tukey-Kramer	<.0001
category	3	7	-0.1583	0.01797	576	-8.81	<.0001	Tukey-Kramer	<.0001
category	3	8	-0.1055	0.01797	576	-5.87	<.0001	Tukey-Kramer	<.0001
category	3	9	-0.06781	0.01797	576	-3.77	0.0002	Tukey-Kramer	0.0068
category	3	10	-0.05505	0.01797	576	-3.06	0.0023	Tukey-Kramer	0.0693
category	4	5	0.1924	0.01797	576	10.71	<.0001	Tukey-Kramer	.0001

category	4	6	0.005624	0.01797	576	0.31	0.7544	Tukey-Kramer	1.0000
category	4	7	-0.01707	0.01797	576	-0.95	0.3424	Tukey-Kramer	0.9947
category	4	8	0.03579	0.01797	576	1.99	0.0469	Tukey-Kramer	0.6052
category	4	9	0.07344	0.01797	576	4.09	<.0001	Tukey-Kramer	0.0020
category	4	10	0.08620	0.01797	576	4.80	<.0001	Tukey-Kramer	<.0001
category	5	6	-0.1868	0.01797	576	-10.40	<.0001	Tukey-Kramer	<.0001
category	5	7	-0.2095	0.01797	576	-11.66	<.0001	Tukey-Kramer	<.0001
category	5	8	-0.1566	0.01797	576	-8.72	<.0001	Tukey-Kramer	<.0001
category	5	9	-0.1190	0.01797	576	-6.62	<.0001	Tukey-Kramer	<.0001
category	5	10	-0.1062	0.01797	576	-5.91	<.0001	Tukey-Kramer	<.0001
category	6	7	-0.02270	0.01797	576	-1.26	0.2070	Tukey-Kramer	0.9612
category	6	8	0.03017	0.01797	576	1.68	0.0937	Tukey-Kramer	0.8071
category	6	9	0.06781	0.01797	576	3.77	0.0002	Tukey-Kramer	0.0068
category	6	10	0.08058	0.01797	576	4.48	<.0001	Tukey-Kramer	0.0004
category	7	8	0.05286	0.01797	576	2.94	0.0034	Tukey-Kramer	0.0966
category	7	9	0.09051	0.01797	576	5.04	<.0001	Tukey-Kramer	<.0001
category	7	10	0.1033	0.01797	576	5.75	<.0001	Tukey-Kramer	<.0001
category	8	9	0.03765	0.01797	576	2.10	0.0366	Tukey-Kramer	0.5318
category	8	10	0.05041	0.01797	576	2.81	0.0052	Tukey-Kramer	0.1370
category	9	10	0.01276	0.01797	576	0.71	0.4778	Tukey-Kramer	0.9994

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