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Well Water Quality in Southern Butler County, Pennsylvania

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WELL WATER QUALITY IN SOUTHERN BUTLER COUNTY, PENNSYLVANIA

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By

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ABSTRACT

WELL WATER QUALITY IN SOUTHERN BUTLER COUNTY, PENNSYLVANIA

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Dissertation supervised by Dr. John Stolz

The increase in unconventional shale gas extraction in Pennsylvania has resulted in an increased number of groundwater contamination claims. Well water quality was investigated in southern Butler County, PA where 387 unconventional gas wells have been drilled since 2006. A total of 121 households participated in a survey and 238 well water samples were tested. Specific conductivity, pH, and dissolved oxygen in these samples were measured in the field and seven anion concentrations and thirty metal concentrations were measured in the lab. A subset of 91 water wells was also tested for light hydrocarbons (methane, ethane, ethylene, propylene, propane, butane). Pennsylvania DEP file reviews were used to create GIS maps indicating legacy oil and gas, unconventional wells, and plot water testing results. Results indicate few wells had high quality groundwater, with 86% containing one or more contaminants above

(secondary) Maximum Contaminant Levels, with manganese (56%), iron (47%), fluoride (18%), TDS (18%), pH (17%), aluminum (17%) the most common.

DEDICATION

I would like to dedicate this paper to my parents, Linda & Scott Sr., to my brothers Kevin and Brian, to my girlfriend Alexa, and also to all my friends and family for their continuous love, support, and encouragement, as I pursued my master's degree here at Duquesne University.

ACKNOWLEDGEMENT

I would like to first off thank Dr. Stolz for taking me under as one of his graduate research assistants, and for the guidance and mentorship he has provided me throughout my journey in the program. I would like to thank the entire Stolz lab group; Shyama Alawattegama, Renee Krynock, Colleen Nolan, Colin Brown, and Tyler Umstead for their constant help and participation in this study. Without their continuous energy, drive, and dedication towards this research, this study would not have been possible.

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1.1 Groundwater of Pennsylvania

About 40 million U.S. residents rely and use groundwater sources for drinking purposes (Clemens et al., 2009, Swistock et al., 2009). Aquifers are a term used to describe these underground water sources, usually in geological units, that provide usable, high quantities of water for many purposes, including a drinking water source (Fetter, 2001). These subsurface water sources are classified on many different features, including their composition (i.e., sand and gravel), permeability, location, size of the reservoir, and water yield. These water-bearing zones can be defined as either confined or unconfined aquifers. Confined aquifers are separated from the overlying environment by a layer of impermeable rock or soil (i.e., clay), protecting the water bearing rock from potential sources of contamination that could potentially seep in from the surface (Fetter, 2001). An unconfined aquifer can have influence of water that seeps down from the surface to the water table. Preserving sources of water within both confined and unconfined aquifers is essential in sustaining our growing populations, and providing a reliable water source for future generations.

The movement of groundwater in these aquifers is influenced by porosity, permeability, and hydraulic gradient, as defined by Darcy's Law, which describes groundwater flow velocity (Fetter, 2001, Flaherty, 2014, Fleeger, 1999, Waller, 1988). Along this flowpath, the properties of aquifer can vary, such as primary porosity, which forms when the rock first develops, and secondary porosity, forming after the rock was created during weathering. A common source of secondary porosity is rock fracturing

(Fetter, 2001). As water flows through these fractures, the openings often increase in size due to increased chemical weathering at the water rock interface thus increasing the permeability in the rock (Fetter, 2001). Through hydrological processes, water travels downward from recharge zones and eventually out through discharge zones, such as lower elevation streams. The topography and elevation influence unconfined aquifers, but may or may not affect the movement of a confined aquifer's groundwater source, dependent on the geology and location. These aquifers can additionally be influenced by rock composition, and the geology of the material including sandstone, limestone, and granite aquifers, or sand, gravel, and clay aquifers (Fleeger, 1999, Waller, 1988). The geology, pressure gradients, permeability, and often topography of an area, can affect groundwater flow. In order to effectively utilize these groundwater sources, it is important to understand the dynamics of the groundwater regime.

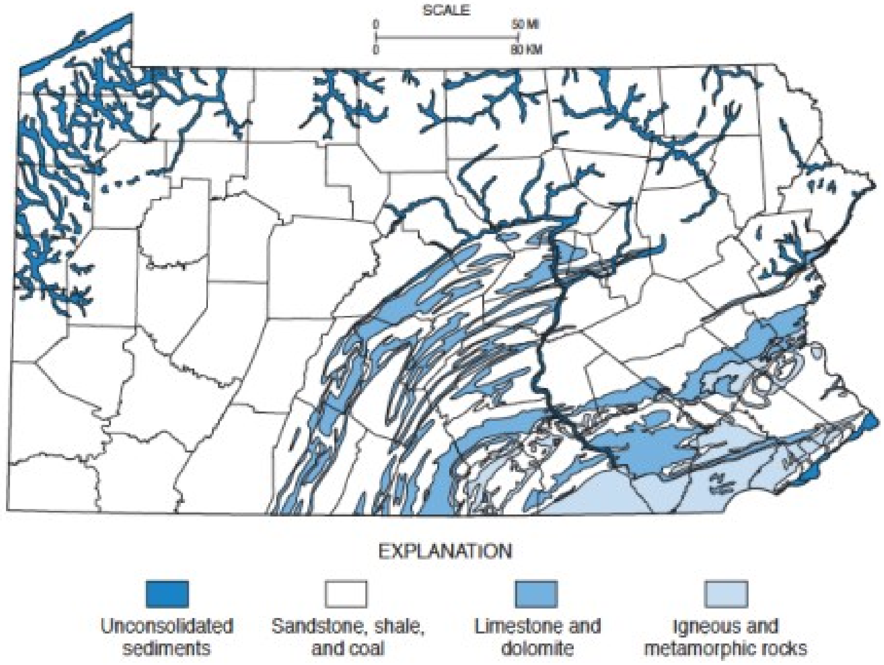


Figure 1 Rock and sediment types across Pennsylvania

(PA DCNR, Fleeger, 1999).

1.1.1 Utilizing groundwater for residential drinking water use

Groundwater supplies over 4.5 million Pennsylvanian residents with drinking and daily water use, which is about 37 percent of the population (Clemens et al., 2009, Merideth et al., 2001). In Pennsylvania, several different types of aquifers exist, including unconsolidated (i.e., sand and gravel) aquifers and consolidated (i.e., sandstone and fractured shale, carbonate, and crystalline bedrock) aquifers. Water-bearing coal seams also provide a source of drinking water as well throughout the Appalachians (Clemens, et al., 2009).

In order to extract water from these aquifers and maintain high quality drinking water for residential use, private water wells need to be optimally located and properly constructed following approved methods. Well construction techniques vary, but generally consist of methods including, dug (older), drilled (most common using mounted percussion also known as cable tool), rotary drilled, artesian (access unconfined aquifers), or driven types (Conners, 2013, Waller, 1988). Well water is used for many purposes including domestic drinking use and irrigation. Wells, when constructed properly, can be effective methods of groundwater extraction (Conners, 2013). All types of wells should be lined with pipe casing, properly sealed, and screened. Wells that are not properly constructed are susceptible to vertical migration of contaminants from surface or shallower water bearing zones, and risk degrading the quality of the aquifer (Lindsey et al., 2014).

Water wells located in rural areas that are in close proximity to each other have a higher probability to have water quantity and flow issues when there are large amounts of water usage. This can result in a localized cone of depression of the water table or potentiometric surface, potentially influencing the migration pathway of contaminants in proximity to these wells as a result of the water level decline (Fetter, 2001, Waller, 1988). Residents who have private drinking water wells are responsible for maintenance and water treatment for their systems, unlike municipal water sources. Residential well owners are recommended to test annually for fecal coliforms, and every three years for pH and total dissolved solids (TDS) (Penn State, 2015). Analyzing for these types of parameters provides indications of potential well construction or well maintenance issues and may also indicate other contaminants may be present within the well (Swistock, et al., 2009, Waller, 1998).

Groundwater quality in Pennsylvania can vary depending on the regional geology and local stratigraphy. Overall, typical Pennsylvania groundwater has concentrations of approximately 10 mg/L of dissolved oxygen, a pH value of around 6.5-6.8 standard units (s.u.), and conductance of around 350 μS/cm (Eckhardt et al., 2012). In western Pennsylvania, 18 percent of private wells contain more acidic levels of pH, below 6.5, while levels greater than 8.5 occur in less than 2 percent of drinking wells (Clemens et al., 2009). In addition to low pH, the groundwater in western PA has been found to have elevated total dissolved solids (TDS), with concentrations of approximately 500 milligrams per liter (mg/L). Generally, the groundwater quality in Butler County correlates to the stratigraphy (Poth, 1973).

1.1.2 Groundwater Protection Programs

The Environmental Protection Agency (EPA) initiates programs that apply to groundwater source protection for drinking and residential daily use. Regulations are usually established and enforced at the state level, and legislation is broken down into differentiating categories including; groundwater classification; standard setting; land-use management; and water-use management (EPA, 1990). The different categories and divisions of policies help states develop and plan different management strategies to ensure that the groundwater is safe to use in their state. The Safe Drinking Water Act (SDWA) requires states to develop these source water assessment programs also known as SWAPs, which evaluate and identify drinking water risks and challenges that states may have to their public water supplies, whether it be municipal or well water use (EPA, 2012, EPA, 1990). One type of program SWAPs have developed are source water protection case studies, providing examples of local water protection programs based on geological region. The programs help local governments with best practices, planning, and comprehensive plans against varying sources of pollution (EPA, 2012).

The 1986 amendments to the SDWA established the EPA's Wellhead Protection Program (WHPP), which specifically manages underground sources of drinking water, involved in developing comprehensive programs that protect human health from groundwater contaminants and pollution (EPA, 1990). All U.S states implement this program, but can choose to adopt more stringent standards and enforcement. The regulations vary from state to state, depending on the type of geological features and challenges associated with groundwater resources. States and even local governments establish different management plans, educational information programs, public guidance, and even establish voluntary participation (EPA, 2012). All information provided to the public contains information and guidance to establishing a well with proper construction and methods, types of water yield, defining the various sources of contamination in the areas, and contingency plans if the water becomes polluted (EPA, 1990).

The EPA also established a Sole Source Aquifer protection program (SSAs) that designates aquifers that provides at least 50 percent of the groundwater source for drinking water uses (EPA, 2012). These SSA programs under the SDWA establish a SSA designation in these areas that prevents certain types of land use or development that may pose potential risks of contamination. These areas have few or no alternatives to drinking water supplies, review proposed projects and development to ensure that the groundwater sources do not become contaminated.

1.1.3 Sample Area: Butler County

Butler County, located in the Appalachian Plateaus, covers an area of approximately 795 square miles in west-central Pennsylvania, and lies about 34 miles north of Pittsburgh (Poth, 1973).

Figure 2 Location of the study area of Butler County in reference to Pittsburgh, Pennsylvania.

The county (Figure 2) primarily contains farmland, residential use, several recreational parks including Moraine State Park, hundreds of abandoned oil and gas wells, roughly 655 abandoned strip mines, 8 active mines (aggregate, lime, sand and gravel) and eight sanitary landfills, which is shown in Figure 27. (Poth, 1973). In addition, Butler County has various types of historical and contemporary industries including steel and chemical manufacturing facilities. Bedrock consists of the Pottsville, Allegheny, and Conemaugh Groups of the Pennsylvanian Period throughout the county, with the majority of the county underlain by the Conemaugh Group (Figure 3). Aquifers found within Butler County, are generally two types; either bedrock consisting of sandstone and shale layers with coal seams often present (depths ranging from 80 to 400 feet); or unconsolidated deposits consisting of sand and gravel (depths ranging from 20 to 250 feet) with high iron concentrations (Clemens et al., 2009). Water quality of the sandstone and shale contains dissolved solids of roughly 200-250 mg/L, whereas the water quality of the unconsolidated deposits is approximately <200 mg/L) (Clemens et al., 2009, Poth, 1973). The number of mines, conventional wells, and varying permeability of the stratigraphy form complex groundwater systems in the area. The complexity revolves around determining and distinguishing pollutants from the naturally occurring contaminants from the geology, surface contaminants from poorly maintained wells, historic issues from the damaging environmental practices, and present day activities within an area.

After a review and study of the county's groundwater resources in 1973, the U.S. Geological Survey found that the groundwater in Butler County has been historically known to contain elevated concentrations of iron content, as well as TDS, exceeding state regulations (Poth, 1973). In addition to this elevated iron content, large amounts of discharge and pollution have been claimed from septic tanks, landfills, and abandoned surface and subsurface mines, and oil and gas wells (Poth, 1973). In the groundwater quality survey conducted by the USGS, a total of 48 well water samples were collected. A total of 23 samples exceeded concentrations of 0.3 mg/L for iron, and 500 mg/L of TDS within the drinking water, which are regulated as Secondary Maximum Contaminant Levels (SMCLs).

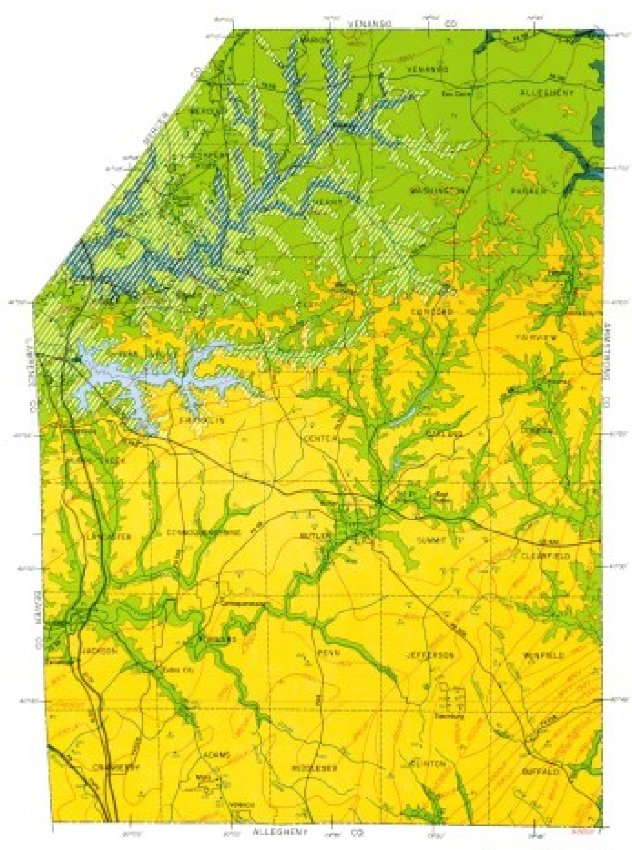


Figure 3 Generalized geologic map of Butler County, illustrating the varying geologic groups across the county (Poth, 1973).

In the survey, Poth indicates that 76% of the wells sampled and completed in the Allegheny Group had dissolved iron concentrations greater than 0.3 mg/L and elevated concentrations of sodium and chloride. The Conemaugh Group, shown in Figure 3, makes up over two thirds of southern Butler County, where samples were found to have relatively high iron concentrations (0.12 to 2.2 mg/L with an average of 0.28 mg/L) which is lower than the dissolved iron typically found in wells completed in the Allegheny and Pottsville Groups, and exhibited low concentrations of chloride and sulfate (Poth, 1973).

The geological map from Poth, 1973 show the geology of the sample area of Butler County, PA. In Figure 3, the striped yellow, light green, and dark green areas are glacial lake deposits mostly in the northern part of the county. The yellow areas, which take up over two thirds of the southern portion of the county, are the Conemaugh Group, consisting of sandstone, shale, limestone, thin coal beds, and red beds. The light green areas show the Allegheny Group consisting of sandstone, shale, limestone, and commercial grade coal beds, while the dark green areas show the Pottsville Group made up of sandstone, shale, and thin coal beds (Poth, 1973). In addition to the mapped geology of Butler County, the water chemistry information and data derived from the USGS survey in 1973 provide a base line for common groundwater quality parameters throughout the county. This survey provides a source of groundwater quality data that can be compared and related to future data collected in the county.

1.2 Groundwater Contamination

About 80 percent of the 4.5 million residents in Pennsylvania that rely on groundwater sources, are satisfied with their drinking water (Clemens et al., 2009, Merideth, 2001, Swistock et al., 2009). This strong dependence on groundwater highlights the importance of protecting these sources of drinking water from sources of contamination (Vidic et al., 2013). Through the use of water quality testing and monitoring, the levels of inorganic constituents (i.e., Ca, Na, K, Fe, Mn, Mg) and trace elements (i.e., As, Cr, Cd) of natural waters can be compared to the elevated levels of the same constituents within polluted waters. The comparison can help provide indications that different sources of contamination may be present (Fetter, 2001).

There are federal regulations and standards set by the Environmental Protection Agency (EPA), known as National Primary and Secondary Drinking Water Regulations (NPDWRs and NSDWRs) (EPA, 2003). The drinking water standards are defined as Maximum Contaminant Levels (MCLs) and SMCLs, as previously stated. These levels are regulated under the SDWA, which are set to protect public drinking water sources due to human health issues associated with elevated concentrations (EPA, 2003, Fetter, 2001). Inorganic chemicals (salts, metals, and minerals) that have Primary and Secondary MCLs are shown and summarized in Table 1. (EPA, 2003).

The primary constituents regulated are enforceable due to the potential health effects to the public, whereas the secondary contaminants are not regulated or enforced at the federal level, but may be at the state level. The secondary drinking water standards act as guidelines for water facilities. They provide a management method through the comparison of elevated levels of constituents that may affect the aesthetic conditions of the water source, regarding the taste, smell, and color (EPA, 2003).

Table 1. EA's National Primary* and Secondary** Drinking Water Standards and the Maximum Contaminant Levels (MCLs) for parameters we tested for (EPA, 2003).

Constituent	EPA's MCL (mg/L)
pH**	6.5-8.5
Fluoride (Fl)**	4.0
Chloride (Cl)**	250.0
Nitrite (NO2)*	3.3
Nitrate (NO3)*	44.3
Sulfate (SO4)**	250.0
Total Dissolved Solids (TDS)**	500.0
Aluminum (Al)**	0.05-0.20
Chromium (Cr)*	0.10
Manganese (Mn)**	0.05
Iron (Fe)**	0.3
Copper (Cu)**	1.0
Zinc (Zn)**	5
Arsenic (As)*	0.01
Selenium (Se)*	0.05
Silver (Ag)**	0.10
Cadmium (Cd)*	0.01
Antimony (Sb)*	0.006
Barium (Ba)*	2
Mercury (Hg)*	0.002
Lead (Pb)*	0.02
Uranium (U)*	0.03

Contamination can occur through activities and development within the recharge areas of the aquifer, percolating through the soil and bedrock into the groundwater regime (Merideth et al., 2001). There are various types of anthropogenic activity and natural sources that can potentially cause surface and groundwater contamination and impact the water quality throughout Pennsylvania. Human activity can be associated with leaks from underground storage tanks and pipes, oil and gas migration from fluids, and gases from improperly abandoned coal mines and oil wells, gases and leachate from landfills, agricultural run-off including pesticides and nutrients, bacteria and protozoa from septic leachate and poor agricultural activities, and spills and releases from current industries including oil and gas exploration (Foster & Chilton, 2003, Merideth et al., 2001, Waller, 1988). Contamination from these sources may include microbial pollutants such as fecal coliforms and *E.Coli*, inorganic chemicals including arsenic, barium, copper, iron, manganese, and lead, and organic chemicals such as volatile organic chemicals (VOCs), such as benzene, methyl tert-butyl ether (MTBE), xylenes, tetrachloroethylene (PCE), and trichloroethylene (TCE) (Fontenot et al., 2013,8 Swistock et al., 2003). Water quality degradation can also occur from the use of brine throughout the county. Similar to many areas of the U.S., brine contamination can degrade water quality through various ways including, leachate and runoff from increased use of road-salts (halite) for de-icing purposes, as a by-product from oil and gas exploration (Waller, 1988).

The past and recent development of oil and gas can be attributed to potential sources of contamination to shallow drinking water aquifers (Clemens et al., 2009, Waller, 1988). Abandoned and incorrectly completed wells can serve as pathways for contaminant migration. These contaminants that enter the shallow groundwater regime may include the downward migration of surface water degraded by sewage, road salt, or other contaminants and the upward migration of gases and potentially some liquids that could include VOCs and dissolved metals. However, determining the sources of these contaminants can be difficult as constituents from abandoned wells may be similar to poorly completed active wells, and in turn may be similar to industrial wastes or even naturally occurring contaminants in the bedrock beneath Butler County, which includes elevated concentrations of iron and methane (Brantley et al., 2014, Harrison, 1983, Waller, 1988). There are over 300,000 oil and gas wells historically drilled in Pennsylvania, and thousands more undocumented, many of which are orphaned and not properly sealed, which can contribute to water contamination (Brantley et al 2014, Lampe

& Stolz, 2015). The extent of the oil and gas exploration and development are shown in Figure 4 and Figure 5.

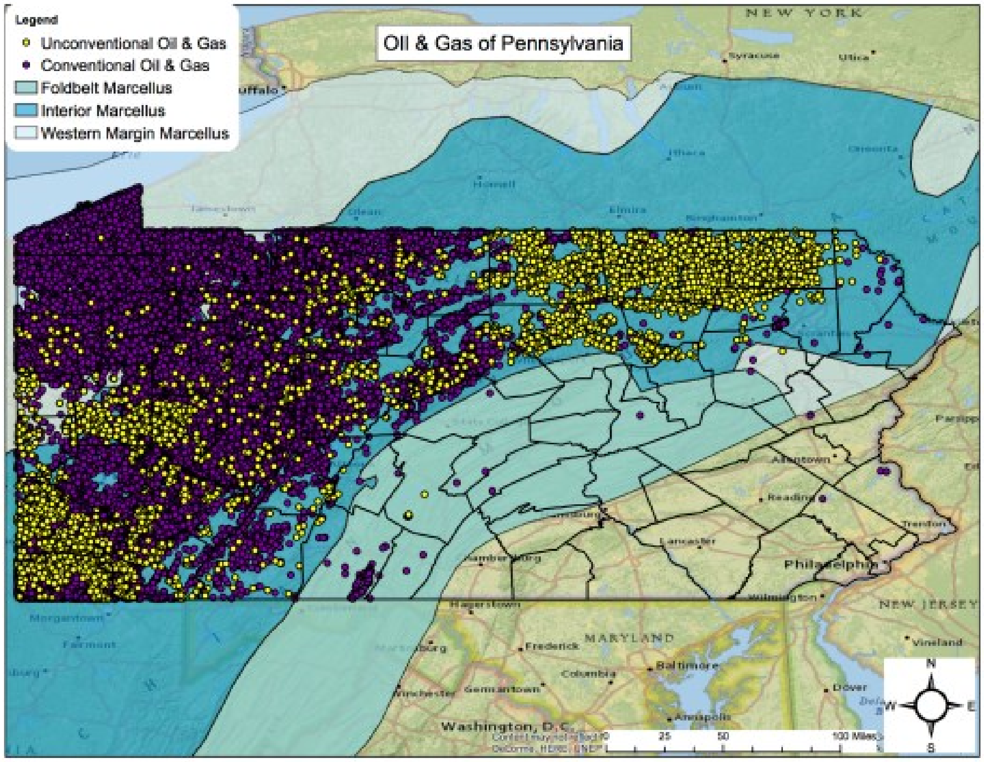


Figure 4 Oil and gas well locations (both conventional- shown in purple and unconventional- in yellow) throughout Pennsylvania (PA DEP, 2014).

Methane often occurs naturally in the environment and can be present in groundwater sources, due to the natural microbial production. It can also be thermogenic methane, produced from the thermal breakdown of organic matter occurring naturally within the shallow coal beds and coal seams throughout the county. In addition, thermogenic methane can be associated with shallow aquifer contamination from the gas well and storage fields, abandoned mines, failed well completions, and though faults or fractures within formations can also allow flow from depths (Boyer et al., 2012, Brantely et al., 2014, Darrah et al., 2014, Revesz et al., 2010, Vidic et al., 2013). In order to determine sources of oil and gas pollution, researchers in the past have used isotopic analysis of methane, which is an efficient and characteristic method in determining if the source is either natural or anthropogenic (Sharma et al., 2014). Due to the lack of health impact indications, there are no regulations for methane concentrations in drinking water, however the PA DEP defines 7 mg/L as a concern, and 28 mg/L as explosive (Brantley et al., 2014, PA DEP, 2013).

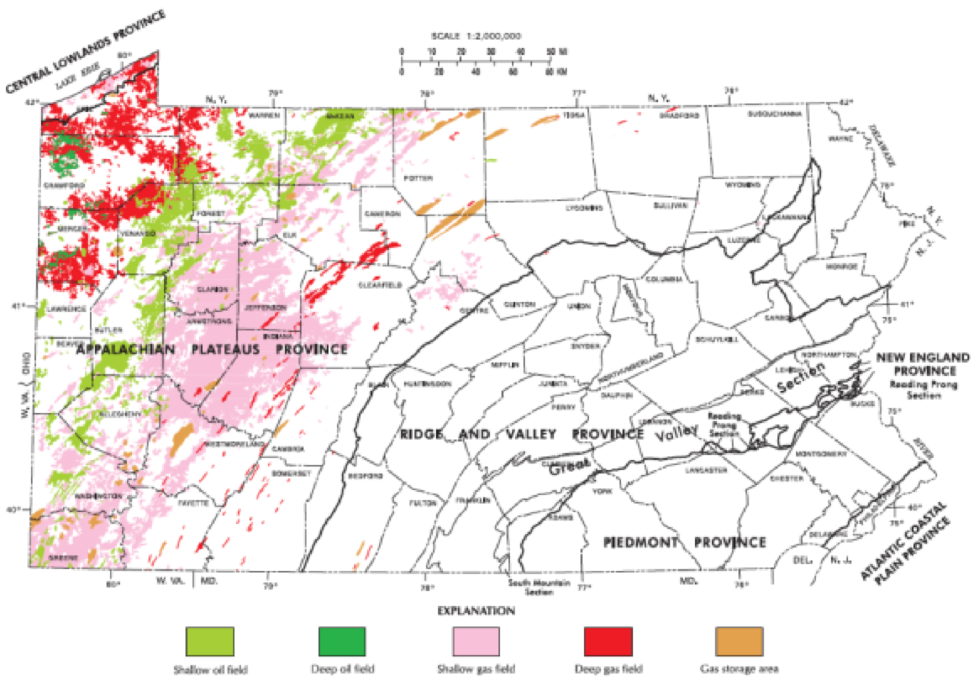


Figure 5 Locations of oil and gas fields in western Pennsylvania

(PA DCNR, Dresel & Rose, 2010).

1.3 Recent Oil and Gas Development

The increase in energy production from unconventional shale reservoirs can be found across the United States, present in over 30 states, and consisting of around 20 shale formations, including the Eagle-Ford and Barnett Shale plays in Texas, the Bakken Shale play in North Dakota, and the Utica, and Marcellus Shale formations within the Pennsylvania, Ohio, and West Virginia region, shown in Figure 6. (Lampe & Stolz, 2015, Vengosh et al., 2014, Warner et al., 2014). The hydrocarbon rich formations have recently become a more feasible method of energy extraction, resulting from the improved development of vertical and horizontal drilling techniques and improved hydraulic fracturing methods.

Nationwide, the shale gas industry accounts for roughly 25% of the natural gas production, and projected to increase to over 50% by the year 2035 (Arthur, et al., 2008, Boudet, et al., 2014, Manuel, 2010, Sovacool, 2014). The U.S. Energy Information Administration found approximately 25,000 trillion cubit feet (TCF) of accessible natural shale gas worldwide, and within the U.S., reservoirs containing over 2,552 TCF, with the ability to supply our energy demand for 110 years (Brittingham et al., 2014, Bustin, 2012).

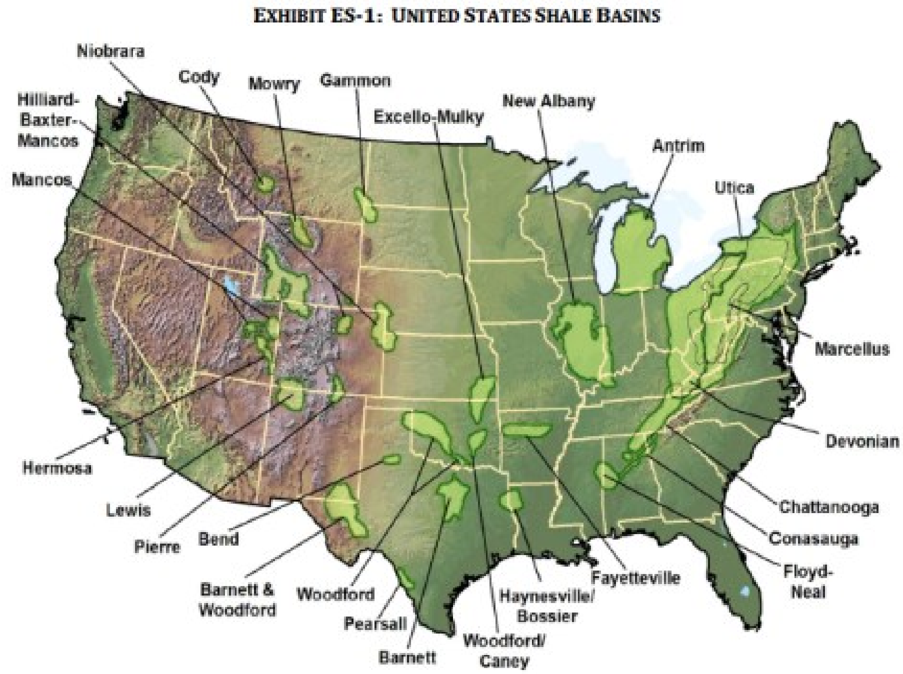


Figure 6 The location of the major shale plays within the lower 48 states of the U.S. (US DOE, 2009).

The Marcellus Shale has had a significant amount of development and extraction for oil and natural gas since 2004, and one of the most extensive across the U.S. (Bustin, 2012, Vidic et al., 2013). The Marcellus is located within the Hamilton Group, which was deposited during the Middle Devonian Period (Dresel & Rose, 2010, Engle & Rowan, 2014, Kiviat, 2013, Willard et al., 1939). This formation, over 350 million years old, is comprised of sandstone, siltstone, and shale (Soeder & Kappel, 2009). Marcellus' name is derived from the town in New York, in which the layer of black shale outcrops (Schuman & Vossoughi, 2012)

This Middle Devonian formation in the Appalachian basin has an average thickness of 150 feet, lies roughly 2,000 to 8,000 feet under the majority of the northern and western areas of Pennsylvania, and stretches roughly 95,000 square miles from New

York to Ohio and Virginia (Lampe & Stolz, 2015, Brantely et al., 2014, Engle & Rowan, 2014, Soeder & Kappel, 2009). The USGS conducted an assessment in 2011 showing the Marcellus divided into three units; the Western Margin Marcellus unit, the Interior Marcellus unit, and the Foldbelt Marcellus unit, with the Interior unit containing the thickest sections of the formation (Figure 7). The lateral extent of the formation is also shown in Figure 8, as well as variation in thickness of the formation across the Commonwealth of Pennsylvania, shown in Figure 9.

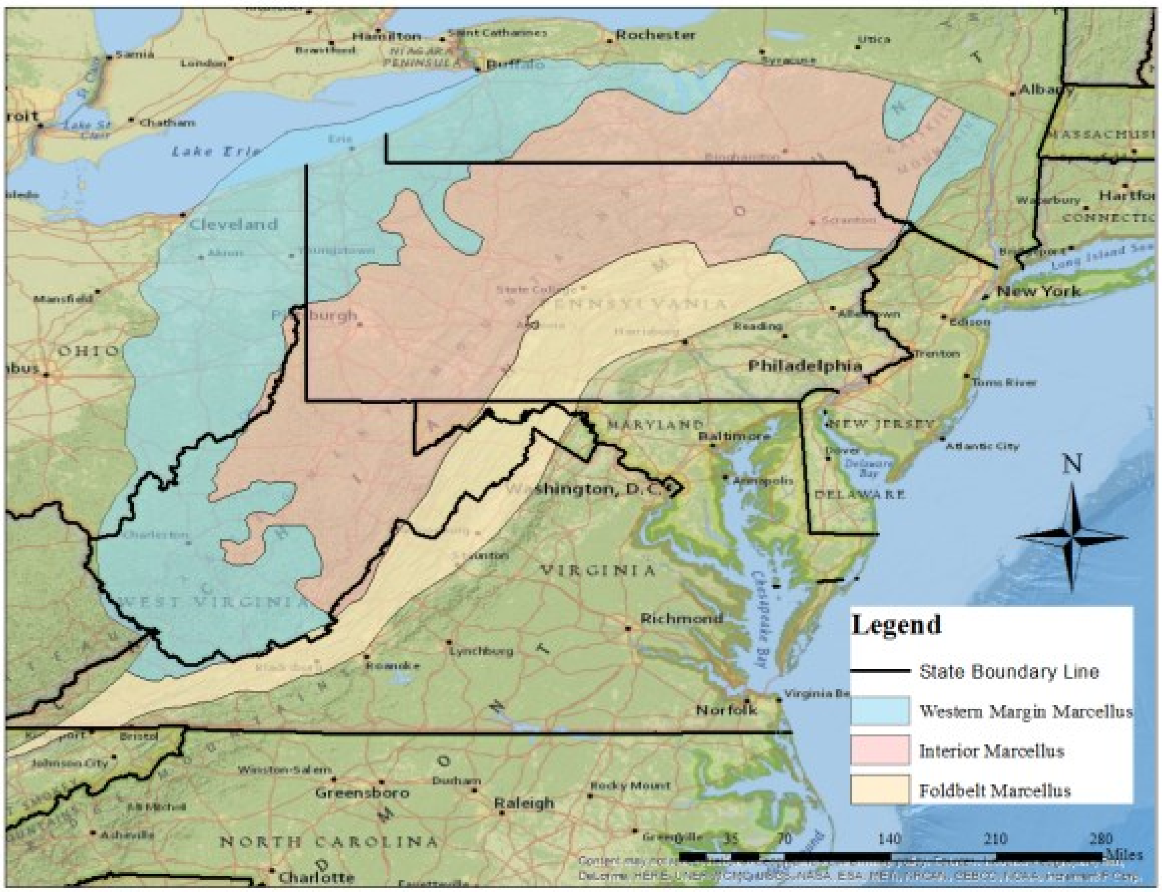


Figure 7 Marcellus Shale, and the three divisions of the formation including the Western Margin, the Interior, and the Foldbelt Marcellus units.

The characteristic nature of this black shale compared to other sedimentary rocks is its typically higher porosity, lower permeability, and its ability to retain large amounts of fluids and gases, making it distinct from others (Schuman & Vossoughi, 2012). This deep underground reservoir attributes to over 7,234 unconventional shale gas wells, which made up of 29 percent of the natural gas production in the country at the end of 2012 (Brantely et al., 2014, Vengosh et al., 2014). It is estimated that the Marcellus Shale contains approximately 489 trillion cubic feet (TCF) of natural gas within the formation, which accounts for over 20% of the total recoverable gas in the U.S (Arthur, et al., 2008, Blohm et al., 2012, Coleman et al., 2011, Lautz, et al., 2014, Vidic et al., 2013). This vast amount of gas stored is estimated supply 60,000 new wells by the year 2030 (Kiviat, 2013, Sovacool, 2014).

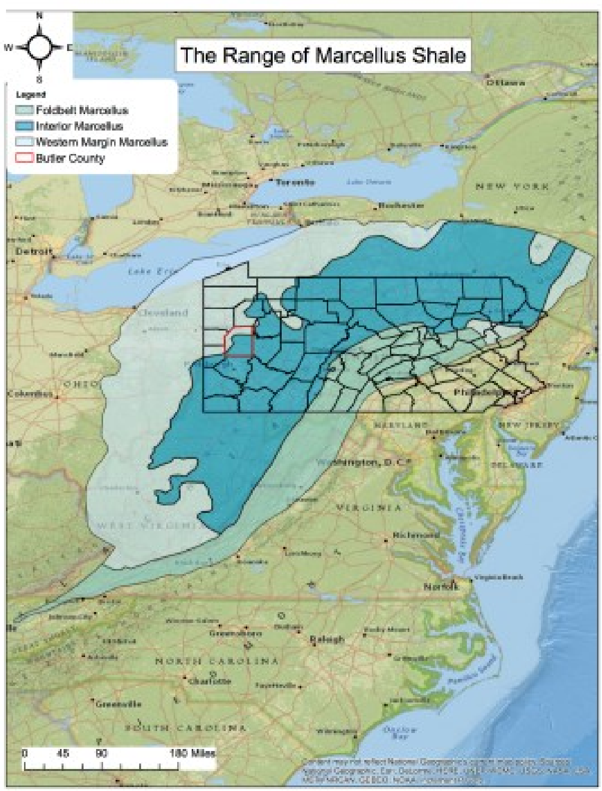


Figure 8. Location of the study area, Butler County, Pennsylvania in reference to the extent of the Marcellus Shale formation.

In addition to the massive Marcellus shale play within the majority of north and western Pennsylvania, there is the Utica Shale, from the Late Ordovician Period. This formation is another rich black shale, containing massive oil and gas reserves, but lies roughly 2,000 to 3,000 ft. deeper under the Marcellus, with an area covering roughly 31.6 million acres of gas and 15 million acres of oil potential (Kirschbaum et al., 2012). Both the Marcellus and Utica shales throughout Pennsylvanian region are expected to consist of 33% percent of the nation's energy increase of natural gas by 2040 (Cluff et al., 2014).

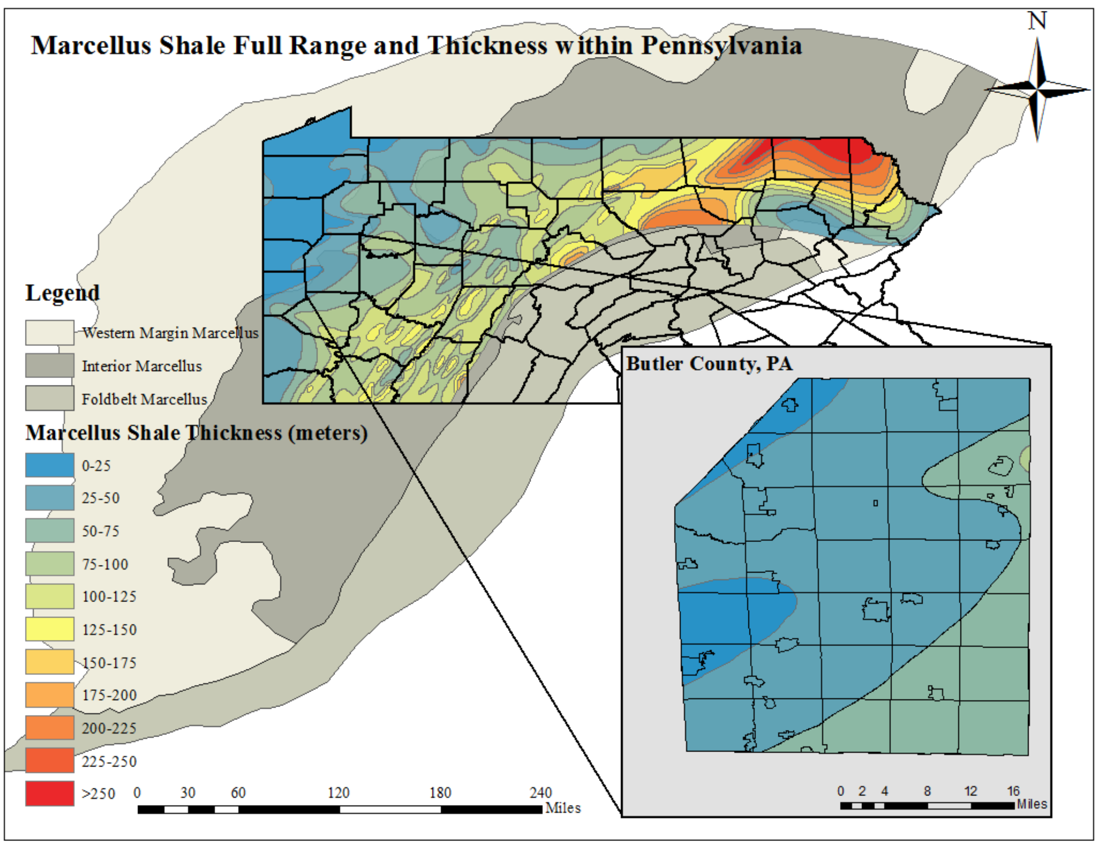


Figure 9 Varying thickness of the Marcellus Shale formation across the Commonwealth of Pennsylvania, and the study area of Butler County.

1.3.1 Unconventional Shale Gas Development

The significant increase of hydraulic fracturing activity due to technology advancements throughout Pennsylvania has resulted in an ongoing debate on how much these processes cause threats to human health and to the environment. Unconventional oil and gas development uses a method combining two technologies, horizontal drilling and hydraulic fracturing, known as unconventional shale gas extraction (Ratner & Tiemann, 2014). This process is an intensive process that has recently become an economically feasible technique for accessing low permeable (tight), high organic carbon (black) shales (Arthur et al., 2008, Barbot et al., 2013, McKenzie et al., 2012, Vidic et al., 2013). Unconventional drilling extracts the usable hydrocarbons from formations including coal-bed methane (CBM) and organic rich shale (Sovacool, 2014). The hydrocarbons within the shale have formed from the compression and pressure of organic matter within sedimentary rock over the course of millions of years, which have become trapped between two impermeable geologic formations that keep the gases confined, and present for extraction, resulting in what is referred to as an unconventional reservoir (Flaherty, 2014).

Conventional wells are drilled and completed vertically, typically targeting relatively shallow formations that exhibit greater permeability than unconventional reservoir rock. Conventional oil and gas reservoirs in western PA include the Upper Devonian Period Bradford Sandstone. Whereas the unconventional wells are a combination of vertical and horizontal drilling, targeting deeper, low-permeable formations such as the Middle Devonian Period Marcellus Shale, or the Ordovician Period Utica Shale in Pennsylvania (Baihly et al., 2010, Rahm et al., 2011, Willard, 1939). Both conventional and unconventional drilling completion methods use hydraulic fracturing. However, the intervals hydrofractured in conventional wells are shorter and use fewer fluids, about 50-100 times less water use, than during the processes relative to the development of unconventional reservoirs (Jenner & Lamadrid, 2013). The process of unconventional drilling includes the initial vertical drilling, then the cementing of large diameter steel casing across the overburden and then successively smaller diameter steel casings are cemented into place. This casing is used to isolate the fresh water bearing zone, the coal bearing intervals, shallow oil and gas bearing zones. The drilling continues to the targeted kickoff depth, at which point the drill string begins to turn and eventually becomes horizontally oriented at the unconventional reservoir, which begins approximately 500 ft. above the top of the target formation (Rivard et al., 2014). Once the desired horizontal length, or lateral within the targeted formation is attained, the hydraulic fracturing process begins, occurring in short segments of a few hundred feet each. This process uses the injection of large amounts of water and proppant, usually sand, at high pressures from 6,000 to 10,000 pounds per square inch (psi) (Boudet et al., 2014, Lampe & Stolz, 2015, Soeder & Kappel, 2014, Sovacool, 2014).

Historically, hydraulic fracturing fluids in western PA may have included crude oil or diesel fuel, however in present day, the composition of fracturing fluids differ from some that contain water and sand to others, such as those referred to as slickwater (Rivard et al., 2014). The slickwater fluids are comprised of primarily water and relatively low percentages compared to the total amount of fluids injected (<0.5%), which include additives such as gelling agents, corrosion inhibitors, surfactants, scale inhibitors, stabilizers, friction reducers, acids, and biocides (Ferrer & Thurman, 2015, Mohan, et al., 2013, Sang et al., 2013, Stringfellow et al., 2014, Thurman et al., 2014). One estimate concludes that fluids contain 90.6% water, 8.95% sand or other proppant, and other chemicals making up 0.45% of the remaining fracturing fluids (Mohan et al., 2013). However, the recipe for slickwater type fluids remains a protected trade secret within many oil service companies.

These high amounts of pressure, water, and proppant cause the rock to fracture and remain open, in order to provide pathways for flow of the natural gas from the formations. The water and fluids used to pump and expand the fractures within the formation eventually flow back up and out of the well during production, consisting of formation water (naturally occurring brines), flowback fluids (return during fracturing), and produced wastewater (contains brine and flowback fluids) (Baihly, et al., 2010, Boyer, et al., 2012). Up to 90% of these injected fluids are not recovered (Abdalla et al., 2012, Cluff et al., 2014, Lester et al., 2015, Lutz et al., 2013, Orem et al., 2014, Sang et al., 2013, Stringfellow et al., 2014, Vidic et al., 2013). The produced water containing the fracturing fluids and formation brines are very high in TDS at approximately 160,000 mg/L to up to 345,000 mg/L (Chapman et al., 2012, Haluszczak et al., 2013, Kolesar Kohl et al., 2014, Phan et al., 2015). There can be over six wells drilled horizontally on one pad, extending laterally to distances greater than 2,000 meters (Cluff et al., 2014). Hydraulic fracturing methods also require 2 to 8 million gallons of water per well for a successful completion. Generally, the more water used the better the well production. This high water usage has resulted in concerns of depletion of drinking water resources and the potential for deterioration of surface and groundwater quality (Abdalla et al., 2012, Arthur et al., 2008, Boudet et al., 2014, Brittingham et al., 2014, Rahm et al., 2011).

Depending on the composition of the flowback waters, disposal methods include use of deep injection wells, treated through industrial or municipal owned treatment facilities or can be reused for future hydraulic fracturing procedures (Lester et al., 2015, Lutz et al., 2013). In addition to the flowback and produced water, the drill cuttings, mud, and drilling fluids are considered the largest waste component of the process (Brittingham et al., 2014, Capo et al., 2014, Engle & Rowan, 2014). The drill cuttings can have toxic and hazardous characteristics. These drill cuttings may contain arsenic, barium, and uranium, which pose threats and challenges for disposal (Phan et al., 2015).

1.3.2 Challenges associated with Unconventional Shale Gas Development

Unconventional shale gas drilling has caused many concerns within local communities regarding issues involving loss of forests, increased societal stress, pollution, air emissions, introduction of greenhouse gases (GHGs, i.e., CO_2 and methane), surface and groundwater contamination, and depletion of drinking water resources (Boudet et al., 2014, Brittingham et al., 2014, Kiviat, 2013, Stern et al., 2014, Vengosh et al., 2014, Wang et al., 2011, Weber & Clavin, 2012). Although there has not been a direct connection linking unconventional shale gas development to groundwater contamination reported in peer reviewed literature, the PA DEP investigations have reported 243 positive determinations out of over 3,000 complaints (Inglis, & Rumpler, 2015, Pennsylvania Department of Environmental Protection (PA DEP), 2014, Tiemann & Vann, 2013). This confusion can be attributed to the complexity of the nature of the entire extraction and transmission process of the oil and gas industry. The complexity increases the difficulty to pinpoint specific sources of contamination within groundwater sources. The issue surrounding this activity is the differentiating anthropogenic sources of contamination from naturally occurring metals (i.e., elevated concentrations of iron and manganese), methane migration from coal beds, contamination from past industrial sources, and the introduction of salts from agriculture, septic waste, and de-icing methods. The recent drilling activities have risks including the migration of stray gas, possibly resulting from fractured or poorly bonded annulus cement or failed production casings, spills and leaks during transportation, intrusion of metal-rich brines from produced wastewaters, and improper disposal of wastewaters, (Darrah et al., 2014, Kahrilas et al., 2014, Rahm & Riha, 2012, Warner et al., 2012).

Due to the high levels of potentially hazardous constituents such as barium, strontium, arsenic, and selenium within Marcellus shale produced water, disposal of the wastewater also causes issues with water contamination associated with the process (Balaba & Smart, 2012). The most common occurrences for contamination are through accidental spills on site, due to well blowouts and cementing failures, as well as spills from transportation through trucks and pipelines (Kahrilas et al., 2014, Tiemann & Vann, 2013). Public concerns have risen due to the amount of chemicals unrecovered from the hydraulic fracturing process, or improperly disposed of as wastewater (Manuel, 2010, Tiemann & Vann, 2013).

Well development produce waste flowback and produced fluids containing elevated levels of TDS and brines containing heavy metal concentrations, along with radionuclides and organics, which cause disposal and treatment issues, and can potentially pollute overlying aquifers and surface water (Murray, 2013, Soeder & Kappel, 2009). This flowback water can reach concentrations of 68,000-354,000 mg/L of TDS, containing inorganic and organic elements, with varying concentrations depending on the location and geological formation (Lester, et al., 2015, Wilson & Van Briesen, 2013). This flowback is characterized by the high concentrations of chloride, sodium, calcium, and bromide, barium, and strontium (Barbot et al., 2013). There have been reports of contamination attributed by shale gas activities with issues relating to constituents including iron, manganese, aluminum, and brines including barium, chloride, and high TDS (Boyer et al., 2012, Brantley et al., 2014).

1.4 Distinguishing Sources of Contamination Using Geochemical Ratios

To identify anthropogenic impacts and sources of contamination to groundwater quality, the use of chemical indicators, geochemical ratios (i.e., Cl:Br), and proportion of metals, are a few of the methods that have been used in past research. These analytical approaches have provided researchers with forensic tools to determine the likely sources of constituents responsible for the degradation of water quality. These sources of contamination may include salinization, precipitation, septic tank leaks, farm and agricultural runoff, and past and recent oil and gas activity.

Wastewaters associated with oil and gas activity have distinct elements and compositions that distinct elements and compositions that can be thought of as a chemical fingerprint (Lautz et al., 2014). Brines originate from the slow dissolution of electrolytes such as from large inland seas that were present in this region during the Devonian Period, and minerals in deep underground formations, and from the evaporation of seawater evaporation, and the dissolution of salts and minerals that give the unique chemistry at different locations (Dresel & Rose, 2010). Throughout Pennsylvania, these brines reside in the sedimentary rock and can be found across the entire state. In the past, brines have been analyzed within western Pennsylvania's formations, with high concentrations of sodium, calcium, and chloride and acidic pH values, due to the oxidation of high iron (Fe^{2+}) concentrations, and the composition of the host formation (Dresel & Rose, 2010). The Na, Cl, and Br concentrations from oil and gas reservoirs are similar to evaporated seawater, halite or road salts, and precipitation, therefore distinguishing them apart is a challenge. However, pollution from salinization, abandoned mine drainage, and oil and gas activity can be identified using ratio methods as previously described involving Na, Cl, Br, Fe, Mn, and sulfate (Foster & Chilton, 2003, Mullaney et al., 2009).

The use of concentrations of sodium to chloride mass ratios and chloride to bromide mass ratios (Na:Cl and Cl:Br) have been used to differentiate among sources of anthropogenic and naturally occurring constituents within aquifers and groundwater, due to the use of bromide as an indicator of evaporation (Dresel & Rose, 2010, Katz et al., 2011, Lautz et al., 2014, Wilson & Van Briesen, 2013, Mullaney et al., 2009). Chloride and bromide are two components of TDS generally tested for in water chemistry analyses, and are commonly found within oil and gas wastewaters and formation waters in elevated levels (Soeder & Kappel, 2009, Wilson & Van Briesen, 2013). Due to chloride having a slightly lower aqueous solubility and a far greater abundance and concentration in natural fluids, plotting the concentration of chloride to mass or molar ratios of the two elements, enables the ability to distinguish between non-impacted groundwater, and other wastewater sources including septic and municipal waste water, and deep basin brines (Katz et al., 2011, Kelly et al., 2010, Lautz et al., 2014, Mullaney et al., 2009). These sources have specific ranges of Cl:Br ratios, which can be used to compare to groundwater samples collected to determine the type of source contamination.

Other research and studies have examined water chemistry data from groundwater samples overlying the Marcellus Shale formation. Some of the constituents that were analyzed and correlated included isotopic ratios, and metal proportions such as Na, Ca, Mg, Ba, Sr, and Li in relation with chloride concentrations (Vengosh et al., 2011, Warner et al., 2012). The direct relationship between the different metals and the chloride concentrations allows the ability to distinguish samples from types of dilution or mixing with brines and other source water, and potentially intrusion of fluids from the local shale gas development processes.

Drinking water wells in rural communities have also been examined in the past by illustrating the relationship between methane and higher end hydrocarbons, such as ethane concentrations found in drinking water, in relation to the distance to the nearest gas well (Jackson et al., 2013, Osborn et al., 2011). Lower ratios of methane and ethane that fall below levels of 100 could suggest contamination from thermogenic sources, rather than biogenic (Jackson et al., 2013, Osborn et al., 2011). Other past research has also examined methane concentrations both natural and methane due to leakage from faulty well casings (Darrah et al., 2014). In relation to leaks and spills, other research has found that oil and gas wastewaters have the potential to contaminate groundwater resources and soil from accidental spills and leaks on site (Sang et al., 2013)

Water sampling provides researchers with the ability to examine all types and sources of pollution. The concentrations of metals and constituents relating to different sources of anthropogenic pollution, the composition of different brines, processes involved with oil and gas wastewater, and hydrocarbon data, benefit researchers with a greater understanding and ability to differentiate groundwater contamination from the many anthropogenic sources and natural factors within the environment.

Section 2: Specific Aims, Hypotheses

2.1 Specific Aims

The purpose of this research is to gain a better understanding of groundwater quality and related groundwater quality issues throughout southern Butler County, Pennsylvania. This site has been a focus over the past few years due to the recent, increase of unconventional shale gas development in the area, as well as the increased number of complaints and concerns of groundwater contamination. This research is an extension of the initial survey and water quality study begun by Alawattegama et al., 2015. Due to the lack of information of well water quality in western Pennsylvania, this research will help determine if there is a relationship between unconventional shale gas extraction and contamination of groundwater. There were four proposed specific aims for this project to help gain an effective perspective of drinking water quality in the region.

Specific aims included:

- 1) Identify communities in southern Butler County that report water quality concerns and experience extensive amounts of unconventional oil and gas drilling development;

- 2) Initiate a survey to question and evaluate information regarding their private drinking water, to determine if residents have had any recent changes to their well water quality or quantity;
- 3) Acquire participants to fill out the survey and acquire well water samples in both areas with and without unconventional shale gas extraction, and perform water chemistry analyses using four methods; A) In-field tests using a YSI-Multimeter (temperature, pH, dissolved oxygen, specific conductivity, TDS); B) Tests for cations using ICP-MS (a suite of 30 metals); C) Test anions using Ion Chromatography (fluoride, chloride, bromide, nitrite, nitrate, phosphate, sulfate); and D) Light hydrocarbons using standard gas chromatography (methane, ethane, ethene, propane, propylene, butane);
- 4) Collect geographic coordinates (i.e., longitudinal and latitudinal) of well head locations in combination with the survey data, water chemistry data, PA DEP file reviews, for use in geographic information systems (GIS) database systems (ESRI ArcMap 10.1), to evaluate the proximity of the participants to unconventional shale gas development, and assess the potential impacts of unconventional shale gas extraction on local groundwater sources.

2.2 Hypotheses

1) Groundwater in southern Butler County has been impacted by past anthropogenic activities.

2) Geochemical ratios (i.e., Cl:Br; Na:Cl; and Ba:Cl to Br:SO_4) are effective tools in providing additional information on water quality impacts and sources of contamination.

Section 3: Materials and Methods

This research involved collection and sampling of residential well water in several areas in southern Butler County, Pennsylvania as an extension of the work begun by Alawattegama et al., 2015. The private well water samples obtained over the course of the research have been accomplished from residents who have had either complaints of their drinking water quality, or from concerns with potential contamination, which reside in areas where unconventional shale gas development is present. There was additional collection of background information, laboratory testing and analyses, and data interpretation. The overall study included: (1) completed surveys from participants; (2) Sample collection from residential water wells; (3) water chemistry testing; (4) data analysis, which included geographical mapping.

3.1 Residential Survey

The lack of historic well water quality data and information throughout western Pennsylvania, has resulted in the need for a qualitative analysis of water quality in this region. A survey was designed to collect information regarding potential changes in the participant's groundwater quality, quantity, or other observable changes. The examination of water quality was based on the increased number of inquiries from residents who had complaints of their drinking water, and more people becoming concerned with their water source. This survey would help determine if there were any previous conditions of their water that may have an effect on our interpretation and analyses of the water sample. The survey consisted of six questions relating to residential well water quality that have been reviewed and approved by the Internal Review Board (IRB).

The six questions are as follows:

1. Do you have well water and where is your well located?
2. What kind of well is it (e.g. artesian, rotary, cable tool)?
3. Do you know how deep the well is and have you noticed a change in your well depth?
4. Have you noticed any change in water quality (taste, smell, color) and if so when?
5. Have you noticed any change in water flow or quantity?
6. Have you had the water tested and would you be willing to share those results?

Residents that participated the survey also reviewed and signed a consent form that provided them with information regarding confidentiality, funding, and the overall purpose of the research. (See Appendices A and B).

3.2 Sample Acquisition

3.2.1 Well Water Sampling

Residential well water was purged for approximately 10-20 minutes; until measurements were stabilized ensuring that the well water being sampled was from the groundwater formation. The samples were acquired by bypassing all filtration systems, water softeners, and other purification systems, and if not possible, it was otherwise noted. Sampling consisted of four techniques: (1) In-field analyses of water chemistry using a YSI-Multi Meter; (2) Samples were collected in a 1 L French square glass jars (trace metal grade, Fisher Scientific, Pittsburgh, PA, USA); (3) Samples were acidified with nitric acid (HNO_3) to ensure preservation and collected in a 60 mL glass jar; and (4) A subset of samples were taken using (2) 40 mL EPA VOA butyl septa vials and sent out to an independent certified lab for additional testing for a suite of light hydrocarbons. Water samples were kept in a cooler and stored on ice until proper storage could be achieved in the laboratory at 4°C (EPA, 2015, Radtke). Reused bottles for this study were sterilized using standard autoclaving procedures to destroy any microorganisms and other types of contamination before using again out in the field.

3.3 Water Chemistry Analyses

3.3.1 YSI Professional Plus Multi-meter

Using the YSI method was performed in order to gain initial readings of water quality by using an in-field YSI-Professional Plus Multi-meter device (YSI Incorporated, Yellow Springs, OH, USA). This device includes several probes that analyze for: Temperature (°C), Dissolved Oxygen (% and mg/L), pH (standard units), Pressure (mmHg), Specific Conductivity (µS/cm), and Conductivity (µS). The YSI Multi-meter requires pre-laboratory calibration standards including temperature, dissolved oxygen, chloride (100 mg/L and 10 mg/L solution), specific conductivity, with 1,000 µS/cm solution, and pH (4.0, 7.0, and 10.0 solutions) solution to ensure accuracy within the field. The calibrations took roughly 2-5 minutes to stabilize before the data was recorded.

3.3.2 Ion Chromatography (IC)

Using the EPA Method 300.0, an ion chromatography system analyzed for several anions, which included: fluoride, chloride, nitrite, bromide, nitrate, phosphate, and sulfate (Pfaff, 1993). Samples were prepared by filtering through a 0.22 or 0.45 µm PES filter (VWR, Bridgeport, NJ) and a Dionex OnGuard II M filter (Dionex, Sunyvale, CA, USA) for removal of transition metals and suspended solids. Dilution was only necessary for samples with specific conductance above the chromatograph's range (0-1500 $\mu S/cm^3$). Dionex polyvials (Dionex, Sunyvale, CA, USA) were filled with 5 mL of the filtered sample.

A Thermo Scientific Dionex AS-DV auto-sampler delivered samples to the Dionex ICS-1100 Ion Chromatography System (equipped with a conductivity cell and UV/VIS detector). The Thermo Scientific Dionex Chromeleon 7 Chromatography Data

System controlled instruments and collected and processed the data. An IonPac AS22 Carbonate Eluent Anion-Exchange Column (2 x 250, 6.5 μm particle diameter) with an IonPac AG22 Guard Column (2 x 50mm) combined with an anion self-regenerating suppressor ASRS-300 separated the anions.

3.3.3 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Using EPA Method 200.8, the Inductively Coupled Plasma Mass Spectrometry (ICP-MS) system analyzed a suite of 30 metals and cations from the well water samples. These samples were prepared by collecting 1 mL of sample filtered through a 0.22 or 0.45 μm PES filter (VWR, Bridgeport, NJ). The samples were then sub-boil distilled with 2% nitric acid. Beryllium, germanium, and thallium were added as internal standards.

A Perkin-Elmer NexION 300x (Waltham, MA, USA) IC-ICP-MS system was used in collaboration with Dr. Dan Bain's laboratory at the University of Pittsburgh, using EPA.

3.3.4 Independent Certified Lab

The subset of samples were collected using (2) 40 mL EPA VOA butyl septa vials without headspace, kept in the dark on ice at 4 °C, and delivered to an independent certified lab for additional testing for a suite of light hydrocarbons including methane (0.1 μg/L), ethane (0.01 μg/L) , ethene (0.01 μg/L), propylene (0.02 μg/L), propane (0.01 μg/L), and butane (0.03 μg/L) (parentheses show Lower Detection Limits (LDL)). The lab uses analytical method WA1 and RSKSOP-175 including standard gas chromatography with flame ionization detector (FID) and thermal conductivity detector (TCD), with sample preparation and calculations for dissolved gas analysis in water samples using a GC headspace equilibrium technique. Quality assurance and quality control (QA/QC) procedures included: the signing of a chain of custody to ensure samples are acquired at the correct address; water samples are logged, tracked, and kept at 4 °C until analysis takes place within 7 days of collection.

3.4 Data and GIS Mapping

The study area of Butler County was plotted and mapped using the ArcMap 10.1 ArcGIS software (ESRI ArcMap 10.1). Spatial maps were created using the resident's well water locations (decimal latitude and decimal longitude) obtained as part of the in-field survey and sample acquisition process from the participating residents. Using the well water coordinates and water chemistry data that was analyzed, in combination with PA DEP file reviews, and publicly available databases from the Pennsylvania Spatial Data Access (PASDA), spatial maps were created in order to determine if there was any correlation between households with elevated levels of constituents and anthropogenic activity in the area.

Elevated water chemistry data were projected onto spatial maps. This process resulted in more easily recognizable correlations between the Interpolation Spatial Analyst Tool, enabling the ability to show residents who exceeded (S)MCLs visually, and displaying where individual levels of elevated constituents and where hydrocarbons were present. Well coordinates acquired were plotted in ArcMap 10.1, to determine the approximate distance of each private well water source to the nearest unconventional drilling site, and were classified either pre-drilling or post-drilling samples. Table 2 displays source data associated with the data mapping used in this research.

Table 2. GIS source data

Data Layer	Source
Base Maps	Pennsylvania Spatial Data Access, PASDA. The Pennsylvania Geospatial Data Clearinghouse http://www.pasda.psu.edu
Abandoned Mine Lands	Pennsylvania Spatial Data Access, PASDA. The Pennsylvania Geospatial Data Clearinghouse http://www.pasda.psu.edu
Abandoned/Orphan Oil and Gas Wells	Pennsylvania Department of Environmental Protection, Office of Oil and Gas Management, http://www.portal.,state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297
Drilled (SPUD) Oil and Gas Wells	Pennsylvania Department of Environmental Protection, Office of Oil and Gas Management, http://www.portal.,state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297
PA County Boundaries	US Department of Commerce, US Census Bureau, 20112 TIGER/Line Shapefiles
Oil and Gas Locations	Pennsylvania Spatial Data Access, PASDA. The Pennsylvania Geospatial Data Clearinghouse http://www.pasda.psu.edu
Marcellus Shale Divisions and Thickness	Pennsylvania Department of Conservation and Natural Resources, PADCNR, Oil and Gas: Marcellus Shale Maps and Digital Data, http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/marcellus/marcellus_maps/index.htm

Section 4: Results

4.1 Residential Survey Results

As part of the ongoing water sampling study, the survey and water chemistry data collected for Butler County residents from a period from August 2011 through December 2014. Survey questionnaire included information regarding the resident's water source, type of well, issues regarding water quality (smell, taste, color) and quantity (reduced flow or amount), and if the resident has had prior testing. A summary of the survey results is displayed in Appendix D.

A total of 121 residents participated in the survey and water acquisition study. All but two residents had well water sources; the other 2 residents retrieved their drinking water from a spring source. For well construction type, 42% of the residents (51) had drilled wells, 34% (41) were unknown about their well type, 8% (10) had rotary constructed wells, 8% (10) had pounded wells, 5% (6) with cable tool wells, and only 2 residents reported dug wells, and 1 resident reported having an artesian well. The average well depth was 190.25 ft., and the median well depth was 155 ft., with the shallowest water well-being 30 ft., and deepest well approximately 1000 feet Approximately 26% of residents did not know their well depth.

Out of the 121 participants, a total of 59 (48%) had reported a change in either water quality or quantity with their water source, 52 (43%) residents did not report any issues and were just concerned with their water quality for future purposes, and 11 (9%) were unsure of any changes. Approximately 53 homes (43.8%) reported to have some sort of water quality issue (color, smell, taste), and 17 (14%) reported water quantity issues (reduced flow, amount).

Of the 53 residents who reported to have water quality issues, 18 residents (34%) had multiple types of complaints of water quality changes involving taste, smell, and color changes. An additional 18 residents (34%) reported to have changes in only the smell of their water, 15 (28%) residents had seen changes only in their water's color, and 2 (4%) residents had taste issues regarding their drinking water. (Some residents reported problems with more than one quality issue).

According to the survey results, roughly 70 (57.8%) participants of the 121 total within the survey, have had prior testing of their well water, with 33 of the 70 participants having industry predrill water testing, 19 independently tested, and 4 DEP tested for various parameters. A limited amount of pre-drill water test results were obtained through the survey.

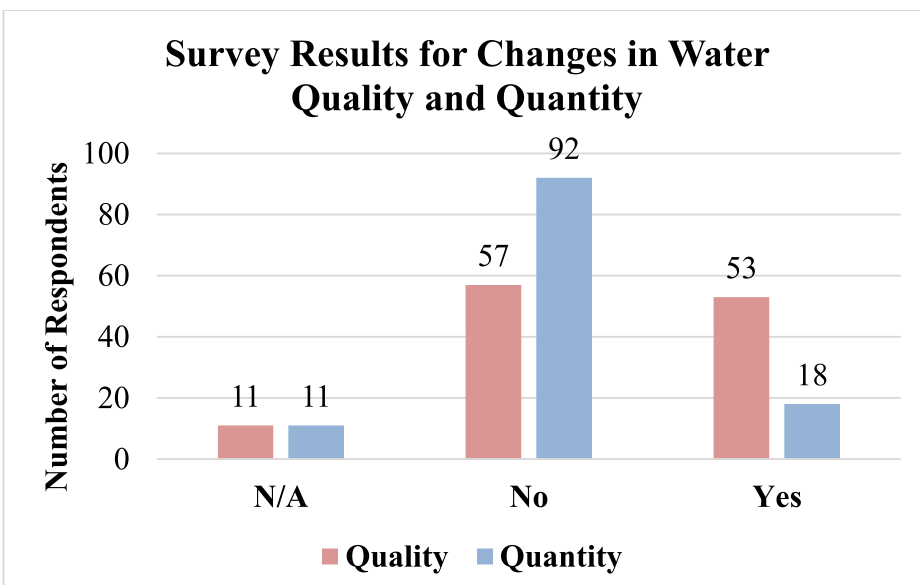


Figure 10 Survey results of general water quality and quantity changes from the 121 respondents who reported water quality changes with either 'Yes, No, or Unsure (N/A)'

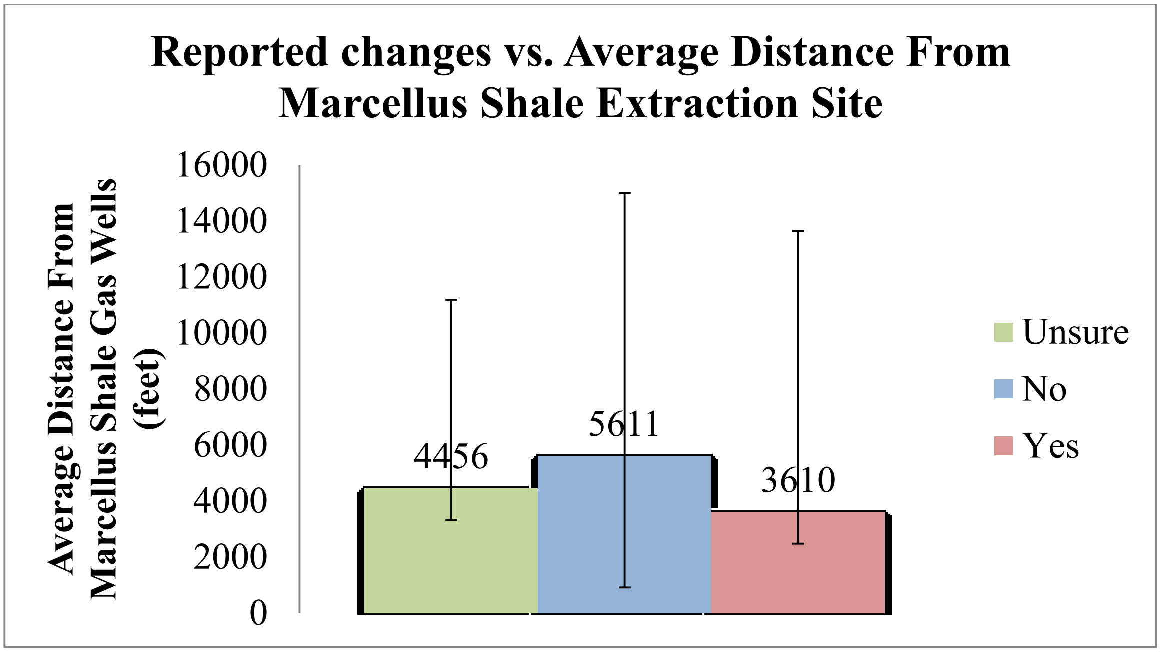


Figure 11 Survey results for changes in aesthetic water quality (taste, smell, color) from 121 residents, and the average distances of their wellhead to the nearest unconventional well.

Figure 11, illustrates the residents who had reported changes in their water source stating either, yes, they have seen changes in their water quality (53 residents), no, they have not seen changes in their water quality (57 residents), or if they were unsure or did not complete that part of the survey (11 residents). Of the 53 residents who reported 'yes' to changes in water quality, their well head locations were located an average of 3610 feet from the nearest unconventional well pad. The closest participant that reported problems in water quality was approximately 1,139 feet away from the nearest well pad, and the farthest resident that reported changes was about 13,636 feet away. Eleven participants that were unsure of changes in water quality, or did not complete that portion of the survey, were an average of 4,456 feet away from the nearest well pad, with the closest resident at 1,329 feet, and farthest at 11,187 feet away. The 57 residents who reported ‘No’ to changes in water quality were located at an average of 5611 feet away from the nearest unconventional oil and gas well pad, with the closest at 916 feet, and the farthest at over 15,000 feet away from the nearest unconventional well pad. In regards to water quantity, 92 residents reported no changes with the average distance approximately 4,488 feet away from the nearest well pad, and 18 residents claiming they have seen changes in water quantity, with an average of 5438 feet away from the nearest unconventional well pad site.

Statistical analysis of variance (ANOVA) was performed using Origin 9.1 program, comparing the resident’s wellhead locations relative distance to the nearest unconventional well, the depth of their well, and if the participant reported changes in their well water. According to the ANOVA, with a p value of 0.05, and 95% confidence interval., the distance to the nearest well was most significant, as well as the relation to well depth and distance.

4.2 IC and ICP-MS Water Analyses Results

A total of 238 water samples from 121 residents were acquired and analyzed between the dates in August 2011 and December 2014. Of the 121 residents sampled, 104 households (86%) exceeded levels of constituents from the Environmental Protection Agency’s Primary and Secondary Maximum Contaminant Levels (MCLs and SMCLs), and 17 residents (14%) did not exceed the EPA’s MCLs or SMCLs.

Of the 121 households that participated in the sample acquisition, 68 (56%) of the residents and 57 (47%) households had levels of manganese and iron that exceeded the

EPA's MCL of 0.05 mg/L and 0.3 mg/L, respectively. In addition to the iron and manganese, 22 (18%) residents had elevated levels of TDS above 500 mg/L, and 22 (18%) for fluoride as well, above 4 mg/L. Aluminum was elevated in 21 (17%) households, and pH was elevated in 21 (17%) of residents water sources (Al >0.05 mg/L and pH outside the 6.5 to 8.5 standard) For pH, 3 households were above the 8.5 limit, whereas 18 wells were less than the 6.5 limit. There were 6 (5%) residents that contained high levels of barium above 2 mg/L, and 2 (1.6%) residents had high chloride, above 250 mg/L. Silver, lead, and nitrate each had 1 resident above their levels of concern (Al >0.1 mg/L, Pb >0.02 mg/L, and nitrate >44.3 mg/L). Results are shown in Figure 12.

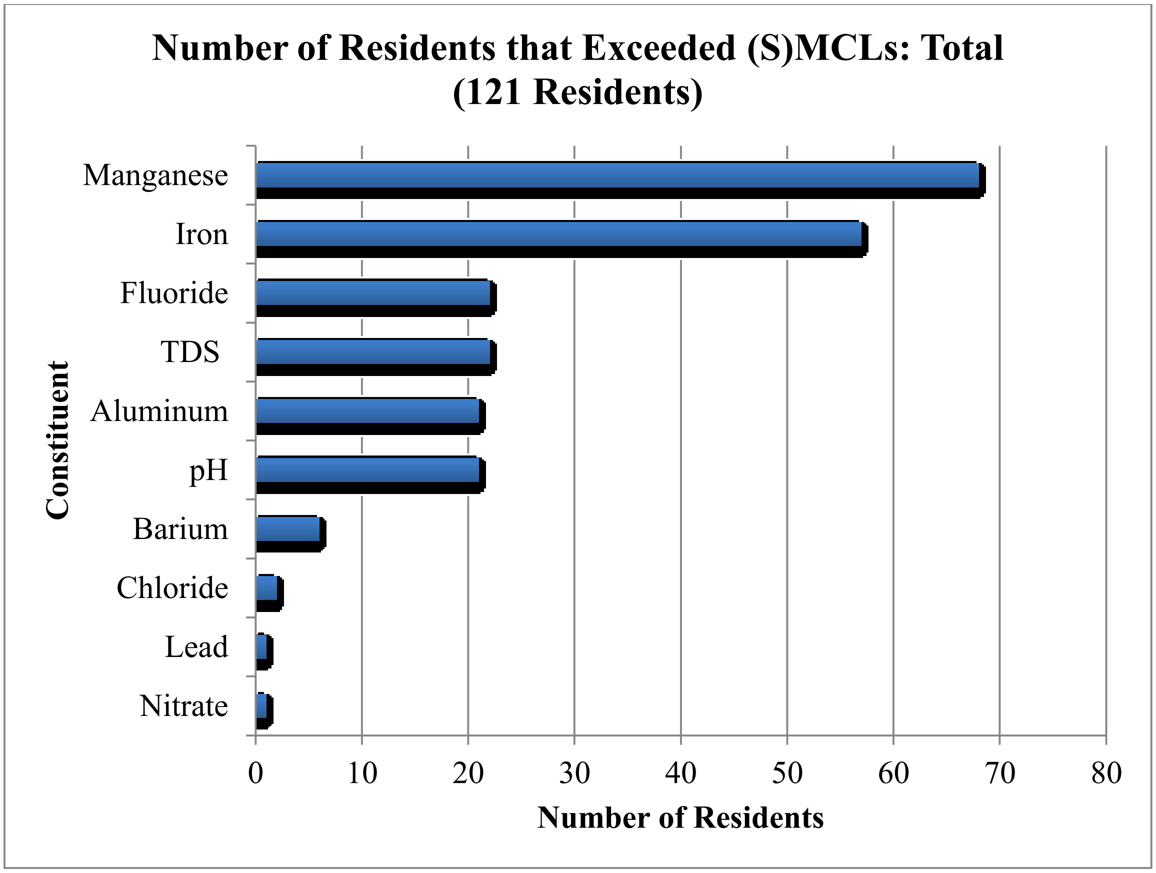


Figure 12 Breakdown of specific contaminants in the wells that exceeded the EPA's Primary and Secondary Maximum Contaminant Levels (MCLs).

Field water chemistry data for temperature, pressure, dissolved oxygen, pH, and specific conductivity were obtained using the YSI-Pro Plus Multi-meter, and are summarized in Appendix F. In addition to field samples, lab analyses using ICP-MS and Ion Chromatography (IC) were performed and results are shown and summarized in Appendix G and Appendix H, respectively.

Of the 17 residents who did not contain any levels of constituents above SMCLs or MCLs, 12 wells were considered clean, good quality drinking water and were established as the reference wells for southern Butler County. The average water quality

Table 3. Average water quality for the 12 reference wells in southern Butler County.

Constituent	Average levels in well water
In-field	
Temperature (°C)	13.9
DO (mg/L)	4.9
pH	6.5
Pressure (mmHg)	658.6
Specific Con. (µS/cm)	381.3
Conductivity (µs)	342.8
TDS (mg/L)	265.0
Anions	
Fluoride (mg/L)	0.2
Chloride (mg/L)	26.5
Nitrite (mg/L)	0.0
Bromide (mg/L)	0.3
Nitrate (mg/L)	8.4
Phosphate (mg/L)	0.1
Sulfate (mg/L)	26.8
Cations	
Na (mg/L)	41.8
Mg (mg/L)	7.2
Al (mg/L)	0.0025
Ca (mg/L)	29.4
Cr (mg/L)	<0.001
Mn (mg/L)	0.0068
Fe (mg/L)	0.113
Cu (mg/L)	0.034
Zn (mg/L)	0.05
Sr (mg/L)	0.32
Ag (mg/L)	<0.0001
Cd (mg/L)	<0.0001
Sb (mg/L)	<0.0001
Ba (mg/L)	0.19
Pb (mg/L)	<0.001
U (mg/L)	<0.0001

constituents for these reference wells acquired from this study are shown in Table 3. Of the initial 17 households, there were 3 households that had detectable levels of multiple hydrocarbons, and only 2 households that had methane detected.

4.3 Subset Sample Water Analyses Results

A subset collection of 144 samples (included within the 238 total samples) was acquired between the dates of January 2013 through December 2014, which included a total of 91 residents (included within the 121 total residents) within the study. Respondent's wells were tested for all parameters (in field YSI Multi-meter, IC, and ICP-MS) in addition to further testing for a suite of light hydrocarbons (methane, ethane, ethylene, propylene, propane, butane) using standard gas chromatography FID/TCD.

Of the 91 water wells tested, 67 wells (73.6%) had detectable levels of one or more of the hydrocarbons mentioned above and 79 (86.8%) had constituents that exceeded levels over the EPAs MCLs or SMCLs. Of the 67 residents who had detectable levels of hydrocarbons, 62 (68.1% of 91 total) had both hydrocarbons detected and contained constituents that were above MCLs or SMCLs. Figure 13 illustrates a flowchart showing the number of households who tested positive for light hydrocarbons and cations using the independent certified lab and ICP-MS methods. It also shows the number of residents and the percentages that had detectable levels of light hydrocarbons, levels that exceeded the EPA's MCLs, or those that had neither.

Figure 14 shows the constituents that were elevated above MCLs or SMCLs from the residents that participated in the sample acquisition. Forty-nine residents, for both iron and manganese, had concentrations that exceeded the levels of concern encompassing 56% of the contaminated samples. In addition, there were 22 samples with pH levels outside of the range of 6.5-8.5 standard units (s.u.), 20 locations exceed SMCLs for Al., 17 for TDS, 6 for barium, and 5 samples exceeded chloride. Lead, nitrate, and chloride each had one resident over the SMCLs. The 67 households that had detectable levels of hydrocarbons were broken down into 42 residents containing multiple hydrocarbons, and 25 residents only having methane detected. Only 7 (7.7%) residents had no detectable levels of hydrocarbons, and did not have constituents exceeding limits of concern. Results for the subset samples are summarized and displayed in Appendix G, Appendix H, and Appendix J.

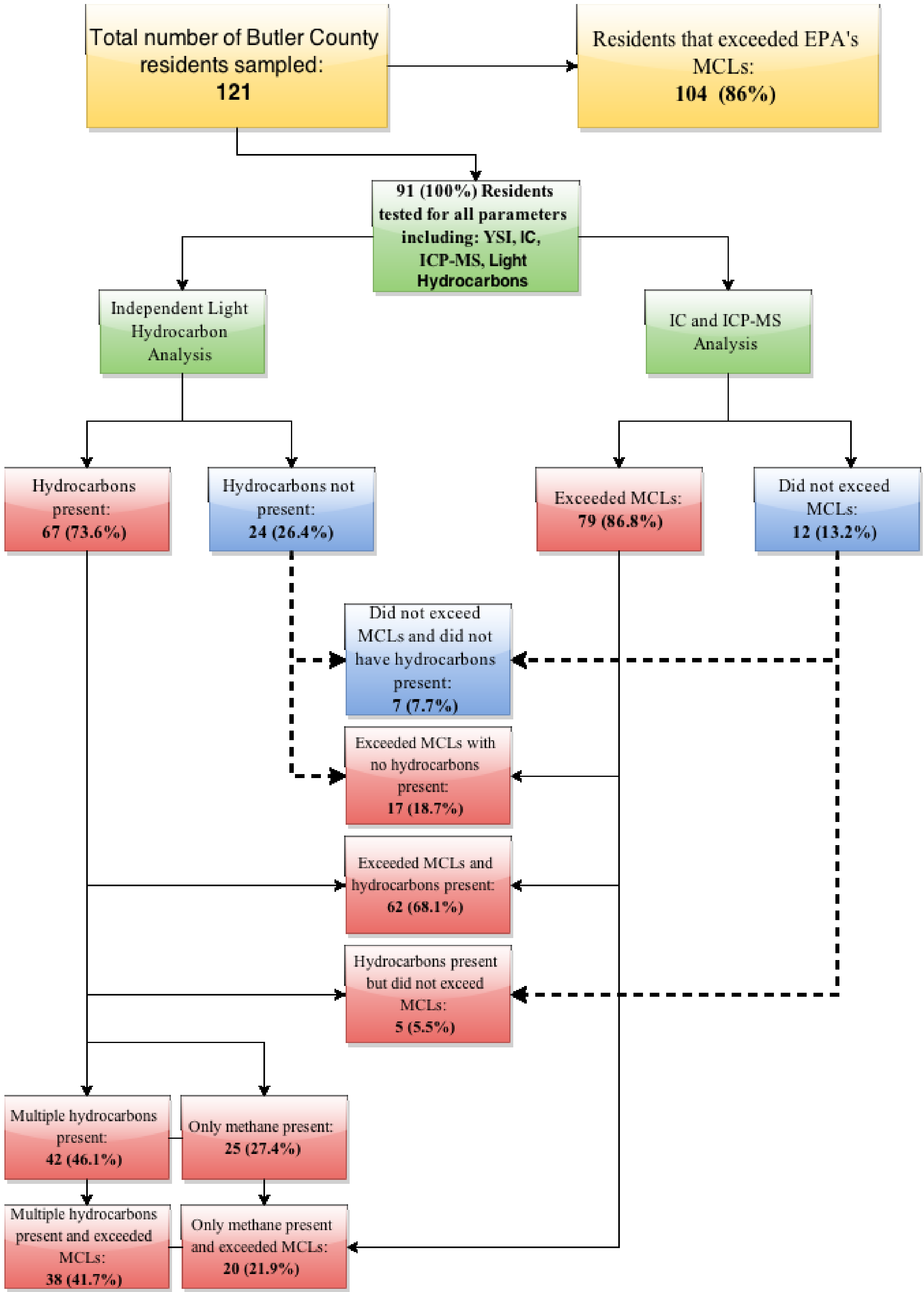


Figure 13 Flow chart of how the water samples were analyzed.

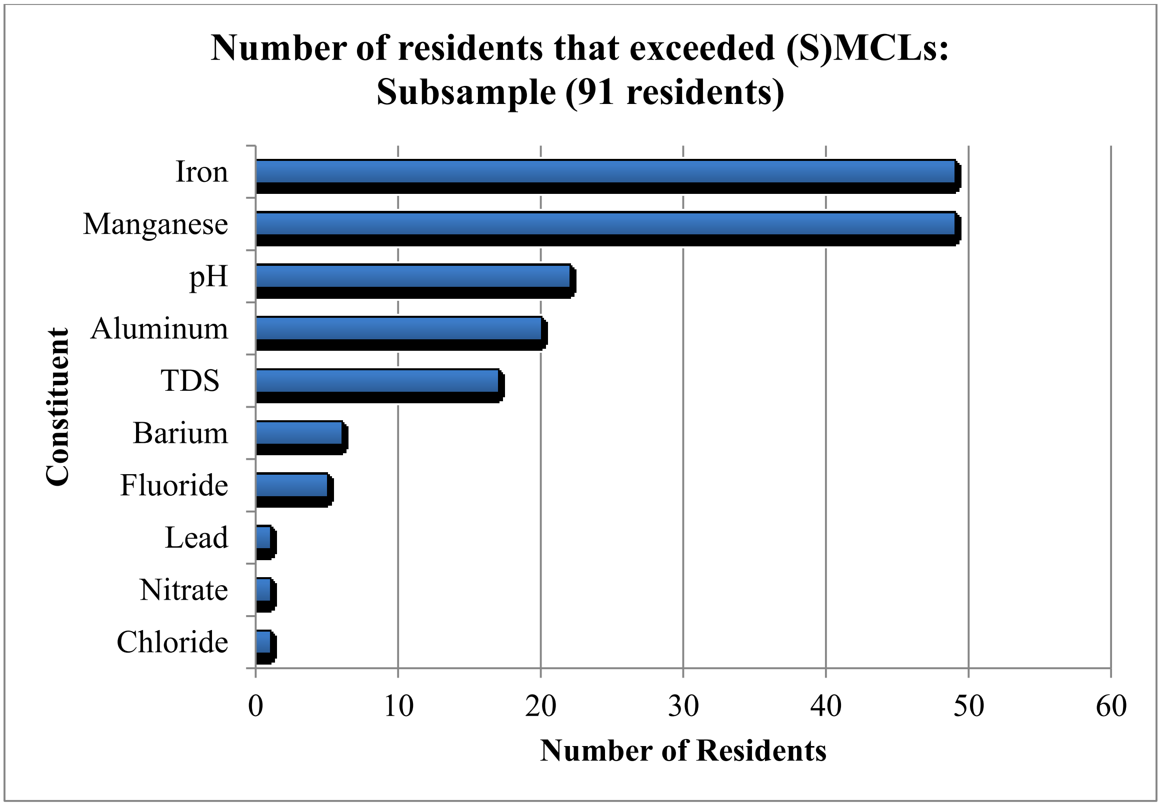


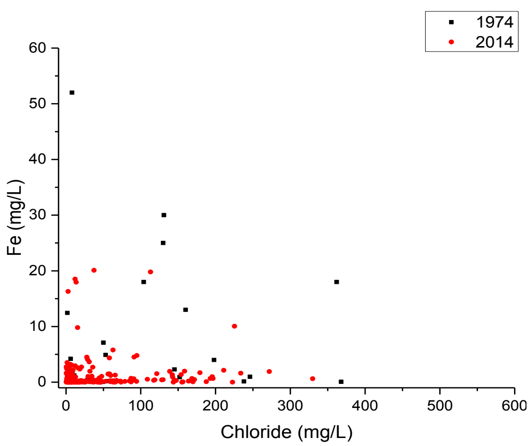
Figure 14 Number of wells tested for all parameters including light hydrocarbons that exceeded the EPA's MCLs and SMCLs, and the constituents.

Table 4. Wells that tested for all parameters including light hydrocarbons, and exceeded EPA's MCLs in relation to the number of residents who had hydrocarbons present.

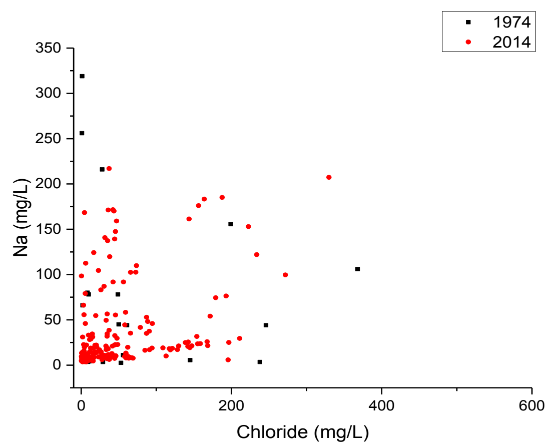
Constituent	**EPA's (S)MCLs**	**Number of residents that exceeded (S)MCLs**	**Number of residents with multiple hydrocarbons (42 of total 91)**	**Number of residents with only methane (25 of total 91)**
pH	(outside the 6.5-8.5 limit)	22	9	7
TDS	500	17	7	6
Fluoride	4	5	3	1
Chloride	250	1	0	0
Nitrite	3.3	0	-	-
Nitrate	44.3	1	0	0
Sulfate	250	0	-	-
Aluminum	0.05	20	8	9
Chromium	0.01	0	-	-
Manganese	0.05	49	31	15
Iron	0.3	49	22	14
Copper	1	0	-	-
Zinc	5	0	-	-
Arsenic	0.01	0	-	-
Selenium	0.05	0	-	-
Silver	0.1	0	0	0
Cadmium	0.01	0	-	-
Antimony	0.006	0	-	-
Barium	2	6	6	0
Lead	0.02	1	0	1
Uranium	0.03	0	-	-

The results showed that 22 of the 49 wells (45%) that exceeded MCLs for iron, had multiple hydrocarbons present in their drinking water, and 31 of the 49 residents (63%) that exceeded MCLs for manganese, contained several varying hydrocarbons as well. 8 of 20 residents (40%) that contained high aluminum levels also contained hydrocarbons, 9 of 22 residents (41%) had poor levels of pH and hydrocarbons present, 7 of 17 residents (41%) that had elevated TDS contained multiple hydrocarbons, 3 of 5 residents (60%) that had high levels of fluoride tested positive for light hydrocarbons, and all 6 residents (100%) that exceeded levels of concern for barium tested positive for having multiple hydrocarbons (Table 4).

A)



B)



C)

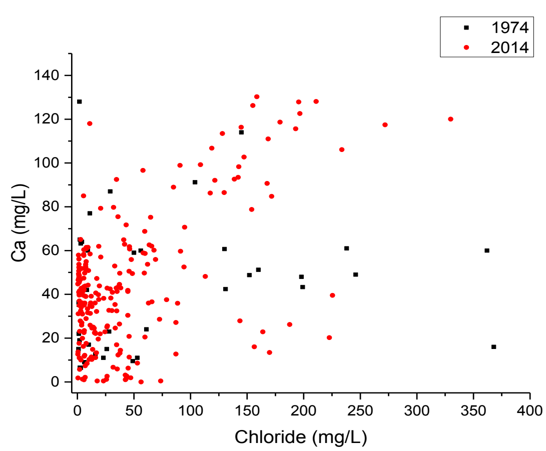
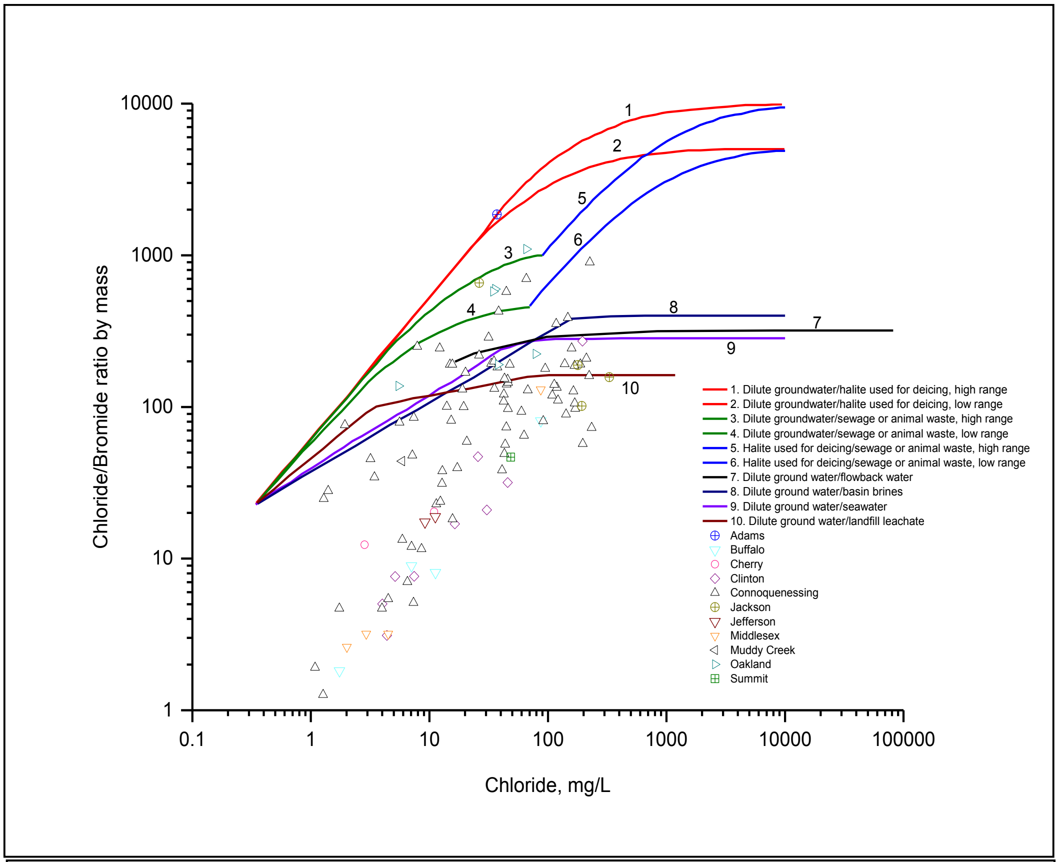


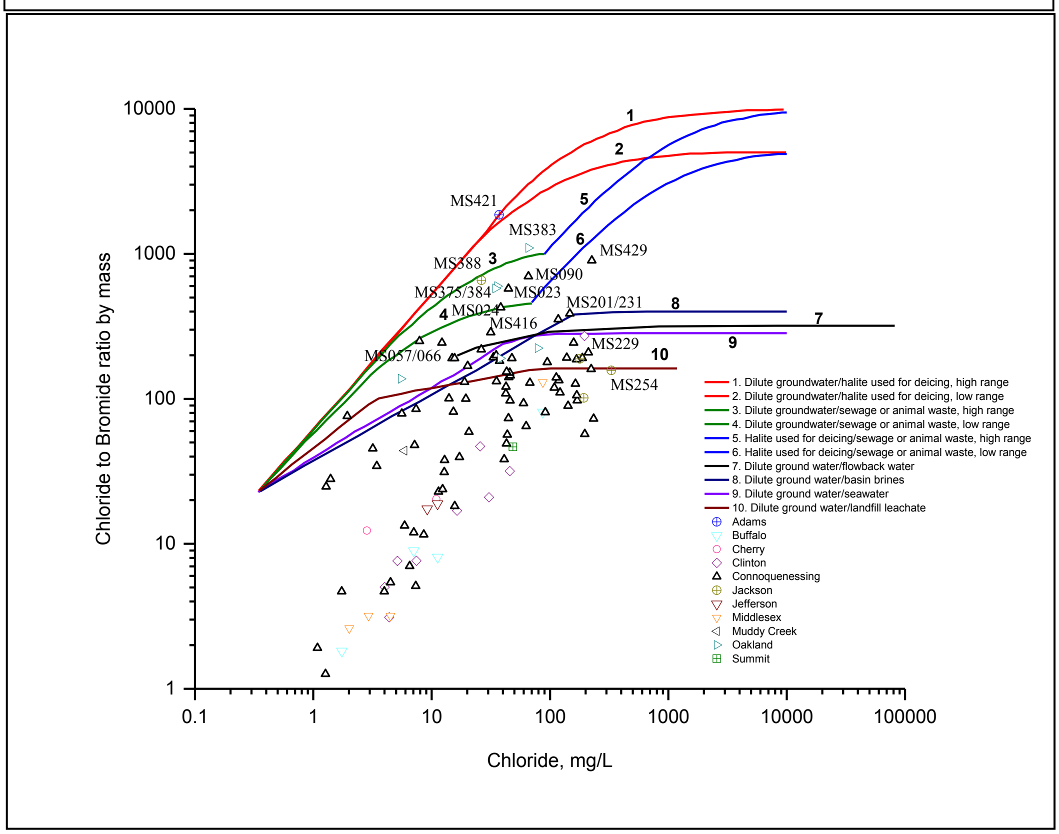
Figure 15 The comparison of historic groundwater chemistry data from Poth, 1973 in Butler County, PA compared to well water data collected from the 2011-2014 water quality research study A) Fe:Cl, B) Na:Cl, C) Ca:Cl.

A)



Chloride/Bromide ratio by mass
Chloride, mg/L
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000
1
2
3
4
5
6
7
8
9
10
1. Dilute groundwater/halite used for deicing, high range
2. Dilute groundwater/halite used for deicing, low range
3. Dilute groundwater/sewage or animal waste, high range
4. Dilute groundwater/sewage or animal waste, low range
5. Halite used for deicing/sewage or animal waste, high range
6. Halite used for deicing/sewage or animal waste, low range
7. Dilute ground water/flowback water
8. Dilute ground water/basin brines
9. Dilute ground water/seawater
10. Dilute ground water/landfill leachate
Adams
Buffalo
Cherry
Clinton
Connoquenessing
Jackson
Jefferson
Middlesex
Muddy Creek
Oakland
Summit

B)



Chloride to Bromide ratio by mass
Chloride, mg/L
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000
1
2
3
4
5
6
7
8
9
10
MS421
MS383
MS429
MS388
MS090
MS375/384
MS023
MS201/231
MS024
MS416
MS229
MS057/066
MS254
1. Dilute groundwater/halite used for deicing, high range
2. Dilute groundwater/halite used for deicing, low range
3. Dilute groundwater/sewage or animal waste, high range
4. Dilute groundwater/sewage or animal waste, low range
5. Halite used for deicing/sewage or animal waste, high range
6. Halite used for deicing/sewage or animal waste, low range
7. Dilute ground water/flowback water
8. Dilute ground water/basin brines
9. Dilute ground water/seawater
10. Dilute ground water/landfill leachate
Adams
Buffalo
Cherry
Clinton
Connoquenessing
Jackson
Jefferson
Middlesex
Muddy Creek
Oakland
Summit

Figure 16. Chloride:bromide to chloride mass ratios were plotted with the binary mixing curves halite, septic, landfill wastes, animal wastes, and brines (Mullaney et al., 2009) B) Specific samples that were labeled and discussed in the text.

Chloride:bromide to chloride mass ratios have been used in the past to help distinguish between types of pollution in water sources (Davis, et al., 1998, Mullaney et al., 2009) These data were plotted using binary mixing curves derived from research performed a USGS study by Mullaney et al., 2009. These mixing curves, generated through algebraic equations of dilution of various types of contamination source data, show the ability of geochemical ratios to distinguish between different types of pollution from chloride contamination to groundwater. These binary mixing curves serve as a method of differentiating between the various sources of chloride contamination into groundwater.

Figure 16 displays the samples taken throughout Butler County, and subdivided by townships, which help identify any trends or correlations between these areas if any were present. Township names and locations are shown in Figure 33. The mixing curves show groundwater being impacted with sources of pollution including halite (road salts, water softener), septic and animal waste, flowback water, landfill waste, and seawater (Mullaney et al., 2009).

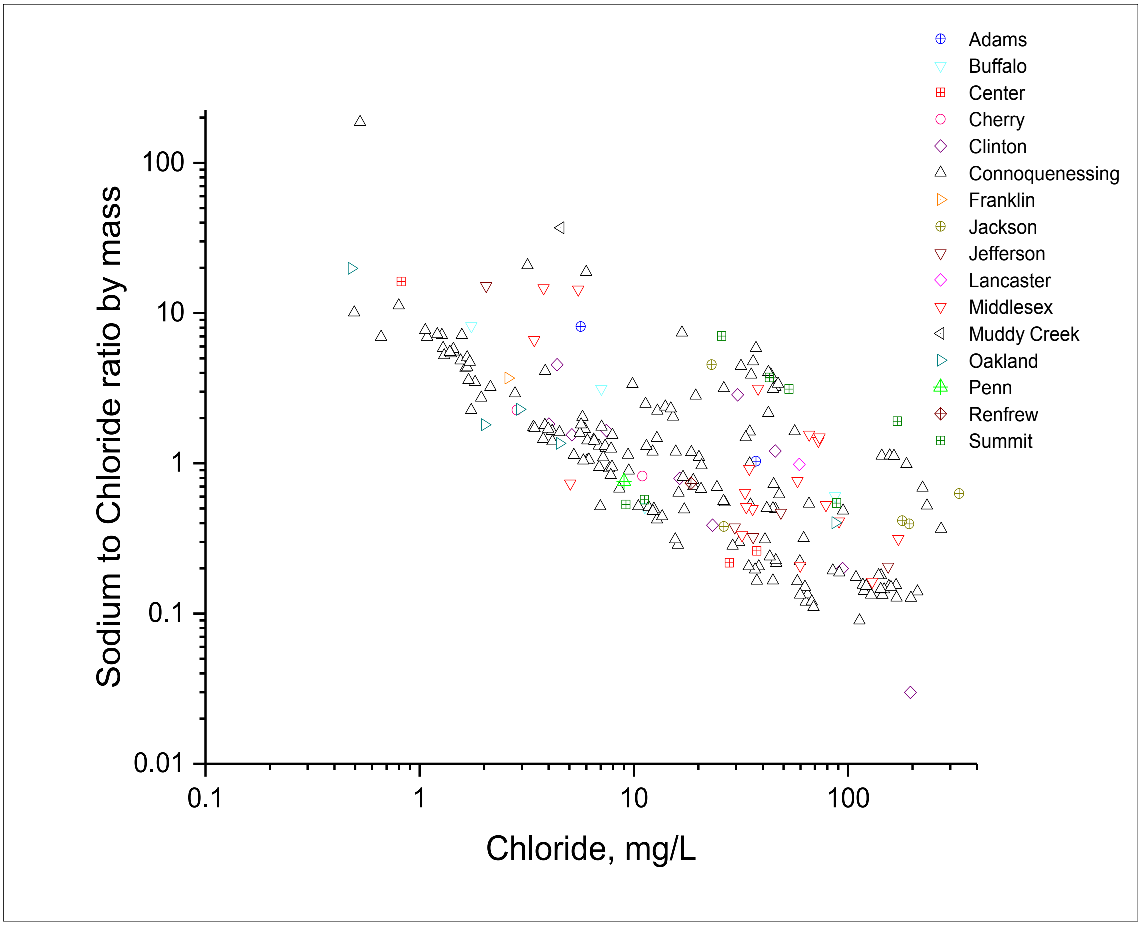


Figure 17 Sodium:chloride to chloride mass ratio plot for all samples in Butler County.

Sodium:chloride mass ratios were examined to investigate the different sources of chloride contamination to groundwater. According to past research (Townsend & Whittemore, 2005, and Panno et al., 2002 and 2006) the Na:Cl mass ratio and chloride concentrations help identify and differentiate sources of pollution similar to the Cl:Br method. The samples in Figure 17 were subdivided by townships, in order to determine if any correlations or trends of contamination exist spatially within Butler County. Township names and locations are shown in Figure 33.

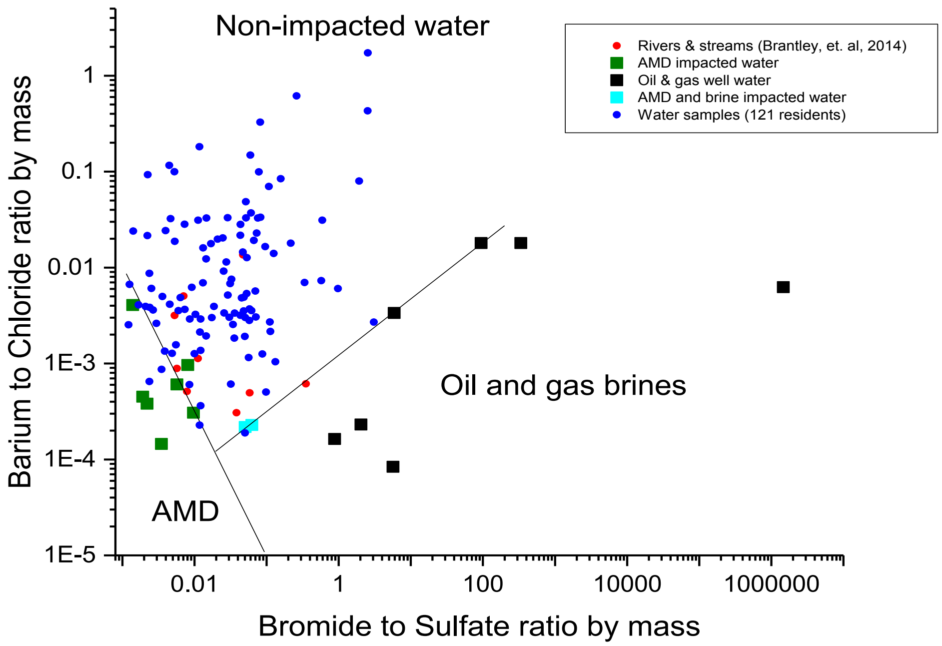


Figure 18 Barium:chloride to bromide:sulfate mass ratio plots for Butler County samples against reference "boundary lines" from Brantley et al., 2014,

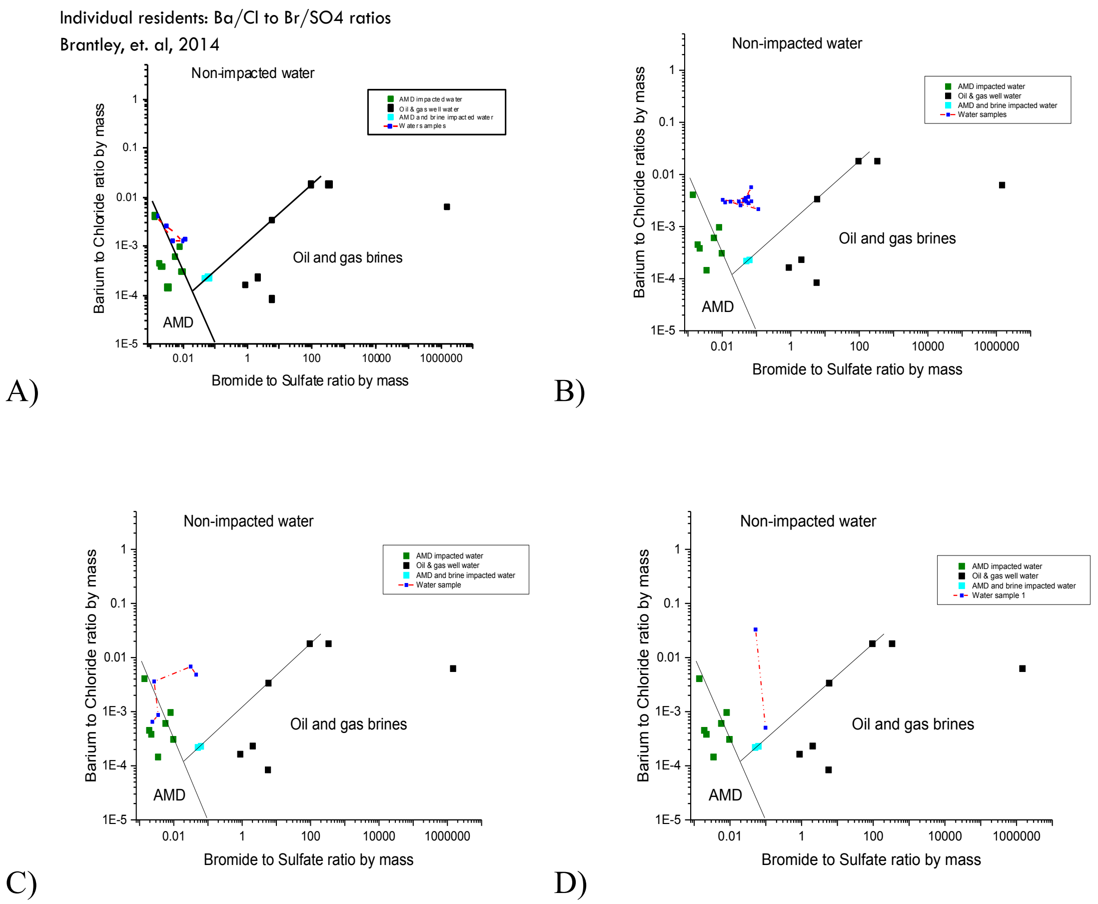
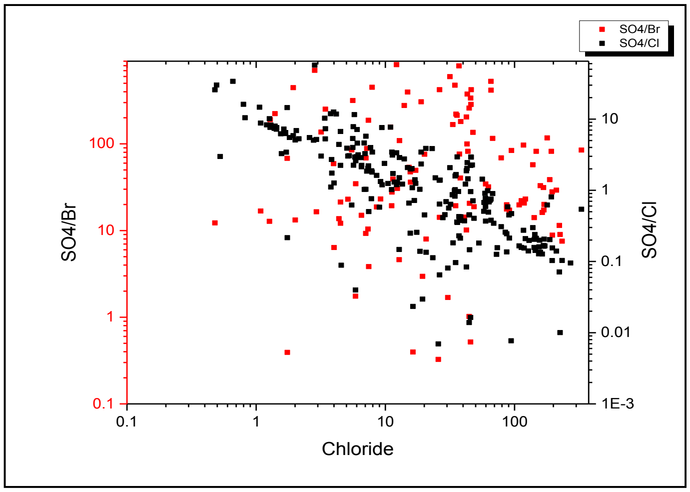


Figure 19 Barium:chloride to bromide:sulfate mass ratio plots for Butler County samples against reference "boundary lines" from Brantley, et al., 2014, showing groundwater changes for 4 individual wells; A) Well sampled from 2012-2014; B) sampled from 2011-2014; C) from 2011-2014; and D) sampled 4/2014 and 5/2014.

A)



B)

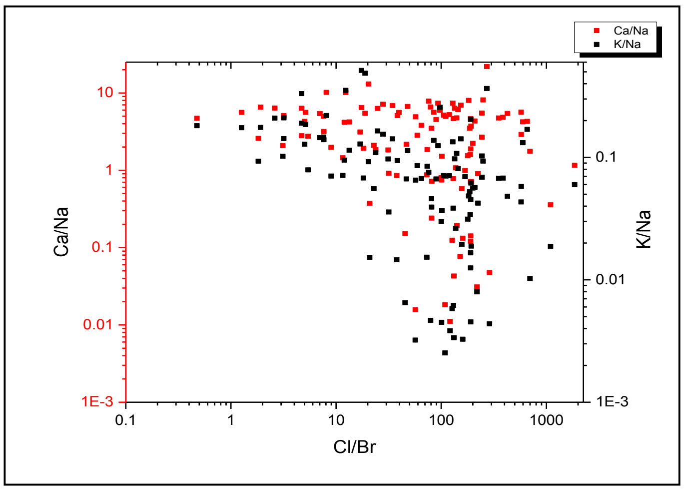
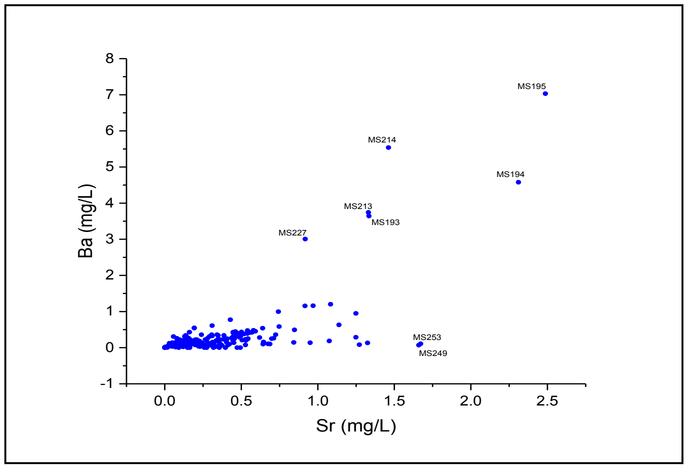


Figure 20 Geochemical ratios of A) Sulfate:bromide and sulfate:chloride mass ratios in relation to chloride concentrations; and B) the calcium:sodium ratios and potassium:sodium ratios in reference to chloride:bromide ratios by mass.

A)



B)

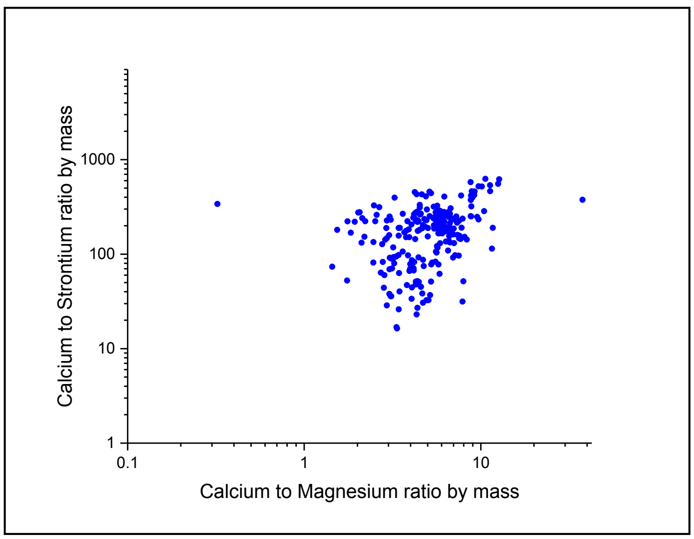
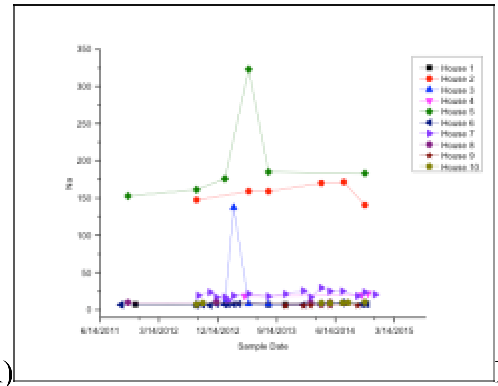
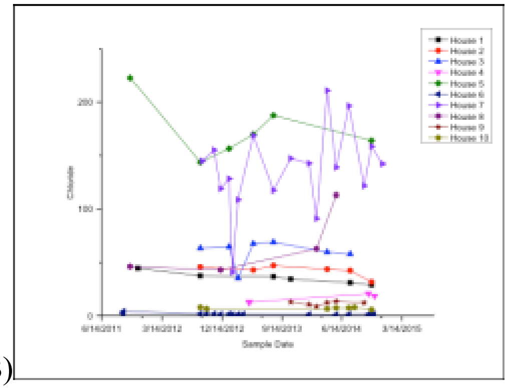
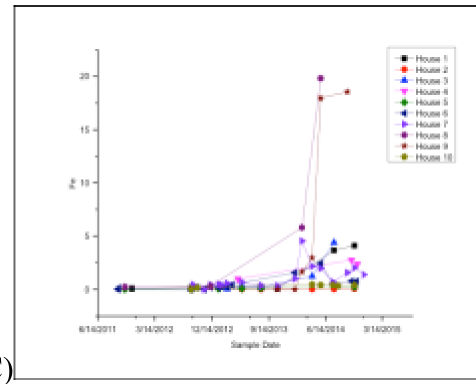
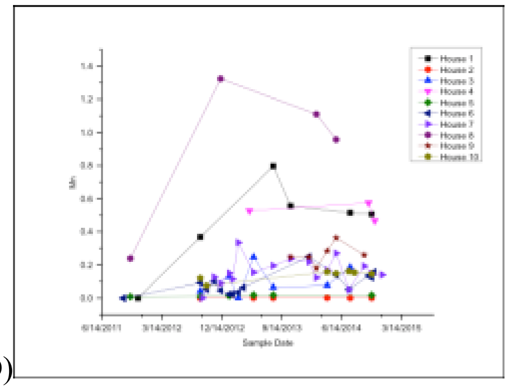


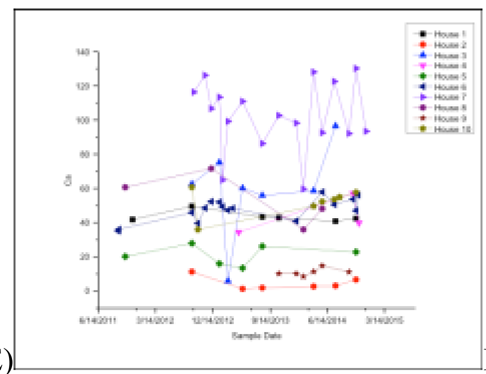
Figure 21 Concentrations of A) barium and strontium ratios; and B) calcium:strontium to calcium:magnesium ratios by mass.

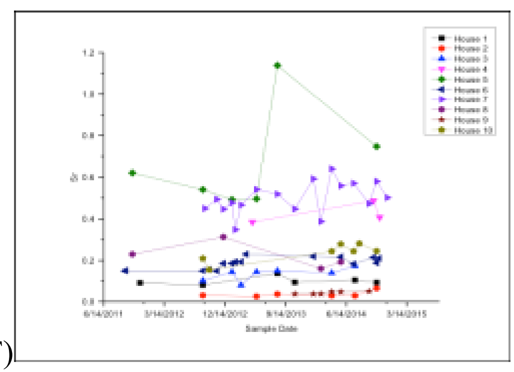

Na
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
A)

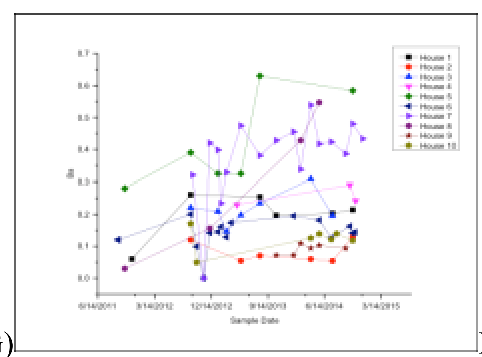

Chloride
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
B)


Fe
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
C)


Mn
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
D)


Ca
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
E)


Sr
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
F)


Ba
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
G)

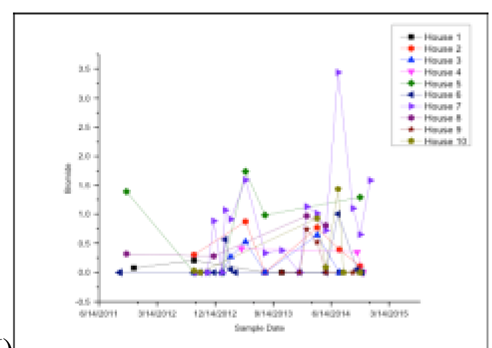

Bromide
Sample Date
House 1
House 2
House 3
House 4
House 5
House 6
House 7
House 8
House 9
House 10
H)

Figure 22 Long term monitoring of 10 wells in a community for anions and cations A) sodium, B) chloride, C) iron, D) manganese, E) calcium, F) strontium, G) barium, and H) bromide.

4.4 Data and Geographical Mapping Results

Using ESRI's geographic information system ArcMap 10.1, the results from the residential survey and water chemistry analyses were plotted and displayed creating geospatial maps. The data collected from the survey and water samples were associated with the extent of the Marcellus Shale play across the region, as well as the locations of unconventional shale gas development throughout Butler County, PA, including drilled wells, shown in Figure 23.

Various maps of the Marcellus Shale were created illustrating the location of the samples in reference to the extent of the formation, shown in Figure 24. The three regions of the Marcellus Shale play, the Western Margin, Interior, and Foldbelt units were illustrated in contract to the thickness of the formation across the state were shown in Figure 25 and 26, display the study area of Butler County, and locations of the water samples acquired and locations of drilled unconventional gas wells. Geospatial map shown in Figure 27 display the extent of orphaned and abandoned oil and gas wells, abandoned mine lands, and conventional wells throughout Butler County.

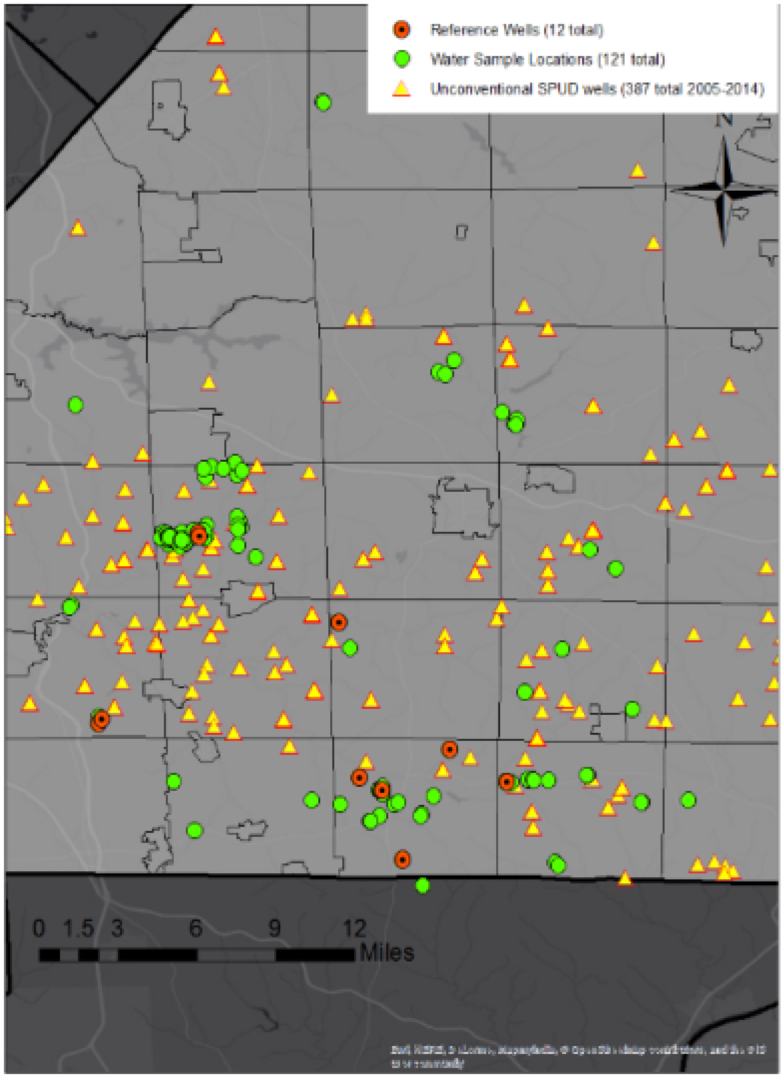


Figure 23 Locations of the residents who participated in the survey and sample acquisition (green), reference wells (red) as well as locations of the 387 drilled (SPUD) unconventional shale gas wells (yellow), in Butler County.

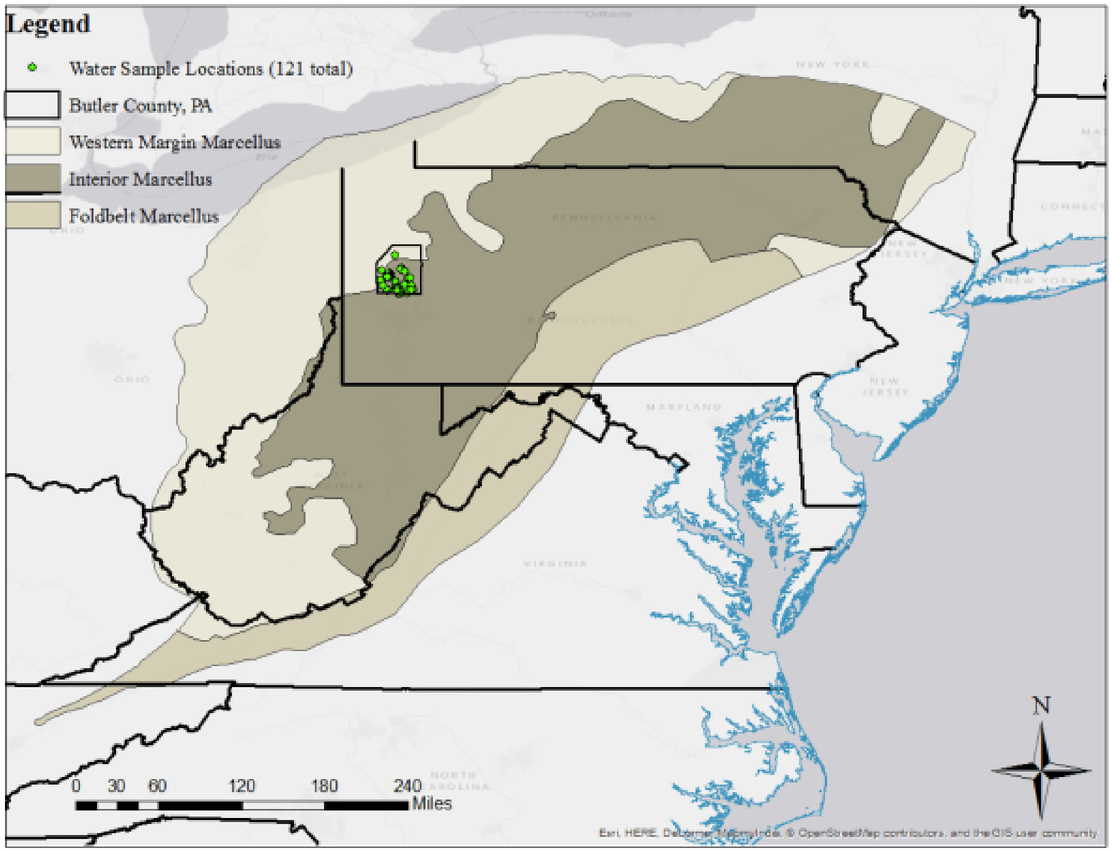


Figure 24 Marcellus shale formation and the three dividing units, along with location of well water samples collected in Butler County, PA.

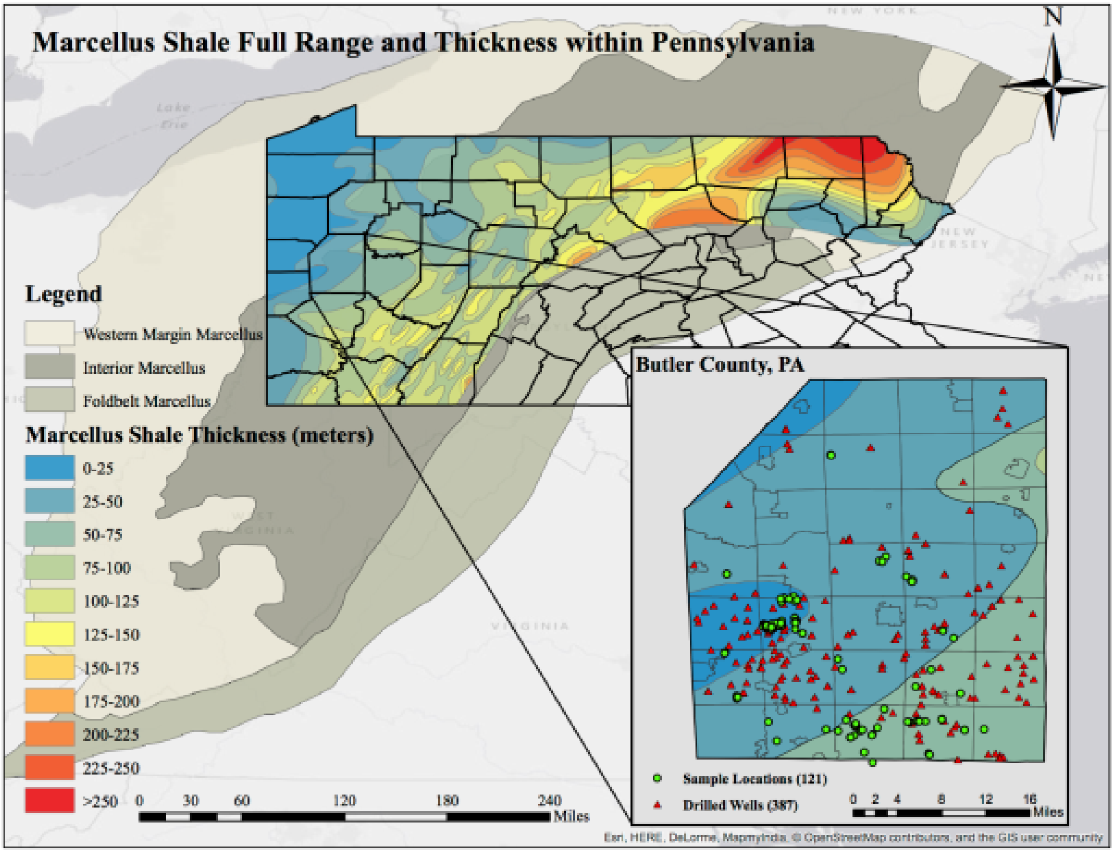


Figure 25 Marcellus Shale formation, including the three dividing units and various thicknesses across Pennsylvania, as well as another data frame showing a close up of the study area of Butler County, PA.

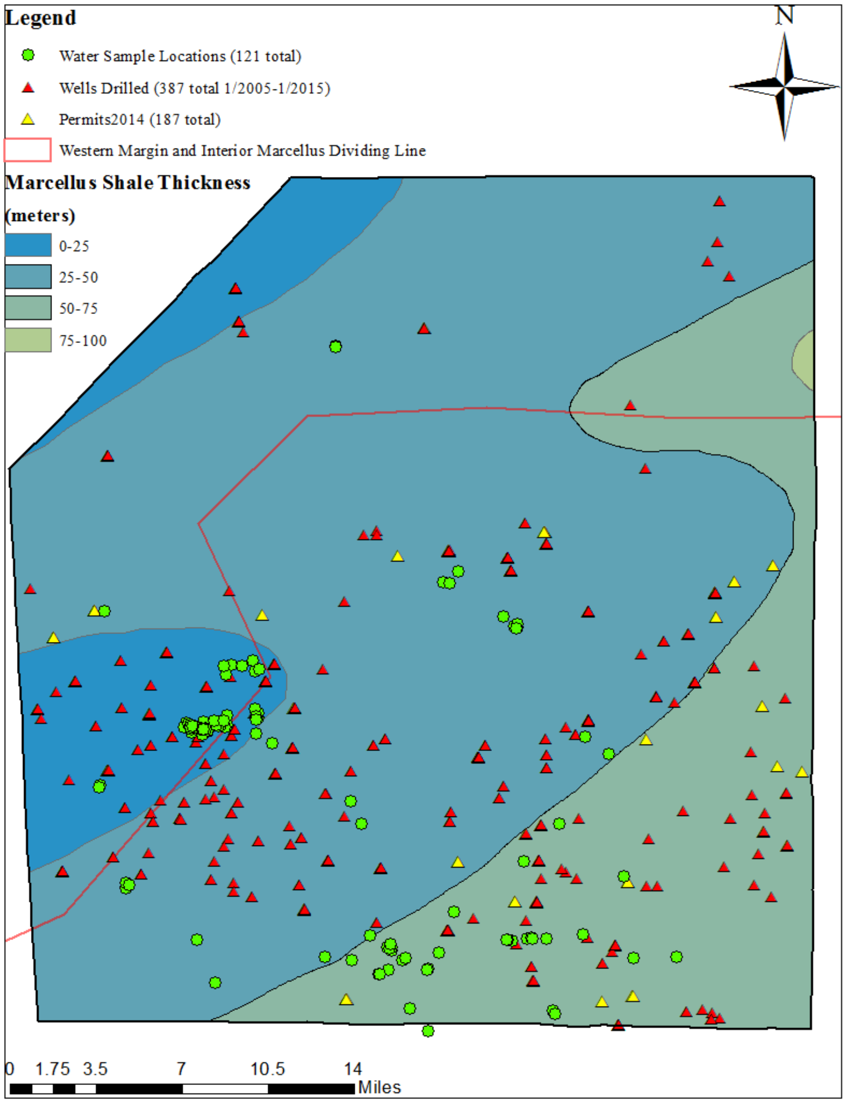


Figure 26 Boundary lines between the Interior Marcellus and Western Margin units, and Marcellus Shale thickness within Butler County, in reference to unconventional wells drilled, and locations of water samples.

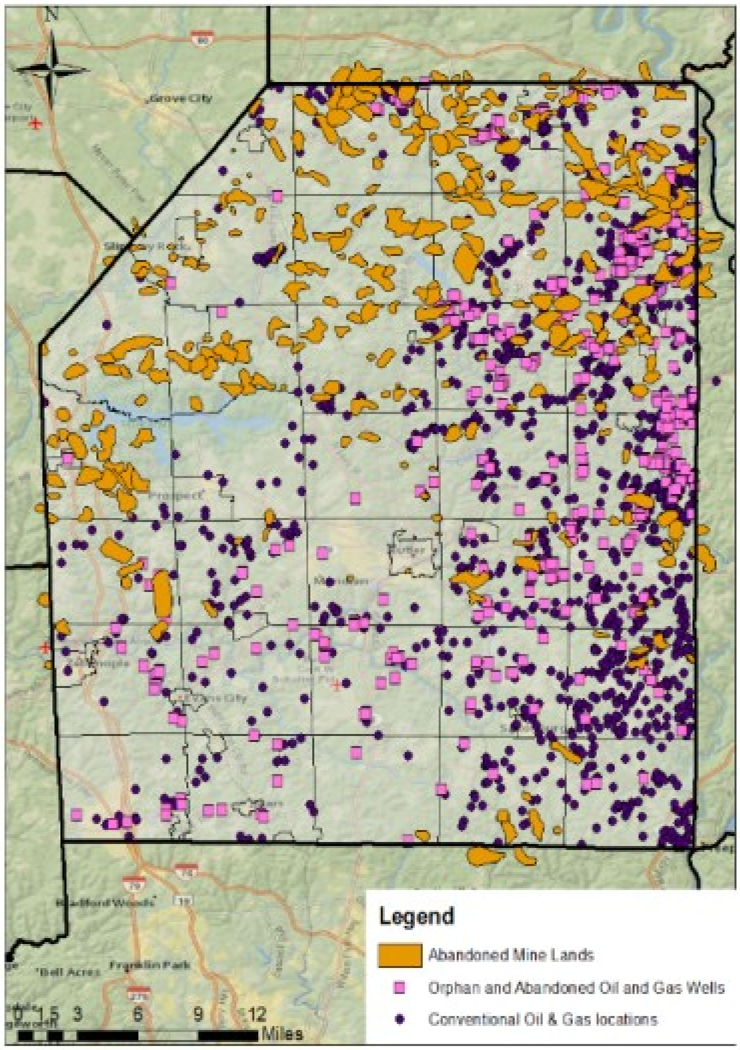


Figure 27 Locations of legacy coal mine, gas, and oil operations; abandoned mine lands (orange); conventional oil and gas well sites (purple); and orphan and abandoned oil and gas wells (pink)

4.4.1 Results of Well Coordinates in Relation to Unconventional Wells

When evaluating the location of samples to unconventional well pad sites, 40 residents (33% of the 121 total residents sampled) were within 2,500 feet of the closest well pad. Of the 40 residents, 28 (70% of the 40 total) had high manganese levels, 17 (42.5%) had elevated iron levels, 15 (37.5%) elevated fluoride levels, 9 (22.5%) residents with high aluminum, 8 (20%) had poor levels of pH outside the 6.5-8.5 range, 5 (12.5%) had high total dissolved solids, 5 (12.5%) had high barium, and 1 (2.5%) sample had high lead levels.

There was a total of 64 residents who were outside the range of 2,500 feet, but less than 10,000 feet from the nearest unconventional pad. Of the 64 residents (53% of the 121 total residents sampled), 35 (54.6%) residents had elevated levels of manganese and 30 (46.8%) residents with high levels of iron, 17 (26.5%) with high TDS, 12 (18.7%) with high aluminum, 11 (17%) households had levels of pH that did not meet EPA's standards, 8 (12.5%) had elevated fluoride levels, 2 (3%) with high chloride levels, 1 (1.5%) household with high nitrate, and 1 (1.5%) household with high barium concentration.

There were 17 participants greater than 10,000 feet away from the nearest unconventional well pad. Of the 17 residents (14% of the 121 total), 11 (64.7%) had high iron levels, 5 (29.4%) with high manganese, 4 (23.5%) had levels of pH outside the EPA's recommended range, and TDS, aluminum, each had one household exceeding the SMCLs.

Of the 91 residents within the subsample, 24 (26.3% of the 91 total) households were within 2,500 feet from the nearest unconventional well pad. Of the 24 residents, 17 (70.8%) had multiple hydrocarbons present, and 6 (25%) tested positive for only methane (Figure 28). The highest level of methane detected within 2500 feet was 1625.61 µg/L and ethane at 71.22 µg/L. A total of 49 (53.8% of the 91 total) residents were outside the 2500 feet range, but below 10,000 feet distance from the nearest well, with 21 (42.8%) residents having multiple hydrocarbons present, and 12 (24.4%) houses containing only methane. The highest level of methane within the 2500 to 10,000 feet range was 14,752.57 µg/L and ethane at 65.12 µg/L. There were 17 participants in the subsample greater than 10,000 feet away from the nearest well pad. Of the 17 residents (18.6% of the 91 total), 4 (23.5%) residents had multiple hydrocarbons present, and 7 (41%) had only methane detected. The highest concentration of methane detected greater than 10,000 feet was 15,038.15 µg/L and the highest ethane concentration was 84.49 µg/L.

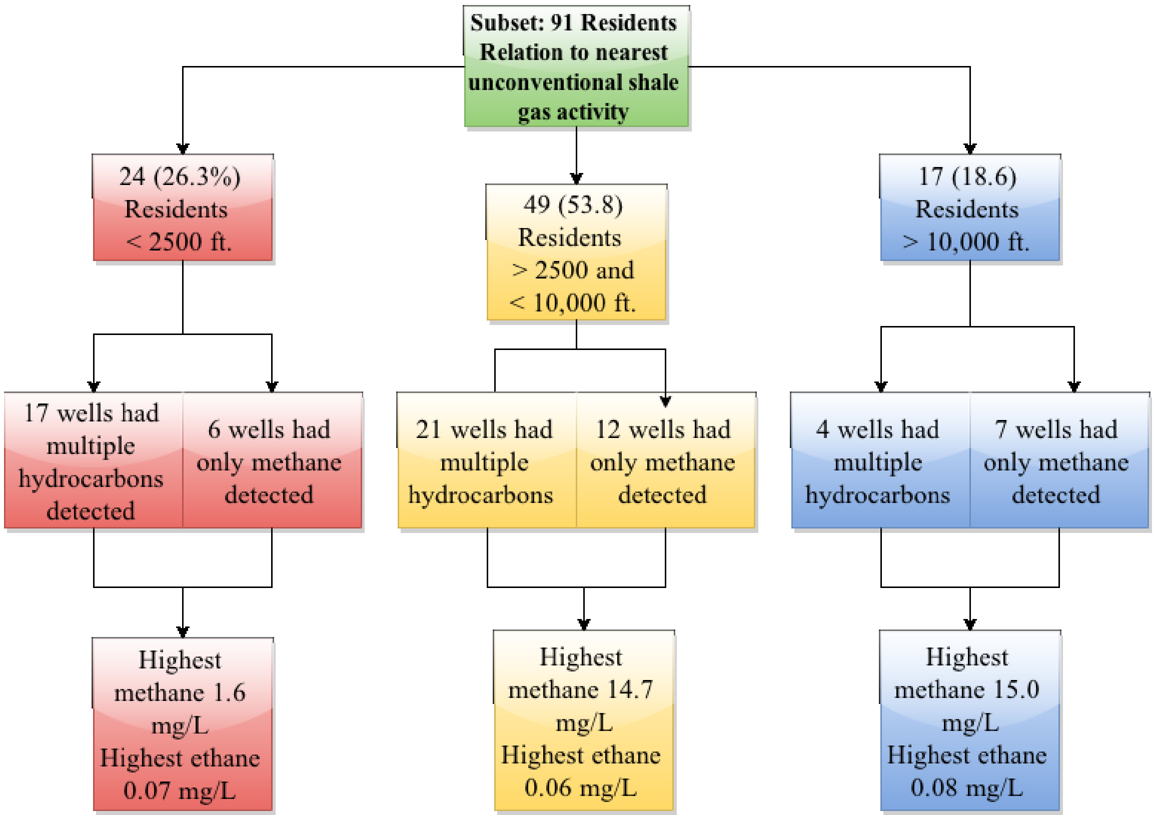
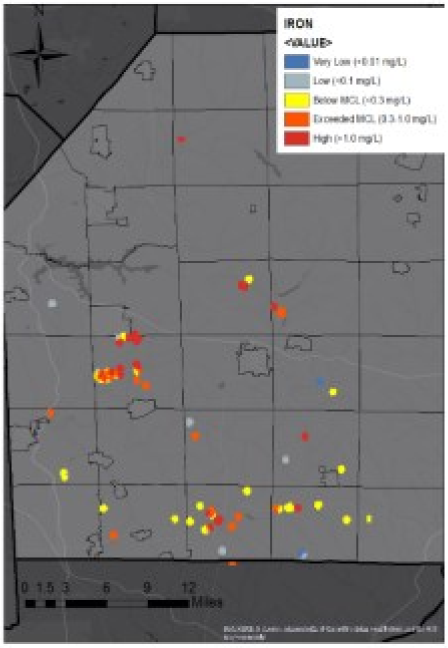
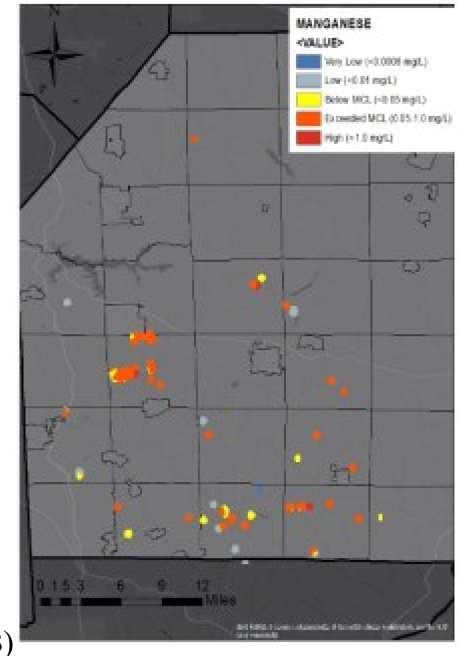


Figure 28 Flowchart showing the breakdown of distances to unconventional drilling activity and number of residents who had either multiple hydrocarbons detected or only methane.

4.4.2 Geospatial Results of Concentrations of Constituents

Geospatial maps of varying parameters were created including concentrations that either exceeded levels of concern throughout the sample area, or indicator parameters that are associated with oil and gas activity, in reference to the drilled wells throughout Butler County. These constituents included iron, manganese, and barium, which are displayed in Figure 29. The subset samples that tested for light hydrocarbon concentrations were plotted as well, including methane, ethane, ethene, propane, propylene, and butane, in reference to locations of unconventional gas wells in Butler County, shown in Figure 30.

A) 

B) 

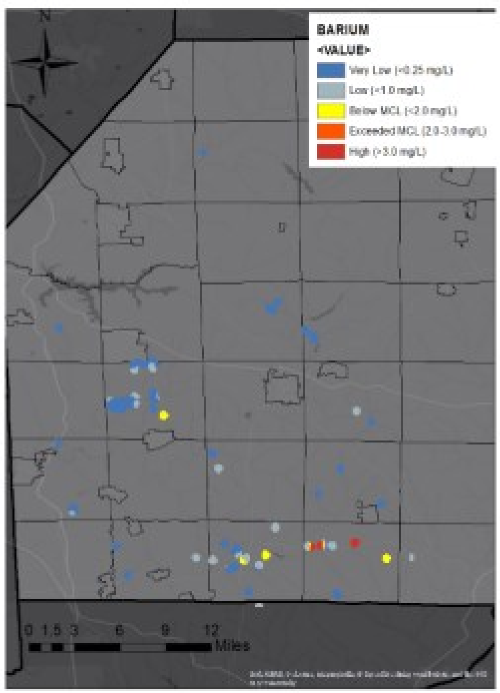
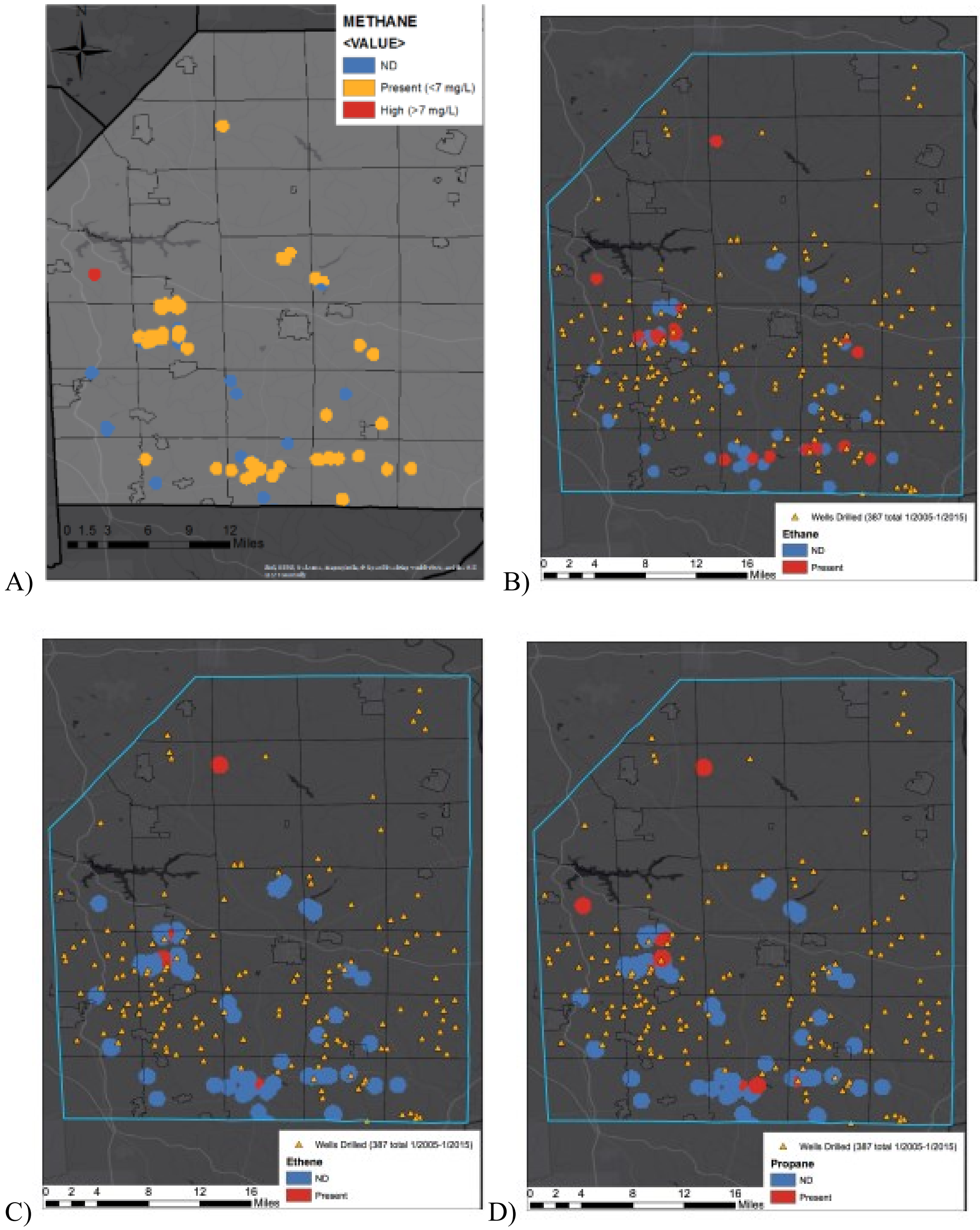
C) 

Figure 29 Geospatial maps indicating levels of metals and their EPA regulated MCLs/SMCLs and levels of concern from well water samples acquired in Butler County A) iron, B) manganese, and C) barium.


A)
METHANE
<VALUE>
ND
Present (<7 mg/L)
High (>7 mg/L)
0 1.5 3 6 9 12
Miles
B)
Wells Drilled (387 total 1/2005-1/2015)
Ethane
ND
Present
0 2 4 8 12 16
Miles
C)
Wells Drilled (387 total 1/2005-1/2015)
Ethene
ND
Present
0 2 4 8 12 16
Miles
D)
Wells Drilled (387 total 1/2005-1/2015)
Propane
ND
Present
0 2 4 8 12 16
Miles

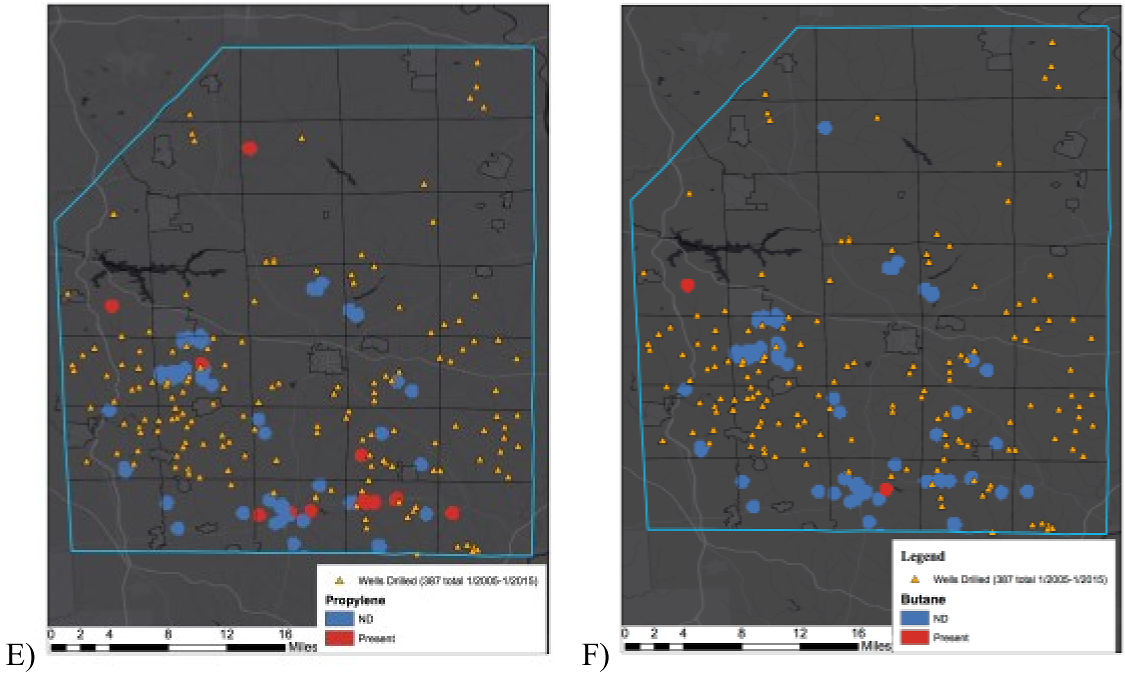


Figure 30 Geospatial detection of light hydrocarbons from well water samples acquired in Butler County, and locations of drilled wells (orange triangles) (PA DEP, 2014) A) methane, B) ethane, C) ethene, D) propane, E) propylene, and F) butane.

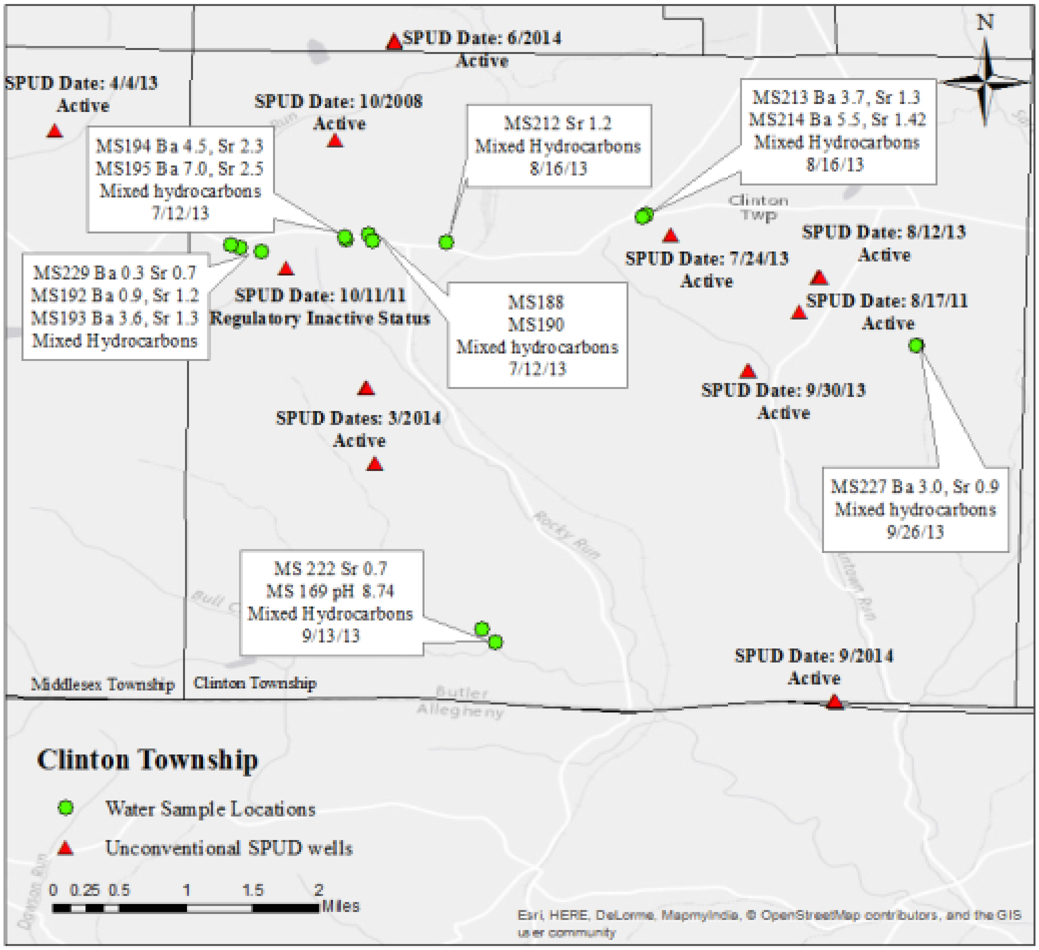


Figure 31 Location of samples with high barium and strontium levels throughout Clinton Township.

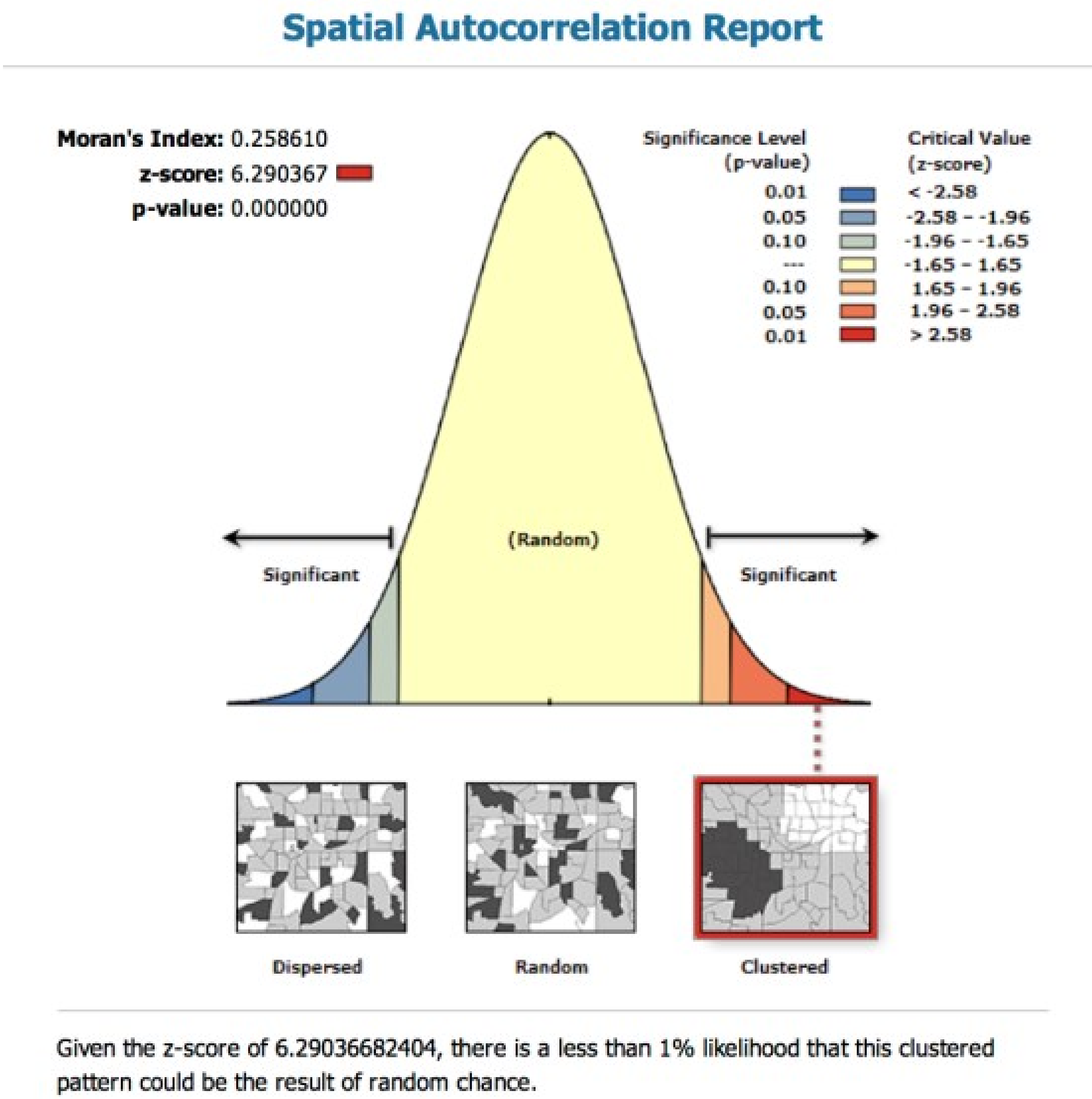


Figure 32 Spatial Autocorrelation Report generated for Sr using Moran's I geospatial tool modified in ESRI ArcMap 10.1.

Using Moran’s I spatial autocorrelation in ArcMap 10.1, several constituents were examined. This geospatial tool helps to identify any local clustering within the data and levels that share common attributes spatially in the area. Based on the amount of clustering or randomness, the constituent receives a z-score and p-value that together indicate whether the data set, values, or parameters are statistically significant. The higher the z-score the more significant the parameter is spatially in the area. Using this spatial analyst tool, several constituents including methane, iron, manganese, barium, and strontium were evaluated. Compared to the others, strontium received the highest, most extreme z-score of 6.29, illustrating that there is a correlation between the elevated levels of Sr, and the location (Figure 32 has legend for comparison). The results shown state that there is a less than 1% chance the clustering is a result of random chance, and are statistically significant, shown in Figure 32. The spatial autocorrelation generated reports that determined that iron (z-score of 2.53) and manganese (z-score of 4.12) were also spatially significant. Barium (z-score of 1.17) and methane (z-score of 1.26) were random and not significant.

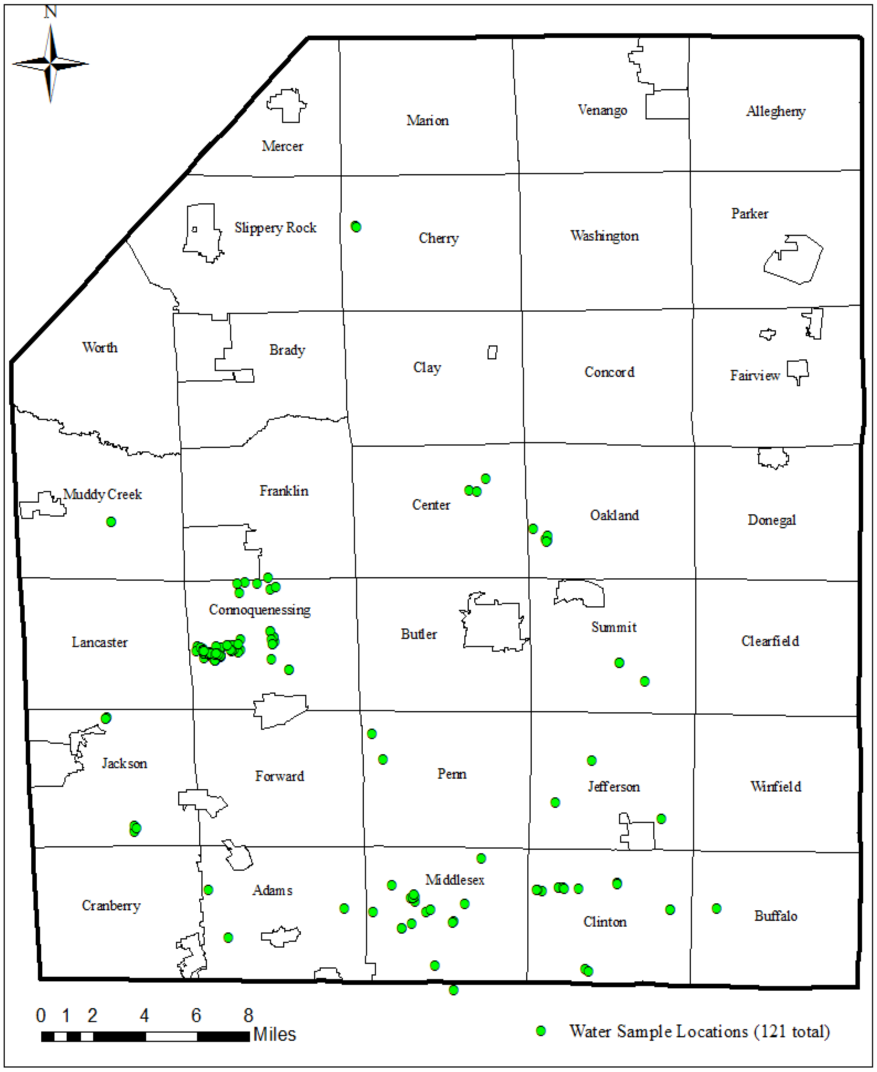


Figure 33 Townships of Butler County, PA and location of well water samples

Section 5: Discussion

There are various processes and subsurface pathways that could affect groundwater quality, making determination and identification of contamination sources challenging. The open nature of the system, allows for a wide variety of contamination sources including anthropogenic effects involved with increased use of road salts, septic tank leakage, landfill leachate, and, oil and gas legacy issues (Capo et al., 2014). Processes including seasonal differences, topographical, physical and geochemical, components have the ability to affect the groundwater analytical results as well. The geology of the area and minerals dissolved in the water source play a significant role in the quality of the water (Lindsey et al., 2014). Geochemical factors within groundwater systems that can affect naturally occurring trace elements include oxidation-reduction actions, solubility of ions, ion competition for sorption, and mixing and dilution components (Ayotte et al., 2011).

Evaluating chemical indicators and geochemical ratios (i.e., Cl:Br mass ratios) within water systems is an important measure and tool in determining sources of contamination. In addition to natural geochemical constituents (i.e., Na, Ca, Mg, Fe, Mn), other chemicals found in relative to anthropogenic activity should be evaluated, including components in oil and gas brines, agricultural runoff, septic tank leachate, and constituents found in recent development unconventional wastewaters (i.e., Cl, Br, Sr, Ba). Future research can provide the opportunity to gain more information and understanding of these components, which could help with future mitigation, remediation, and disposal processes. (Murray, 2013, Thurman et al., 2014).

5.1 Residential Survey Analysis

This water quality study and research focused on an area with various sources of anthropogenic development, in addition to the recent unconventional shale gas development. The area additionally, relies on groundwater sources for private drinking use. Participants within the survey and sample acquisition were not selected in any way, but were incorporated into the study due to community outreach and responses to either: 1) Complaints or changes in water quality or quantity, or 2) Concerns that their water quality would change due to recent shale gas development in their areas. The final survey results initiated in 2011, and completed at the end of 2014, indicated that a total of 59 of 121 (48.7%) reported a change in either well water quality or quantity since drilling began in the area.

The majority of residents who participated were sampled during the past two years, where drilling has also seen a significant increase in the area, with 52 residents participating in 2014 and 39 residents in 2013. Of the 59 residents who reported to have some sort of water change or issue, 53 residents reported having changes in the quality of water, mainly color and smell. These signs of water quality could be connected with the area's extensive history of conventional oil and gas development, in addition to abandoned wells, strip mines, and coal mines, as shown in Figure 27. These water quality issues were mostly complaints of orange, red, yellow color changes, as well as black sediment, which are associated with high concentrations of iron and manganese within private water systems, previously seen in water sampling by Poth, 1973. The increased number of coloration and smell issues reported is suggestive of sulfate and trace elements resulting from abandoned mine drainage (AMD), which is a common source of water pollution throughout Pennsylvania.

The majorities of the water samples acquired within the study has already been subject to areas with recent unconventional shale gas development and are considered post-drilling samples. However, the drilling within Butler County has seen a significant increase since 2012, therefore changes in water quality could have followed and led to the increased claims of groundwater contamination to the PA DEP. The assorted number of complaints of groundwater change over the course of the study occurred at different times, which could be influenced by numerous sources, including well depth and the distance their home is in reference to the nearest unconventional well pad site. According to the data acquired and plotted, shown in the results Figure 11, the average distance where a resident has had claimed their water quality has changed is approximately 3,610 feet, which is 1,000 feet outside the range where the industry conducts pre-drilling water testing. This could indicate that the distance of 2,500 feet is not an optimal distance to use as a standard for residents who may experience changes in their groundwater source.

5.2 Water Chemistry Analysis

The water chemistry analysis performed for this study consisted of 44 parameters in total., focused on inorganics constituents and metals, including 7 in field parameters, (temperature (°C), dissolved oxygen (% and mg/L), pH, pressure (mmHg), specific conductivity (μS/cm^3), conductivity (μS), and TDS (mg/L)), 7 anions (fluoride, chloride, nitrate, bromide, nitrate, phosphate, and sulfate (mg/L)) and 30 cations, such as sodium, calcium, aluminum, manganese, iron, arsenic, copper, and barium (mg/L), to name a few.

All these inorganics can be found naturally within the groundwater and geology of the area, and also have the ability to become introduced anthropogenically and deposited into the environment.

5.2.1 High levels of Iron and Manganese

The results from the well water sampling found that of the 121 residents, 68 (31%) and 57 (26%) residents had levels of manganese and iron that exceeded the EPA's SMCL of 0.05 mg/L and 0.3 mg/L, respectively. These two elements collectively made up over half of the water quality issues associated with this study. Since iron and manganese are usually found naturally together in water systems, this is an indication that a total of 57% of the residents that had water quality concerns and reports of contamination were involved with these two constituents. Both iron and manganese occur naturally in the environment, with the reduction and oxidation reactions and geological conditions within the aquifer and groundwater sources, controlling the concentration of these trace elements. Shown in data plot A in Figure 15, the iron levels found in 1973 were compared to samples taken throughout this research from 2011 to 2014. The plots with iron concentrations in comparison to chloride concentrations was an effective way to compare the two data sets, illustrating that the iron concentrations from the past and present were consistent and evenly spread across the scatter plot.

Reduction and oxidation reactions have a significant effect on the quality of groundwater. These reactions can change the valence state of trace elements (including iron and manganese), hydrogen sulfide, and methane (Lindsey, et al., 2014). Iron and manganese are more likely to be found in anoxic water conditions, where the dissolved oxygen content is very low, and slightly acidic with pH around 4-7 (WHO, 2011). Iron under the anoxic conditions of groundwater, appear clear, however when exposed to oxygen, the element oxidizes and change from the dissolved form, to an orange and red colored suspended, solid form. High iron and manganese can be associated with changes in well water quality, displaying these orange, red, and brown coloring, and small black particulates indicating manganese is present (Clemens et al., 2009, Dvorak et al., 2014, Lindsey et al., 2014). High levels of iron and manganese are not seen in all water sources, but are common throughout Pennsylvania. Low levels are not considered a health risk, but can cause issues and raise concerns with drinking water taste, smell, and color. The elevated levels become an aesthetic issue and nuisance, from staining pipes and fixtures within homes, and promoting bacteria growth within private water systems (Clemens et al., 2009, Dvorak et al., 2014).

Historically, Butler County's groundwater sources have supplied residents with clean, drinkable water, however there are some constituents that have always been issues throughout many communities. In a USGS summary of groundwater in Butler County, PA by Poth in 1973, of 48 water sampled collected, 23 exceeded (48%) iron levels above 0.3 mg/L, above the current SMCLs for drinking water.

Elevated levels of manganese within aerobic groundwater sources can be connected with industrial pollution and land use activities such as mining (WHO, 2011). Throughout the extent of Butler County, historic coal mining still remains the primary activity that causes water pollution issues. Abandoned mine drainage (AMD) and other oil and gas legacy issues exposing iron, manganese, and sulfide to water sources, is known to significantly influence the quality, quantity, and uses for water supplies including both surface and groundwater (Cravotta III, 2008) Hundreds of abandoned and improperly sealed oil and gas wells reside in the county, many of which could have potentially exposed deep basin brines into groundwater sources (Poth, 1973). The exposure of AMD could occur from the high capacity water withdrawal exposing previously flooded mines to fresh oxygenated water. There is an estimated volume of about 2.3 x 10^9 cubic meters of AMD that is discharged into Pennsylvania's waters a year, due to these legacy issues, causing significant damage to aquatic ecosystems and water sources (Kondash et al., 2013). Iron and manganese are constituents that help to identify effects of this AMD and legacy issues, in addition to elevated levels and concentrations of pH, aluminum, and sulfate (Cravotta III, 2008).

In addition to 57% of the residents containing high manganese and iron, 21 residents had high aluminum concentrations, and an additional 21 residents had poor pH levels, with the majority of pH values being less than 6.5, more acidic from the iron precipitation. The combination of elevated levels of iron, manganese, aluminum, and pH is suggestive of geologic formations in the area and some anthropogenic activity. The significant increase in unconventional shale gas extraction in these areas with extensive amounts of abandoned mines and oil and gas wells, indicates that there may be potential disturbances in the subsurface environments. The increased amount of iron and manganese can also form from the end results of the unconventional oil and gas processes, with these iron and manganese precipitates occurring, in addition to calcium, barium, and sulfate precipitation, all which reduce gas production of the well (Lester, et al., 2015).

5.2.2 Sources of Contaminants Associated with Unconventional Shale Gas Extraction

The shale gas extraction process is an intensive process that uses large amounts of water, sand, and chemicals injected at high pressures into organic-rich formations deep underground. The initial flowback water and produced wastewater associated with hydraulic fracturing within the Marcellus Shale contains elevated levels of TDS. The Marcellus produced water has shown in past research to have significantly high levels of sodium, chloride, barium, bromide, and strontium (Barbot et al., 2013, Clemens, et al., 2009). Brines associated with the produced waters of the Marcellus formation and from leaking oil and gas wells also contain levels of Na, Ca, Mg, Cl, Ba, Br, and Sr at high concentrations that make them distinct from other sources (Chapman et al., 2012, Dresel & Rose, 2010). Therefore, accurate end members for various sources of pollution should be used to distinguish between the Marcellus produced water and the brines from improperly sealed oil and gas wells. In addition to elevated levels associated with TDS, the presence of lithium and boron can be sourced from Marcellus brines and anthropogenic chemicals involved with the processes as well (Warner et al., 2014).

Using the concentrations of the metals from the water samples, ratios including chloride to bromide ratios (Cl:Br), sodium to chloride (Na:Cl), and others (i.e., Ba:Cl to Ba:SO_4 mass ratios) have been used in the past to differentiate between sources of anthropogenic and naturally occurring constituents (Davis, et al., 1998, Katz, et al., 2011, Lautz et al., 2014, Mullaney et al., 2009, Wilson & Van Briesen, 2013). Sources of contaminants that can be differentiated from using chloride and bromide concentrations include sewage and septic leachate, road salts (halite), and deep basin brines which can be referenced to oil and gas operations. The significance of chloride and bromide within this study is that they are two components of TDS generally tested for in water chemistry analyses, and are commonly found within oil and gas wastewaters and flowback and formation waters in elevated levels (Soeder & Kappel, 2009, Wilson & Van Briesen 2013). Bromide has been shown to be a good indicator for distinguishing between sources of contamination due to its enrichment within formations from the degradation of organic materials, in contrast to chloride concentrations (Panno et al., 2006)

Lautz et al., also used bromide to chloride ratios and sodium to chloride ratios to determine if sources including halite (road salts), septic effluent, animal waste, and brines, had effects on water samples acquired from southern New York state. Other ratios such as bromide to chloride ratios, sulfate to chloride ratios, and sodium to chloride ratios have been used in past research from Townsend & Whittemoore 2005, which helped indicate zones of mixing from fresh to saline water with oil brine and manure liquid. Chloride to bromide and chloride to fluoride ratios were used by Vengosh & Pankratov, to determine sewage-associated contamination in groundwater.

For this study, chloride to bromide mass ratios were used to assess different sources of pollution. Data plots are shown in Figure 16. The mass ratios for Cl:Br can range from values between 10 to 100 for run off from urban streets, 100 and 200 for shallow groundwater, while sewage and septic with values between 300 and 600, halite contaminated waters between 1000 and 10,000 (Davis et al., 1998, Katz et al., 2011).

Using the Cl:Br ratios enable the ability to distinguish some multiple salinity sources that have chemical concentrations from other sources. Some of these sources of pollution include halite or road salts, which can have a Na:Cl ratio around equal to 1, and low ratios of Br:Cl. Another source is septic tank leachate, which can have Na:Cl ratios greater than 1, high nitrates, low ratios of Br:Cl (Vengosh et al., 2011). Abandoned mine drainage is another common source of pollution throughout Pennsylvania as mention above, which has effects such as low pH levels, and levels of sulfate detections. In reference to the shale gas industry, Marcellus brines can have ratios of Na:Cl lower than 1, high Br:Cl. Hydraulic fracturing fluids (slickwater) contain high amounts of Ca, Sr, B, and Ba, which are constituents that enable researchers the ability to trace influences of these fluids within water sources (Vengosh et al., 2011).

The chloride to bromide mass ratios used in relation to the mixing curves from Mullaney et al., 2009, helps assist in indicating the potential sources of contamination from various sources. Referring to Figure 16, mixing curves 1 and 2 include dilute groundwater/halite used for deicing for the high and low range. One sample from Adams Township (MS421) was greater than 15,000 feet away from the nearest unconventional well. The Cl:Br ratio for their water source falls along mixing curve 1, indicating that the water source could be impacted from chloride levels associated with halite and from deicing in the area. (Sample collected in November 2014).

The mixing curves 3 and 4 show the high and low range for possible groundwater contamination from sewage or animal waste. Several samples from Connoquenessing Township, Oakland Township, and one sample from Jackson Township fall in between the high and low range mixing lines, with one sample from Oakland plotting along the high range curve. Connoquenessing Township is a rural area, and highly farmed, which could correlate to this source of groundwater pollution. However, the water samples from Oakland and Jackson Townships are not directly set in highly rural and farmed areas, which is interesting to have that type of contamination suggested. Mixing curves 5 and 6, show possible water contamination and movement from sewage or animal waste to/from higher chloride levels involved with halite/road deicing. Only one sample from Connoquenessing fell close to the lower range curve. Township names and locations are shown in Figure 33.

Mixing curves 7 (dilute groundwater/flowback water), 8 (dilute groundwater/basin brines) and 9 (dilute groundwater/seawater), are all very closely plotted, illustrating the complexity to determine precisely the source of contamination within then water source. No Cl:Br levels were found plotted along the flowback water mixing curve, but several water samples fall along the mixing curve 8, indicating potential signs of intrusion from deep basin brines migrating into groundwater sources. However, there are several samples clustered between mixing curves 9 and 10, with one sample in particular, MS229 which shows concentrations of chloride contamination that associate with seawater intrusion, and is roughly 1,800 feet away from the nearest unconventional well pad. A group of samples from Connoquenessing and Jackson Townships fall around mixing curve 10, showing the possibility of dilute groundwater/landfill leachate as a source of contamination in those areas.

Water impacts from Na and Cl are common sources of pollution, to both surface and groundwater reserves (Panno et al., 2006). Elevated levels of Na and Cl serve as indicators of a water quality problem and using the sodium to chloride ratios allow the ability to distinguish sources of contamination with high sodium and chloride levels (Panno et al., 2006). These contamination sources can be associated with various origins including use of road salts or halite in urban areas, precipitation, leakage from septic and animal wastes, seeping municipal landfill wastes, and natural rock sedimentation as well as deep basin brines (Panno et al., 2002) Elevated levels of sodium and chloride can be correlated with increased road deicing activity during the winter months across the state, however many rural areas where sampling occurred had low road traffic and therefore halite and road salts could be less of a concern for groundwater contamination. The plots shown in Figure 17 illustrate the Na:Cl ratios to chloride, for different townships within Butler County. According to past research by Townsend & Whittemore, 2005, and Panno, et al., 2002 and 2006, the Na:Cl mass ratio and chloride concentrations help identify and differentiate sources of pollution similar to methods like Cl:Br ratios. Figure 17 shows a decreasing Na:Cl ratio with increasing Cl concentration indicating there may be a source of agricultural waste present.

Constituent ratios including barium to chloride (Ba:Cl) and bromide to sulfate (Br:SO_4) have been used as well to determine sources of contamination for surface waters from AMD and oil and gas brines (Wilson & Van Briesen, 2013). All samples that had levels of Ba, Cl, Br, and sulfate were plotted, with the majority of the samples falling into the 'non-impacted' water area. There were multiple samples along the mixing lines between AMD and non-impacted water, and therefore could have supported the previous section of legacy issues polluting groundwater supplies. No samples had concentrations within the oil and gas brine area, although there were a few samples along the non-impacted water and brine mixing line, and could have some sort of influence or impact, but there is no clear indication that brines are associated with those samples. The similarity between the sources of road salts, brines, and from Marcellus flowback also add to difficulties when differentiating between them.

Using barium to strontium mass ratios, all samples collected were plotted in log form shown in Figure 21 A. The graph illustrates the majority of the water samples clustering, and several outliers with high concentrations of barium and strontium. Samples MS193, MS194, MS195, MS213, and MS214, all located in Clinton Township, show some irregularity compared to the rest of the samples, raising concerns. Through further investigation, all samples are within 2,500 feet of the nearest unconventional shale gas well, with three of the residents roughly 1,000 feet away from the activity (Figure 31). In addition to the high barium ranging between 3.6 and 7.0 mg/L (MCL is 2.0 mg/L) and levels of strontium present, all but one sample has elevated levels of manganese above the SMCL of 0.5 mg/L, and all samples have multiple hydrocarbons present including methane, ethane, propane, and propylene. Their well depths are all in the range of 100-150 feet deep, suggesting that they share the same groundwater source, and showing similarities in the contamination across the five households.

The signs of elevated concentrations of barium and strontium, can be associated with produced water from the Marcellus formation, and also indicators of brines from Upper Devonian gas wells (Dresel & Rose, 2010). Therefore, households with high barium, detectable levels of strontium, as well as hydrocarbons present are important parameters to consider when investigating water quality issues associated with nearby unconventional drilling. Elevated levels of barium were only found in one area of southern Butler County, in Clinton Township. Barium cannot be found in aqueous systems where sulfate is present, However, if the water samples collected contain concentrations of iron, manganese associated with AMD and legacy issues, then barium might be precipitating out of the solution, therefore not being able to be detected, giving an inaccurate measurement.

The Ca:Sr ratios have been used in past research to help determine sources of pollution and irregularities within water sources (Capo et al., 2014, Chapman et al., 2012). Above, the Ca:Sr to Ca:Mg ratios were plotted, displayed a clustering of all the water samples collected, aside from two samples, MS210 and MS053, which fall outside the cluster (Figure 21 B). The samples seem to vary with high and low concentrations of Ca and Mg in relevance to each other, and not separated due to Ca or Sr concentrations. This could be from the varying hardness of the two water sources, and the type of bedrock that could potentially be dissolving ions within the aquifer, such as limestone. MS210 has no constituents above the EPA's MCLs or SMCLs, but contained mixed hydrocarbons, and is within 2,500 feet away from the nearest unconventional well pad. Sample MS053 has elevated TDS above 500 mg/L, pH levels above 8.5, and contains varying mixed hydrocarbons, in addition to the irregular Ca:Sr and Ca:Mg mass ratios, showing that using the ratio can help determine issues associated with the water source. Ba and Sr concentrations are similar to Ca and Mg, so using both ratios help indicate any sources of contamination within water sources.

5.2.3 Temporal Analyses of Samples

The barium:chloride to bromide:sulfate ratios were plotted and used to examine changes in groundwater chemistry for several residents who have had their water sampled over the course of the study period from 2011 to 2014 (Figure 19). The plots were constructed to match the mixing space from Brantley et al., 2014, showing zones for abandoned mine drainage influenced waters, oil and gas brine influenced waters, and non-impacted waters, based on the Ba:Cl and Br:SO4 mass ratios. Figure 19 A shows groundwater concentrations of Ba:Cl and Br:SO4 moving over time along the AMD impacted water and non-impacted water region. However the region is suggestive, but not definitive of AMD impacted water, due to the similarity of the ratios along the zones. Figure 19 B shows the groundwater concentrations and the temporal movement all within the non-impacted water region. The plots that stand out and raise concerns are Figure 19 C and D. Plot C shows that the earlier water samples could have been suggestive of AMD impacts, and over the course of years have moved toward the non-impacted zone. The unconventional shale gas development for this area was initialized during the earlier sampling periods, which could have impacted the water, and over time has been returning to a more normalized state. Plot D shows a rapid change in groundwater chemistry within a one-month period, indicating a significant change and flow within the groundwater source. The temporal changes from this case study illustrate the significance in monitoring wells seasonally, near development, in order to detect and observe potential changes in water quality that may occur naturally.

5.2.4 Methane and hydrocarbons

The leakage of methane from wells into groundwater or into the atmosphere raises many concerns for health and the environment, and forces the need to gain a greater understanding of the potential effects the gas can have (Teasdale et al., 2014). Methane can either be biogenic, produced from bacteria, or thermogenic, formed from high pressure and breakdown of organic matter deep underground. However, differentiating the two types can be challenging due to both occurring naturally as well. Research in the past through isotopic analysis of methane has been able to distinguish between thermogenic and biogenic methane, which can help attribute contamination to Marcellus Shale gas activities. The natural microbial produced methane contains a unique isotopic composition that can help distinguish biogenic methane from thermogenic production, including potential methane migration from the shale gas industry's processes (Jackson et al., 2013, Osborn et al., 2011, Sharma et al., 2014). Migration of methane and other hydrocarbons into water sources can arise from water wells screened across coal seams, poorly cased abandoned wells, shallow oil and gas fields, coal beds located within and below the aquifer, and the addition of new pathways within the ground from activity such as seismic events or hydraulic fracturing (Revesz et al., 2010). However, no direct evidence of methane migration from the Marcellus has been documented, rather the isotopic signatures suggest that the methane found in Butler County, was produced from sources and formations above Marcellus, such as coal bed methane from shallow rock units of the Carboniferous Period, in which the water wells are screened across, and did not relate to hydraulic fracturing processes (Molofsky et al., 2011, Osborn et al., 2011, Sharma et al., 2014).

Results of the subset sample showed that, 91 residents who had light hydrocarbons tested for, 67 (73.6%) residents had detectable levels of one or more hydrocarbons within their water source, including either methane, ethane, ethene, propane, propylene, or butane. Of the 73.6% of wells that contained detectable levels, 15% of wells had detectable levels of methane above 0.1 mg/L. From the 67 residents who were tested positive for hydrocarbons, 41 households contained multiple hydrocarbons within their water source (primarily ethane) and 25 households only had methane detected.

The detection of hydrocarbons within water sources can be linked to the resource exploration and development industry by the detection of other heavier hydrocarbons that associated with the natural gas liquids (NGLs) or ‘wet gas’ that is extracted from the formation (Sovacool, 2014). These natural gas liquids include gases such as ethane, butane, and propane, which were detected individually or together within the 41 samples throughout southern Butler County. Using methods from past research on methane migration and detection within water systems, levels of methane were matched to higher chain hydrocarbons as ratios, such as ethane, or butane (Jackson, et al., 2013 and Osborn, et al., 2011). The ratios that are calculated to be low (<100), are suggestive of thermogenic origin, rather than biogenic. Using this method, 11 of the 67 residents that had detectable levels of hydrocarbons including methane, had ratios lower than 100. This is suggestive that the dissolved gas could be thermogenic within these areas close to unconventional shale gas development. Of these 11 samples, 7 residents were within 2,500 feet of the nearest unconventional well pad, which is the distance established by oil and gas companies as households most susceptible to changes in water supply, if any occur at all. This methane and other hydrocarbons found within these private water systems in relation to the distances to unconventional well sites could have migrated into the shallow groundwater sources following several pathways. Methane can travel through natural pathways and conduits, moving upward from the deep sedimentary gas formations and oil and gas fields, and into the overlying soils and groundwater sources (Van Stempvoort et al., 2005). The migration of hydrocarbons in Butler County is primarily due to coal bed seams in the underlying bedrock, but can also come from faulty annulus cement, production, and casing failures, as well as migration through newly opened fractures and vertical pathways potentially created during the hydraulic fracturing processes (Darrah et al., 2014, Osborn et al., 2011).

5.3 Interpretation of Data and Geographical Mapping

Using the water well head GPS coordinates collected from the 121 residents who participated in the survey from 2011-2014, data maps were created in relation to Marcellus Shale unconventional oil and gas drilled wells (Figure 23). The base map in Figure 23 also display where the reference wells, or wells with no constituents over the EPA's (S)MCLs. This geospatial map illustrates the extent of unconventional wells developed within the county in the last few year, in relation to the samples acquired from the study.

Figure 24 shows the extent of the Marcellus Shale, and the three divisions including the Western Margin, Foldbelt, and Interior Unit where the majority of Marcellus Shale gas operations and activity have been developed. Butler County, PA is located on the edge of the Western Margin and the Interior Unit (Figure 25 and 26) splitting the county diagonally. Of the 387 wells drilled in Butler County the majority are developed in the Interior Unit where the approximate thickness of the Marcellus is 25 to 75 meters, which are the thickest regions in the county. The thickness, as well as the fractures and faults, and rock elasticity, allows production from the Marcellus to maximize the amount of oil and gas to be retrieved from the formation.

In addition to the maps displaying the extent of the unconventional shale wells throughout the county, Figure 27 presents the widespread legacy issues and development including conventional oil and gas operations, abandoned mine lands, and orphan and abandoned oil and gas wells. This map indicates that there have been substantial amounts of historic mining and oil and gas development before the unconventional shale gas development began in 2006. The legacy issues in Butler County have been a persistent source of contamination over the past several decades, and the recent development of oil and gas further increases the risks of water quality degradation.

To further examine the water chemistry data in relation to unconventional sites discussed in Section 4.4.2, geospatial maps were created showing elevated levels of some of the key constituents associated with the oil and gas industry from water samples collected (Figure 29). The map illustrates geospatial levels of A) iron, B) manganese, and C) barium, and their EPA regulated MCLs/SMCLs, in reference to unconventional drilled wells throughout the county. Both iron and manganese display widespread elevated levels across the county in close proximity from drilled wells, indicating that possible legacy issues in combination with new drilling activities could have played a role in contamination or disruption, influencing groundwater quality. Of the 121 residents that were within 2,500 feet of the nearest unconventional well pad, 28 (23%) households had high manganese levels, and 17 (14%) had elevated iron levels. For samples outside of the 2500-foot range, 40 (33%) residents had elevated levels of manganese and 41 (33.8) residents with high levels of iron. This explanation signifies that there are concerns with high iron and manganese in a range of distances from well pads throughout Butler County, as seen in the past from Poth in 1973.

The spatial maps also show high, elevated levels barium and strontium solely in the southeastern portion of Butler County, located where water samples were acquired in Clinton Township. Within this area, 5 samples within 2,500 feet of the nearest unconventional well pad had elevated levels of barium above 2 mg/L, in addition to all 5 samples containing high strontium levels, and multiple hydrocarbons within their water source. Using the spatial autocorrelation Moran's I tool, also showed strontium to be statistically significant in relation to the spatial distribution of the detections. The combination of elevated levels of barium and the detection of multiple hydrocarbons present is suggestive of some source of pollution, potentially from the nearby unconventional shale gas activity.

The 91 participants that were involved in the subset sample with all parameters tested for including the suite of light hydrocarbons were plotted as well, showing where each of the hydrocarbons were found present in relation to shale gas activity (Figure 30). The spatial maps in Figure 30 display that all six hydrocarbons tested for, methane, ethane, propane, ethene, propylene, and butane, were detected in water samples across southern Butler County. Only methane has concentrations of concern according to the PA DEP, which state that levels in a drinking water source greater than 7 mg/L is a concern. Therefore, in Figure 30, map (A) has refined that concern the legend. The most common hydrocarbons found in the water sampled collected were methane and ethane, shown throughout all locations in Butler County. The water quality analysis of the townships within Butler County indicate that Middlesex Township contained water samples with detections of all six hydrocarbons present in the water source, including high levels of iron, manganese, and strontium. Clinton Township was another area where elevated levels of iron, manganese, strontium, and barium were detected, along with present levels of methane, ethane, and propylene.

Even though the residents within close proximity to the unconventional wells, had trace amounts of hydrocarbons and elevated levels of inorganics such as barium, strontium, iron and manganese, there is no indication or definitive migration of stray gas or constituents that could have entered shallow aquifers from failed production cases, faults in cement and annulus, or fractures generated from the hydraulic fracturing processes (Darrah et al., 2014, Harrison, 1983, Murray, 2013, Osborn et al., 2011).

5.4 Case Study: Chemical Parameters within a Community in Southern Butler County, PA

Water chemistry data from 10 residents living in the same community who have had multiple samples acquired over the period of the research study from 2011 to 2014 were further studied and examined for constituents including A) sodium, B) chloride, C) iron, D) manganese, E) calcium, F) strontium, G) barium, and H) bromide, shown in Figure 22. The temporal plots help distinguish and correlate increases or decreases of constituents with different residents sampled in close proximity areas to unconventional oil and gas activity. Several plots show correlation between households include Plot A, where sodium concentrations from House 5 and House 3 elevate during the same timeframe. In Plot C, iron levels spike for House 8 and House 9 during a similar sampling time. In Plot D, manganese levels rise significantly over time in House 1, which positively correlate with a similar rise with House 8. In Plot F and Plot G, the strontium and barium levels in House 5 spiked dramatically simultaneously when compared to the other samples taken within the community. This raises concerns with possible disturbances to that water source. For Plot H, bromide levels throughout several houses seem to increase and decrease concurrently, possibly due to the seasonality of sampling in the area. By monitoring several water sources within the same community, the concentration of the different elements and groundwater flow can be better understood with regards to contamination.

Section 6: Summary and Future Direction

Anthropogenic activity throughout Butler County including the past and recent development of oil and gas activity, has posed challenges to protection and management for the environment. In addition to legacy issues and past anthropogenic activity throughout Butler County, there has been a correlation with the increase of unconventional oil and gas activity, to the complaints regarding water quality and quantity issues in communities that have been exposed to the development. Not only are residents complaining of water quality issues, but the issue has resulted in a greater awareness of water quality issues, and the need to protect water resources.

Throughout Butler County, there have been hundreds of oil and gas wells that have been left abandoned and improperly capped, as well as historic coal mining activities, and other industrial and agricultural business activities. More recently, there have been 387 unconventional wells drilled since the first unconventional well drilled in early 2006, with 318 of these wells still active today (PA DEP, 2015). Since the drilling initiated, there have been 83 violations throughout the county (PA DEP, 2015). This development has led to a study of groundwater throughout the southern portion of the county where the majority of the drilling has been concentrated. Ongoing research performed from 2011 to 2014 throughout southern Butler County has attributed to acquiring about 238 water samples from 121 residents who participated in a survey regarding changes in their water quality and quantity. Survey results showed that 48% of the participants reported to have some sort of water quality issue (color, smell, taste), or quantity issue (reduced flow) since the development has entered their communities.

Water chemistry results indicate that 86% of the wells sampled contained one or more contaminants exceeding the Primary or Secondary Maximum Contaminant Levels, with manganese (56%), iron (47%), fluoride (18%), TDS (18%), pH (17%), aluminum (17%) the most common. Within the 121 total participants, the subset sample of 91 residents comprised of a suite of light hydrocarbon testing, 73.6% were detected to contain one or more hydrocarbons within their well water, and 68.1% had both hydrocarbons detected and contained constituents that were above MCLs or SMCLs.

These indications suggest that the quality of drinking water sources throughout southern Butler County are not a reliable drinking water source, and sources used for consumption should be tested and treated before use. The increased development of shale gas activity in combination to historic legacy issues with abandoned mine lands, improperly abandoned oil and gas wells, and poses an increased risk of contamination to shallow aquifers. The natural fractures and new fractures created by unconventional shale gas development and processes could potentially be contributing to the upward migration of contaminants into groundwater sources. In order to determine this type of contamination, regular monitoring and water testing should be applied in these highly developed areas.

The results of the study support the hypothesis, that the groundwater sources in Butler County have been impacted from anthropogenic activity throughout the county. There are a significant amount of households (86%) that have water that exceeds MCLs and SMCLs by one or more the constituents set by the EPA. The use of chemical ratios (i.e., Cl:Br, Na:Cl, and Ba:Cl to Br:SO_4) and additional water chemistry data proved to be an efficient method in determining the varying sources of contamination throughout the county. However, the significant amounts of various human activities and industrial development over the past few decades creates complex issues with source identification. The extensive amounts of recent unconventional shale gas development throughout the county do pose additional challenges in protection of the groundwater supplies and to the health of residents in close proximity. The processes and development by the industry increases the potential risks of surface and groundwater contamination, as well as other negative environmental and social effects. Ongoing monitoring and water testing projects should be incorporated in future research in order to determine if the hydraulic fracturing process cause contamination to groundwater and lead to harmful water quality changes.

Limitations for this research and study including the lack to performing ongoing monitoring for all 121 participants, which could have helped identify temporal changes, in addition to changes corresponding to oil and gas activity. Future research for this project could involve the continuous monitoring of several groundwater wells in relation to areas before human activities such as unconventional drilling takes place. This continuous collection of data could show tracers that help identify sources of contamination and the differences between groundwater and migrated produced water from the industry, for example levels of barium and strontium. More research could be focused on distinguishing through elements involved with high TDS, including Ba, Sr, Cl, Ca, Br, Na, and radioactive Ra, which have the ability to help distinguish between naturally occurring and anthropogenic sources of contamination (Kolesar Kohl, 2014, Lautz, et al., 2014). The use of chemical ratios (Cl:Br, Na:Cl, and Ba:Cl to Br:SO_4 ratios) have shown to help distinguish between different sources of pollution as well (Davis, et al., 1998, Katz, et al., 2011, Mullaney et al., 2009, Panno et al., 2002). Future direction additionally could involve trace metal and isotopic research in groundwater where elevated concentrations of constituents are found (Liermann et al., 2011). Isotopes of strontium and methane (biogenic versus thermogenic), can serve as effective indicators of source contamination, and future research and investigation could help determine if the contamination is caused by anthropogenic activities or released naturally (Darrah et al., 2014, Osborn et al., 2011).

In addition to contamination issues, new and improved policies and water management practices should be developed for residents using well water and groundwater for drinking use. This research has created awareness and discussion for the many residents that are mainly unaware of the contamination and concentrations of certain constituents in their groundwater drinking water supplies. Another issue regarding the policy involved, focuses on wells constructed throughout the county that may not be constructed properly or monitored efficiently, which is necessary in order to maximize the amount of clean drinking water available in the aquifers. The EPA's Wellhead Protection Program should be revised and modified to inform residents on what sources of pollution are in the area, and what prevention measures to take. Water wells in areas of high anthropogenic activity, such as in areas with high oil and gas operations should be properly constructed and maintained on a regular basis to ensure the overall integrity of the well, and limiting the risks of groundwater contamination (NGWA, 2011).

The use of these geochemical ratios are an effective tool in identifying sources of contamination and should be implemented into new policies that help with source identification for government agencies. The data reflects that regulatory frameworks and construction for drinking wells should be more strictly regulated to ensure potential contamination measures are prevented. Using the same data collected as the PA DEP, but including these different tools and analyses, could help determine a more effective understanding and indicators of contamination. The concentration of different metals is simply not enough to determine and distinguish sources of pollution. Future tools could also combine statistical models with residents who have constituents above drinking water standards. Models such as Recursive Partitioning or RPART and regression tree analysis, can further breakdown and make correlations between constituents elevated above the (S)MCLs and detectable levels of hydrocarbons, much like the flowchart created in Figure 13.

With the recent increase in development of unconventional shale gas extraction, wastewater treatment and disposal methods are considered a significant issue of the present and future, and should be prioritized to ensure that public safety and the environment will be protected (Murray, 2013, Vidic et al., 2013). The differences in shale gas development locations and geochemistry of the subsurface formations result in varying chemicals associated with solid and fluid waste, posing challenges for treatment and disposal facilities. Research could involve testing for both wastewater constituents such as flowback and produced water, solid constituents, including drill cuttings, and the monitoring of groundwater sources of organics, inorganics, and hydrocarbons, in order to obtain an extensive grasp on the effects of this type of energy industry.

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Appendix A: Letter of Consent Form

DUQUESNE UNIVERSITY
BAYER SCHOOL OF NATURAL AND ENVIRONMENTAL SCIENCES
CENTER FOR ENVIRONMENTAL RESEARCH & EDUCATION

331 FISHER HALL
600 FORBES AVENUE
PITTSBURGH, PA 15282
TEL 412.396.4367
FAX 412.396.4092
www.duq.edu/environmental-science

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE: Well Water Survey of Six Counties in Western Pennsylvania

INVESTIGATOR: John F. Stolz, Professor
Center for Environmental Research and Education
Duquesne University, Pittsburgh PA 15282
Phone: 412 396 4367 Fax: 412 396 4092
stolz@duq.edu

ADVISOR: (if applicable:)

SOURCE OF SUPPORT: Heinz Endowments, Colcom Foundation

PURPOSE: In response to the recent incidents in water well quality changes in the area, we are undertaking a survey to determine if there is a pattern to these disturbances and how it relates to the local hydrology. Our goal is to use GIS to map the location of water wells within the local watershed in an effort to locate the source and mechanism of contamination.

YOUR PARTICIPATON: You will be asked 6 questions regarding your water quality and quantity. You will also be asked if you have had previous water testing done and whether you'd be willing to share those results. We may also request a sample of your well water for testing either at the time of the survey or at a later date.

RISKS AND BENEFITS: There are no known risks beyond those of everyday life.

COMPENSATION: There is no compensation for participating in the survey.

CONFIDENTIALITY: All information provided and collected will be confidential. Participants will not be identified in any report or summary of the surveys released.

RIGHT TO WITHDRAW: You may withdraw from the study at any time and we will withdraw your data as well.

SUMMARY OF RESULTS: You will be provided a summary of your well water test results that we conduct and an explanation of these results.

VOLUNTARY CONSENT: I have read the above statements and understand what is being requested of me. I also understand that my participation is voluntary and that I am free to withdraw my consent at any time, for any reason. On these terms, I certify that I am willing to participate in this research project.

I understand that should I have any further questions about my participation in this study, I may call Dr. Joseph, Chair of the Duquesne University Institutional Review Board (412-396-1151).

Please feel free to contact me (Dr. Stolz) if you have any questions (412 396 4367; stolz@duq.edu)

SIGNATURES: Both the researcher and subject should sign, and each should hold a copy with original signatures.

________________________ ____________
Participant's Signature Date

________________________ ____________
Researcher's Signature Date

Appendix B: Survey Questionnaire

Address: ____________________________ County: ____________________

GPS Coordinates: ____________________ ____________________

1. Do you have well water and where is your well located?
2. What kind of well is it (e.g. artesian, rotary, cable tool)?
3. Do you know how deep the well is and have you noticed a change in your well depth?
4. Have you noticed any change in water quality (taste, smell, color) and if so when?
5. Have you noticed any change in the water flow or quantity?
6. Have you had the water tested and would you be willing to share those results?

Notes: ____
____
____
____

Appendix C: YSI Field Data Sheet

YSI DATA SHEET

Address: **Well GPS:**
Date:
Time:
County:
Township:

Test #1		Test #2		Average
Temp (ºC)		**Temp (ºC)**		
DO (%)		**DO (%)**		
DO (mg/L)		**DO (mg/L)**		
pH		**pH**		
Cholride (mg/L)**		**Cholride (mg/L)****		
Pressure (mmHg)		**Pressure (mmHg)**		
Spf. Cond.(µS/cm)		**Spf. Cond.(µS/cm)**		
Cond. (µS)		**Cond. (µS)**		

Notes:

1 **Do you have well water and where is your well located?**

2 **What type of well is it? (e.g. artesian, rotary, cable tool)?**

3 **Do you know how deep the well is?**
Have you noticed a change in your well depth?

4 **Have you noticed any change in water quality, if so when?**

5 **Have you noticed any change in the water flow of quantity?**

6 **Have you had the water tested?**
Would you be willing to share those results?

Notes:

Appendix D: Survey Results for all 121 Butler County Participants
* Industry predrill tested; ^^ DEP tested; ^ Independently tested;

Highlighted areas- Residents (91) who were in subsample tested for light hydrocarbons.

Resident	**Sample Number(s)**	**Water Source**	**Well Type**	**Well Depth (ft.)**	**Change in water**		**Prior Testing**
					Quality (smell, color, taste)	**Quantity (flow)**	
1	MS007, 026, 027, 032, 033, 034	Well	Rotary	330	Yes (color change: black)	Yes (reduced flow)	Yes
2	MS010, 019, 022	Well	Rotary	480	Yes (smell)	No	Yes*
3	MS009, 014, 051, 073, 085, 098, 114, 143, 157, 165 1-2, 255, 319, 333, 407, 410, 411, 420, 425, 426	Well	Drilled	105	Yes	Yes	Yes
4	MS015, 017, 050, 115, 182, 202, 414	Well	Dug	200	Yes (color, smell)	Yes	N/A
5	MS052, 120, 160, 187, 205, 300, 344	Well	Unknown	Unknown	Yes	N/A	N/A
6	MS053, 184, 206, 299, 345, 416	Well	Unknown	700 and 1000	Yes (burning sensation)	No	N/A
7	MS054	Well	Unknown	Unknown	N/A	Yes (flow change)	N/A
8	MS023, 024, 55, 58, 204, 235, 235ac, 346, 419	Well	Cable Tool	195	Yes (color)	No	N/A
9	MS056	Well	Unknown	120	N/A	N/A	Yes^
10	MS057, 072, 301, 324, 338, 357, 412	Well	Cable Tool	185	No	No	Yes*^
11	MS125	Well	Rotary	200	Yes (color: rust color and smell: sulfur)	No	No

12	MS065, 068, 086, 101, 116, 145, 161, 186, 201, 231, 256, 269, 302, 320, 334, 401, 413, 424	Well	Unknown	178	Yes (smell, doesn't drink)	No	Yes*
13	MS066	Well	Unknown	275-375	Yes (smell)	No	Yes*
14	MS067, MS335	Well	Drilled	125	No	No	No
15	MS071, 118, 199, 233, 337, 408	Well	Cable Tool	140	No	Yes (reduced flow)	Yes*
16	MS074, 092, 121, 198, 234	Well	Unknown	125	No	No	Yes*
17	MS087, 272	Well	Cable Tool	130	Yes (smell: sulfur)	No	No
18	MS088	Well	Pounded	165	Yes (color change: brown/yellow)	No	Yes^
19	MS089	Well	Unknown	Unknown	No	No	No
20	MS090	Well	Unknown	Unknown	Yes (color: rust color and smell)	No	Yes^^
21	MS091	Spring	Unknown	Unknown	Yes (has improved)	No	Yes
22	MS093	Well	Unknown	350	Yes (smell: sulfur)	Yes (reduced flow)	Yes*
23	MS099	Well	Pounded	390	Yes (smell, taste, color: orange/red)	No	Yes^^
24	MS100	Well	Unknown	90	Yes (smell)	No	Yes
25	MS018, 020, 102, 270, 321	Well	Drilled	90	Yes (smell)	Yes (lower quantity)	Yes*
26	MS103	Well	Pounded	80	No	No	N/A
27	MS104	Well	Pounded	80	No	No	Yes*
28	MS105	Well	Unknown	Unknown	N/A	N/A	N/A
29	MS106, 336	Well	Unknown	190	No	No	Yes
30	MS107	Well	Unknown	150	Yes (taste)	No	Yes
31	MS108	Well	Rotary	365	No	Yes (pressure change)	No
32	MS113	Well	Cable Tool	185	Yes (color change: rust color)	No	No
33	MS117	Well	Rotary	300	No	Yes (running out)	No

34	MS119	Well	Rotary	350	Yes (taste, smell, color)	Yes (dried up)	Yes*
35	MS124	Well	Unknown	Unknown	Yes (smell)	Yes (pressure/flow low)	No
36	MS126	Well	Drilled	380-400	Yes (smell: sulfur)	No	Yes*
37	MS127, MS200, MS415	Well	Unknown	125	Yes (color)	No	Yes*
38	MS128, MS203	Well	Unknown	200	Yes (smell: sulfur)	No	No
39	MS021, 158	Well	Unknown	175	Yes (smell, color, taste)	No	Yes*
40	MS159	Well	Rotary	290	Yes (smell, color)	Yes	Yes
41	MS164	Well	Unknown	Unknown	Yes (smell: sulfur)	No	No
42	MS169	Well	Rotary	125	No	No	Yes
43	MS171, 172, 173, 409, 422, 427	Well	Unknown	75	No	No	Yes*
44	MS174	Well	Drilled	160	No	No	Yes*
45	MS175, 406	Well	Artesian	100	No	No	Yes*
46	MS183	Well	Unknown	Unknown	Yes (color, and sediment)	No	Yes*^
47	MS188	Well	Drilled	150	Yes (color)	Yes (reduced flow)	No
48	MS190	Well	Pounded-Drilled	145	Yes (smell: iron)	No	Yes^
49	MS192	Well	Drilled	300	No	No	Yes*
50	MS193	Well	Drilled	Unknown	No	No	Yes^
51	MS194	Well	Drilled	> 100	No	No	Yes*
52	MS195	Well	Unknown	Unknown	N/A	N/A	N/A
53	MS207, 318	Well	Unknown	Unknown	No	No	Yes*
54	MS016	Well	Unknown	110	Yes	Yes	Yes*
55	MS209	Well	Pounded	70-100	Yes (spurts of air)	No	No
56	MS210	Well	Drilled	120	Yes (smell: sulfur)	No	Yes^
57	MS211	Well	Drilled	160	No	No	No
58	MS212	Well	Unknown	30	No	No	Yes^
59	MS213	Well	Drilled	150	No	No	Yes
60	MS214	Well	Drilled	Unknown	No	No	Yes*
61	MS215	Well	Drilled	> 100	No	No	Yes*
62	MS221	Well	Drilled	75	Yes (color)	No	N/A

63	MS222	Well	Drilled	225	No (spurts of air out of faucet)	No	Yes*
64	MS223	Well	Drilled	200	No	No	Yes^
65	MS224	Well	Drilled	Unknown	Yes (color: cloudy, smell: sulfur)	No	No
66	MS225	Well	Unknown	Unknown	N/A	N/A	N/A
67	MS226	Well	Drilled	121	No	No	No
68	MS227, 228	Well	Drilled	< 100	No	No	No
69	MS229	Well	Drilled	600	Yes	No	Yes*
70	MS230	Well	Cable Tool	113	Yes (color, sediment debris)	No	No
71	MS232, 232ac, 257, 271, 303, 322, 402	Well	Pounded	135	Yes (color, smell, oil haze, sediment)	No	Yes*
72	MS249, 253	Well	Drilled	80	Yes (color)	No	Yes^
73	MS254	Well	Drilled	80	Yes (color)	No	Yes^
74	MS273	Well	Drilled	65	Yes (smell)	Yes (quantity)	No
75	MS274	Well	Drilled	160	No	No	Yes
76	MS275	Well	Drilled	387	Yes (taste)	No	No
77	MS276	Well	Drilled	101	No	No	Yes^
78	MS277	Well	Drilled	275	No	No	No
79	MS297	Well	Unknown	300	No	No	No
80	MS304	Well	Unknown	320	No	No	No
81	MS298, 318	Well	Unknown	Unknown	N/A	N/A	N/A
82	MS323	Well	Unknown	Unknown	N/A	N/A	N/A
83	MS350	Well	Unknown	300	No	No	Yes
84	MS351, 352, 353, 354, 355, 356	Well	Drilled	200	No	No	Yes
85	MS358	Spring	Unknown	shallow, 20 gallons in basin	No	No	Yes*^
86	MS360	Well	Drilled	80	No	No	Yes*
87	MS361	Well	Drilled	300	No	No	Yes
88	MS375	Well	Unknown	Unknown	N/A	N/A	N/A
89	MS376	Well	Unknown	Unknown	N/A	N/A	N/A
90	MS377	Well	Drilled	70	No	No	No

91	MS378	Well	Drilled	200	No	No	No
92	MS379	Well	Drilled	212	No	No	Yes^
93	MS380	Well	Rotary	300	Yes (color: iron)	Yes (reduced flow)	Yes
94	MS381	Well	Rotary	200	No	Yes	Yes
95	MS382	Well	Pounded	175	Yes (color, sediment)	No	Yes
96	MS383	Well	Drilled	125	No	No	No
97	MS384	Well	Drilled	Unknown	No	No	Yes^
98	MS385	Well	Drilled	Unknown	No	No	Yes^
99	MS386	Well	Drilled	Unknown	No	No	No
100	MS388	Well	Drilled	200	No	No	Yes
101	MS389	Well	Drilled	90	Yes (smell: sulfur)	No	Yes*
102	MS390	Well	Drilled	Unknown	Yes (smell, taste, skin irritation)	No	Yes^^
103	MS391	Well	Drilled	Unknown	No	No	Yes^
104	MS392	Well	Drilled	100	No	Yes (reduced flow)	No
105	MS393	Well	Drilled	265	No	No	Yes
106	MS394	Well	Unknown	80	No	No	Yes^
107	MS395	Well	Drilled	Unknown	No	No	No
108	MS396	Well	Unknown	Unknown	N/A	N/A	N/A
109	MS397	Well	Drilled	110	No	No	Yes^
110	MS398	Well	Drilled	Unknown	No	No	No
111	MS399	Well	Drilled	Unknown	No	No	No
112	MS400	Well	Drilled	160	Yes (smell: sulfur)	No	No
113	MS403	Well	Pounded	175	Yes (color)	No	No
114	MS404	Well	Dug	Unknown	No	No	No
115	MS405	Well	Unknown	60	No	No	No
116	MS417	Well	Unknown	Unknown	N/A	N/A	N/A
117	MS418	Well	Drilled	120	Yes (color, smell, oil haze)	No	Yes*
118	MS421	Well	Unknown	Unknown	No	No	No
119	MS423, 431	Well	Pounded	60-80	Yes (smell)	No	Yes*
120	MS429	Well	Unknown	Unknown	Yes (color: brown)	No	Yes*
121	MS430	Well	Drilled	120	Yes (smell: sulfur)	No	Yes*^^

Appendix E: Minimums, Maximums, Averages, and Number of Samples that Exceeded the EPA's MCLs

Parameter	Min	Max	Average	EPA MCLs	# Exceeded MCLs
Temp (°C)	1.75	26.10	13.37	-	-
DO (%)	5.05	104.30	35.88	-	-
DO (mg/L)	0.50	15.68	3.87	-	-
pH	5.06	8.80	7.08	6.5-8.5	33
Pressure (mmHg)	712.20	750.00	729.13	-	-
Spf. Cond (µS/cm)	37.00	1984.00	485.38	-	-
Cond. (µs)	62.60	1461.00	401.09	-	-
TDS based on SpC (mg/L)	0.00	1289.60	312.48	500	38
Fluoride (mg/L)	0.01	6.72	2.01	4	46
Chloride (mg/L)	0.48	329.90	43.87	250	2
Nitrite (mg/L	0.00	0.00	0.00	3.3	0
Bromide (mg/L)	0.02	3.44	0.66	-	-
Nitrate (mg/L)	0.05	55.89	2.39	44.3	1
Phosphate (mg/L)	0.15	10.76	1.24	-	-
Sulfate (mg/L)	0.18	178.30	27.80	250	0
Li (mg/L)	0.00	0.03	0.01	-	-
B (mg/L)	0.00	0.23	0.04	-	-
Na (mg/L)	3.60	207.30	32.19	-	-
Mg (mg/L)	0.08	40.87	9.05	-	-
Al (mg/L)	0.00	0.53	0.04	0.05	24
Si (mg/L)	0.40	19.73	7.27	-	-
P (mg/L)	0.00	0.32	0.06	-	-
K (mg/L)	0.08	4.74	1.31	-	-
Ca (mg/L)	0.41	130.25	43.93	-	-
Ti (mg/L)	0.00	0.08	0.00	-	-
V (mg/L)	0.00	0.00	0.00	-	-
Cr (mg/L)	0.00	0.03	0.00	0.1	0
Mn (mg/L)	0.00	4.64	0.27	0.05	140
Fe (mg/L)	0.00	20.10	1.32	0.3	99
Co (mg/L)	0.00	0.02	0.00	-	-

Ni (mg/L)	0.00	0.02	0.00	-	-
Cu (mg/L)	0.00	0.34	0.02	1	0
Zn (mg/L)	0.00	1.51	0.07	5	0
As (mg/L)	0.00	0.03	0.00	0.01	1
Se (mg/L)	0.00	0.02	0.00	0.05	0
Rb (mg/L)	0.00	0.00	0.00	-	-
Sr (mg/L)	0.00	2.49	0.34	-	-
Mo (mg/L)	0.00	0.00	0.00	-	-
Ag (mg/L)	0.00	0.10	0.00	0.1	1
Cd (mg/L)	0.00	0.00	0.00	0.01	0
Sn (mg/L)	0.00	0.09	0.01	-	-
Sb (mg/L)	0.00	0.00	0.00	0.006	0
Ba (mg/L)	0.00	7.03	0.31	2	6
W (mg/L)	0.00	0.00	0.00	-	-
Pb (mg/L)	0.00	0.03	0.00	0.02	
U (mg/L)	0.00	0.00	0.00	0.03	0

Appendix F: YSI-Pro Plus multimeter water chemistry data

Sample	Temp-(°C)	DO-(%)	DO-(mg/L)	pH	Pressure-(mmHg)	Spf.-Cond-(µS/cm)	Cond.-(µs)	TDS-based-on-SpC-(mg/L)
MS007	-	-	-	7.4	-	151	-	98.2
MS009	-	-	-	7.73	-	255	-	165.8
MS010	-	-	-	7.68	-	344	-	223.6
MS014	-	-	-	7.79	-	173	-	112.5
MS015	-	-	-	7.58	-	463	-	301.0
MS016	-	-	-	7.93	-	37	-	24.1
MS017	-	-	-	8.18	-	116	-	75.4
MS018	-	-	-	7.72	-	268	-	174.2
MS019	-	-	-	8.45	-	166	-	107.9
MS020	-	-	-	8.04	-	263	-	171.0
MS021	-	-	-	7.9	-	412	-	267.8
MS022	-	-	-	7.65	-	365	-	237.3
MS023	-	-	-	7.77	-	332	-	215.8
MS024	-	-	-	7.49	-	333	-	216.5
MS026	-	-	-	7.29	-	316	-	205.4
MS027	-	-	-	7.01	-	317	-	206.1
MS032	-	-	-	7.11	-	290	-	188.5
MS033	-	-	-	7.31	-	250	-	162.5
MS034	-	-	-	7.15	-	260	-	169.0
MS050	13.40	16.90	1.70	7.84	725.90	1008.50	786.00	627.30
MS051	11.95	21.00	2.25	7.25	725.00	306.00	230.15	191.60
MS052	18.50	67.10	12.11	7.05	724.50	481.60	421.40	294.40

MS053	22.70	40.95	3.50	8.56	724.90	778.00	744.50	492.10
MS054	15.20	51.55	4.93	7.51	724.20	257.00	208.80	162.60
MS055	-	-	-	6.91	-	333.50	-	216.78
MS056	12.20	42.60	4.49	7.99	725.80	214.10	162.00	129.00
MS057	12.90	25.90	2.64	7.26	724.20	421.90	325.00	269.90
MS058	-	-	-	6.59	-	408.50	-	265.53
MS064	12.70	26.80	2.70	6.97	731.90	528.20	403.60	346.45
MS065	14.00	82.80	8.39	7.06	731.74	643.00	508.00	426.40
MS066	12.30	28.80	2.99	6.56	731.20	380.50	290.50	234.98
MS067	12.40	56.35	5.93	7.21	732.00	417.50	322.10	265.14
MS068	13.20	41.25	4.27	6.61	731.50	895.50	693.50	589.55
MS071	17.30	54.60	5.20	6.67	730.60	311.70	266.50	198.71
MS072	14.00	29.25	2.97	6.97	730.10	392.30	311.60	257.60
MS073	12.90	19.10	1.99	7.03	730.40	313.90	242.10	203.65
MS074	14.10	27.10	2.77	6.88	730.20	342.70	272.00	216.00
MS085	11.30	17.60	1.91	7.50	726.00	276.80	204.40	175.57
MS086	13.05	27.70	2.89	7.00	724.75	902.50	696.50	581.10
MS087	10.65	56.80	6.28	7.30	725.20	307.10	222.80	192.73
MS088	14.75	16.55	1.68	7.14	724.90	387.25	311.70	248.50
MS089	10.60	56.20	6.23	7.58	725.80	354.70	257.20	232.90
MS090	42.30	30.85	1.92	7.24	725.60	509.50	675.00	312.26
MS091	11.10	46.40	5.09	7.60	724.90	500.90	367.80	556.40
MS092	12.10	30.40	3.22	7.61	724.70	317.50	239.40	203.91
MS093	11.20	35.90	3.91	7.59	724.40	360.00	265.30	234.20
MS098	11.50	35.10	3.78	7.45	726.50	326.20	242.50	212.03
MS099	11.40	22.90	2.46	7.27	726.40	828.00	614.00	543.40
MS100	11.05	21.75	2.33	7.21	727.00	528.20	387.80	339.17
MS101	16.80	49.40	4.78	6.89	725.50	706.00	595.00	513.50
MS102	12.30	63.40	6.72	6.92	726.20	541.90	411.00	352.30
MS103	9.20	76.90	8.84	6.71	727.50	242.10	169.40	161.66
MS104	13.10	31.10	3.26	6.92	726.20	244.40	189.10	161.85
MS105	12.60	77.60	8.26	6.86	725.70	204.60	156.20	136.96
MS106	12.10	76.70	8.23	6.83	725.70	314.60	237.10	211.97
MS107	10.20	65.90	7.20	6.42	723.20	214.40	154.00	138.45
MS108	17.00	63.50	6.18	6.81	725.00	337.50	285.10	221.00
MS113	7.30	60.50	7.27	7.92	738.70	256.90	170.10	174.79
MS114	10.80	33.70	3.71	7.65	734.70	327.40	238.30	217.36
MS115	10.60	55.70	6.20	7.90	735.30	928.00	672.00	605.15
MS116	11.90	34.80	3.72	7.09	733.90	793.00	595.00	488.80
MS117	10.85	9.00	0.99	7.23	733.90	807.00	588.00	524.55
MS118	10.70	39.60	4.32	7.40	734.10	301.10	218.70	197.34
MS119	-	-	-	-	-	-	-	204.75
MS120	7.40	54.80	6.56	7.18	732.90	492.20	326.90	315.25
MS121	12.60	31.50	3.32	7.16	732.60	300.50	229.30	196.30

MS124	11.50	34.50	3.73	7.14	725.00	1290.50	959.50	818.35
MS125	11.80	16.80	1.70	7.17	724.50	491.00	367.60	336.83
MS126	12.00	18.15	1.95	6.76	724.70	425.40	319.80	276.06
MS127	10.70	37.80	4.16	6.61	725.10	536.00	389.20	352.17
MS128	6.80	8.60	1.04	6.82	724.50	280.60	183.20	184.41
MS143	10.90	33.80	3.72	7.15	712.90	343.80	251.10	219.90
MS145	13.40	54.40	5.68	6.89	712.20	482.70	375.80	310.25
MS157	11.30	34.70	3.80	7.43	731.20	325.40	240.10	187.07
MS158	10.30	104.30	11.63	7.46	731.30	275.70	198.40	172.30
MS159-	15.60	34.00	3.38	7.10	730.50	443.70	363.90	269.69
MS160	9.90	33.90	3.79	7.87	730.90	665.00	474.30	403.00
MS161	11.90	34.10	3.66	7.18	730.00	801.00	601.00	452.40
MS164	12.00	10.60	1.14	6.58	723.80	263.30	198.00	174.98
MS165 1	11.30	19.20	2.09	7.57	722.10	318.50	235.40	205.86
MS169	14.00	5.75	0.59	8.74	728.70	820.00	649.00	533.00
MS171	1.75	30.20	3.19	7.14	-	377.00	-	245.05
MS172	9.96	97.80	11.01	6.55	-	149.50	-	97.18
MS173	9.15	101.50	11.62	6.11	-	98.50	-	64.03
MS174	13.33	19.60	2.03	6.53	-	441.50	-	286.98
MS175	12.96	11.90	1.25	6.98	-	312.00	-	202.80
MS182	12.10	17.10	1.83	8.44	729.70	972.00	733.00	624.00
MS183	11.10	20.40	2.24	7.38	729.80	1429.50	1052	709.80
MS184	13.30	55.40	5.75	8.48	729.40	787.00	613.00	512.20
MS186	17.10	20.10	1.85	7.38	728.20	1005.00	856.00	613.60
MS187	12.70	55.00	5.79	7.15	728.30	487.20	373.60	314.54
MS188	19.65	18.15	1.61	7.16	730.90	273.70	246.85	179.73
MS190	20.25	29.65	2.67	7.59	730.4	341.8	311.9	-
MS192	14.7	35.65	3.54	7.46	730.6	623.25	502.3	405.11
MS193	17.2	26.45	2.52	7.53	730.2	658.5	562.5	428.03
MS194	15.05	17.6	1.77	7.59	730.75	365.95	297.8	237.87
MS195	14.95	43.0	4.32	7.61	730.8	386.7	313.2	251.36
MS198	14.80	23.20	2.34	7.00	727.70	212.80	253.70	225.20
MS199	14.60	47.20	4.72	6.78	728.30	271.90	218.60	194.70
MS200	17.40	13.40	1.28	6.50	728.20	489.90	419.20	343.90
MS201	17.10	17.50	1.68	6.83	727.50	684.00	582.00	485.60
MS202	14.40	41.50	4.19	8.19	728.80	941.00	753.00	750.80
MS203	14.40	29.50	2.99	7.46	727.60	252.60	201.60	180.60
MS204	17.30	17.90	1.70	6.82	727.60	324.80	277.40	233.20
MS205	15.70	78.30	7.68	6.97	727.70	412.30	339.80	255.00
MS206	15.50	39.40	3.93	8.80	727.90	721.00	590.00	501.80
MS207	19.70	19.90	1.82	6.60	729.40	145.60	131.00	93.40
MS209	16.50	41.20	4.02	7.15	731.50	336.30	282.00	227.40
MS210	14.00	16.35	1.67	7.46	734.90	313.10	248.55	218.30
MS211	13.50	10.78	4.44	6.99	733.55	347.20	272.85	243.60

MS212	13.60	16.55	1.73	6.61	732.90	869.50	679.50	579.20
MS213	14.40	7.10	0.66	6.95	730.70	369.20	248.10	252.30
MS214	15.00	15.90	1.59	7.11	730.80	630.00	510.00	415.40
MS215	12.95	74.75	15.68	7.14	734.75	536.65	413.40	369.20
MS221	12.00	56.40	6.05	7.04	725.85	491.70	369.90	319.61
MS222	18.80	8.65	0.80	7.25	731.65	401.40	354.05	260.91
MS223	13.60	71.35	7.39	7.57	727.30	405.00	322.45	263.25
MS224	13.70	11.55	1.19	7.02	725.80	284.80	219.80	185.12
MS225	15.50	27.05	2.72	6.91	725.95	242.75	198.45	157.79
MS226	13.85	14.30	1.46	7.36	731.05	423.60	333.85	275.34
MS227	16.00	11.10	1.09	7.37	729.55	349.55	289.40	227.21
MS228	16.20	61.60	6.02	5.74	729.50	478.30	400.00	310.90
MS229	14.35	7.45	0.76	7.79	730.95	1118.00	892.50	726.70
MS230	16.05	55.15	5.42	7.13	727.30	907.00	752.00	589.55
MS231	12.6	26	2.74	7.23	726.2	867	662	94.41
MS232	13.15	40.10	4.20	6.38	726.45	145.25	112.45	94.41
MS233	13.40	29.90	3.12	6.98	727.00	297.90	231.90	193.64
MS234	14.00	16.00	1.63	7.41	726.20	333.10	262.90	216.52
MS235	12.40	19.60	2.09	7.11	726.40	350.80	266.50	228.02
MS249	13.15	23.20	2.42	7.01	740.85	1273.50	985.00	827.78
MS253	12.20	26.50	2.83	6.98	750.00	1285.00	970.00	835.25
MS254	11.2	49.7	5.32	6.75	747.7	1984	1461	1289.60
MS255	10.3	21.9	2.41	6.89	724.3	319.7	229.4	207.80
MS256	26.1	19.9	1.6	6.82	723	833	845	541.45
MS257	10.1	40.1	4.47	6.12	723	86.8	62.6	56.42
MS269	18.60	22.70	2.11	6.85	718.00	590.00	518.00	383.50
MS270	11.90	44.10	4.47	6.43	718.90	494.60	371.70	321.49
MS271	9.20	42.70	4.88	5.81	718.60	149.70	104.80	97.31
MS272	5.60	41.30	5.13	6.15	718.70	222.10	140.40	144.37
MS273	12.20	55.70	5.98	6.63	720.15	387.85	293.60	252.10
MS274	9.55	55.20	6.28	6.54	728.30	212.80	150.35	138.32
MS275	9.45	44.40	5.05	6.68	728.00	342.25	241.35	222.46
MS276	10.90	13.30	1.45	7.00	729.95	455.70	333.30	296.21
MS277	5.80	68.70	8.58	7.09	729.60	504.65	311.45	328.02
MS297	11.65	39.25	4.24	6.68	731.10	349.05	260.40	226.88
MS298	13.85	37.45	3.57	7.38	724.95	432.95	341.2	281.42
MS299	8.90	10.40	1.19	8.77	724.80	794.00	552.00	516.10
MS300	8.6	67.1	7.8	7.25	724.4	460.3	317.2	299.20
MS301	11.9	39.9	4.28	7.1	724.6	345.6	259	224.64
MS302	11.2	32.3	3.51	6.78	724.2	1124	829	730.60
MS303	10.4	46.7	5.21	6.24	724.5	153.6	111	99.84
MS304	11.95	86.8	9.325	6.29	725.65	110.5	83.15	71.83
MS318	5.20	90.40	11.33	6.79	736.70	420.10	261.90	273.07
MS319	6.70	73.90	9.06	6.89	736.70	429.70	278.60	279.31

MS320	7.4	80.9	8.69	6.85	736.8	827	556	537.55
MS321	8.30	79.70	9.30	6.90	736.80	532.80	363.70	346.32
MS322	9.10	70.00	8.04	6.03	736.80	155.30	108.50	100.95
MS323	10.30	83.80	9.36	6.42	736.80	218.20	157.40	141.83
MS324	11.50	64.20	6.95	6.91	736.80	408.80	304.40	265.72
MS333	12.10	42.30	4.50	7.10	729.30	408.00	308.20	265.20
MS334	17.10	36.90	3.50	6.78	728.60	583.60	496.40	379.34
MS335	16.20	22.85	2.19	7.17	728.95	428.20	357.40	278.33
MS336	14.55	45.20	4.52	6.86	729.50	376.45	302.15	244.69
MS337	14.60	23.00	2.37	6.46	729.50	331.50	226.00	215.48
MS338	13.50	26.00	2.68	7.13	729.20	445.80	348.30	289.77
MS344	20.2	44.7	3.95	6.69	725.3	474.3	433.3	308.30
MS345	15.4	11.8	1.16	8.76	725.8	753	619	489.45
MS346	20.0	20.8	1.89	6.72	725.3	362.3	329.1	235.50
MS350	17.65	49.55	4.70	7.57	730.40	868.00	746.00	564.20
MS351	13.00	9.10	0.93	7.00	722.15	276.85	213.70	179.95
MS352	13.40	25.60	2.60	6.87	723.20	299.50	234.20	194.68
MS353	15.20	11.00	1.08	6.98	722.10	217.50	180.70	141.38
MS354	15.30	59.20	7.96	7.87	722.80	409.90	335.10	266.44
MS355	12.35	34.85	3.70	6.87	722.70	194.75	148.75	126.59
MS356	18.25	15.95	1.48	6.80	722.25	187.00	164.10	121.55
MS357	14.70	11.80	1.17	6.90	721.20	436.80	356.80	283.92
MS358	13.90	63.60	6.51	6.51	727.20	246.80	196.90	160.42
MS360	17.90	10.75	1.02	7.05	734.95	612.00	529.50	397.80
MS361	15.1	10.9	1.09	6.89	734.5	894	724	581.10
MS375	17.30	9.50	0.91	7.08	734.20	631.50	540.00	410.48
MS376	17.00	15.50	1.52	7.41	734.90	527.25	447.55	342.71
MS377	13.05	29.50	3.05	7.24	735.55	360.35	281.20	234.23
MS378	14.15	8.80	0.90	6.66	734.50	837.00	663.00	544.05
MS379	17.55	37.80	3.63	6.72	733.20	525.15	450.25	341.35
MS380	13.40	9.30	0.96	6.61	733.40	684.00	533.00	444.60
MS381	15.75	23.05	2.29	6.94	733.00	784.00	646.00	509.60
MS382	13.30	46.30	4.78	7.07	734.15	517.85	412.35	336.60
MS383	16.65	8.75	0.84	7.11	733.85	837.50	707.50	544.38
MS384	14.15	29.85	3.03	7.19	735.00	637.60	506.65	414.44
MS385	15.25	54.45	5.41	6.81	733.25	316.95	259.00	206.02
MS386	15.70	5.05	0.50	6.67	732.40	718.00	592.00	466.70
MS388	17.10	27.10	2.61	6.65	734.15	485.15	390.15	315.35
MS389	13.70	61.20	6.32	7.17	731.50	250.20	196.80	162.63
MS390	14.05	26.40	2.71	5.88	732.00	606.50	482.30	394.23
MS391	12.80	18.60	1.96	5.72	732.55	384.15	297.70	249.70
MS392	14.30	56.40	5.76	5.45	733.80	296.15	235.60	192.50
MS393	17.25	43.25	4.14	6.41	730.80	330.70	155.80	214.96
MS394	12.85	67.70	7.12	5.44	740.90	984.00	756.50	639.60

MS395	13.70	18.95	1.94	6.22	742.70	534.05	415.45	347.13
MS396	14.60	53.20	5.40	6.07	742.35	300.65	242.70	195.42
MS397	13.90	6.75	0.67	7.41	744.25	610.00	481.50	396.50
MS398	13.25	5.45	0.57	6.88	741.05	554.75	430.85	360.59
MS399	13.55	56.75	5.90	7.17	740.90	757.50	593.00	492.38
MS400	14.35	6.00	0.61	6.80	741.20	569.15	474.85	369.95
MS401	17.40	34.60	3.30	6.21	735.10	792.00	678.00	514.80
MS402	13.30	27.30	2.83	5.06	735.50	151.90	118.50	98.74
MS403	14.10	68.50	7.02	6.27	736.00	212.00	168.10	137.80
MS404	15.05	12.65	1.26	6.98	728.80	740.00	599.50	481.00
MS405	14.55	31.35	3.17	6.52	728.65	563.15	451.45	366.05
MS406	13.30	13.80	1.44	6.94	724.00	376.00	293.40	244.40
MS407	12.00	25.20	2.67	6.73	723.00	397.40	300.40	258.31
MS408	14.90	32.00	3.21	6.53	722.90	314.70	255.40	204.56
MS409	14.50	9.30	0.93	6.66	730.70	458.60	367.50	298.09
MS410	11.60	16.30	1.74	7.47	726.80	334.30	249.20	217.30
MS411	13.20	66.00	6.92	7.52	726.80	338.40	257.80	219.96
MS412	11.60	14.00	1.50	7.16	726.60	402.50	299.70	261.63
MS413	12.70	35.40	3.74	7.01	726.00	1030.00	794.00	669.50
MS414	11.80	27.90	3.01	7.94	727.30	922.00	689.00	599.30
MS415	14.40	15.10	1.64	6.90	726.60	527.40	420.00	342.81
MS416	12.10	45.50	4.67	8.72	726.90	743.00	561.00	482.95
MS417	12.60	27.25	2.87	7.58	726.70	508.50	388.10	330.53
MS418	12.85	14.55	1.53	7.29	726.70	705.50	542.50	458.58
MS419	13.20	42.00	4.34	7.33	725.70	329.80	256.10	214.37
MS420	11.50	-	-	6.66	724.00	316.00	234.00	205.40
MS421	12.30	5.65	0.61	6.32	737.90	512.05	389.15	332.83
MS422	11.80	28.90	3.17	6.22	738.30	408.00	303.10	265.20
MS423	13.80	46.40	4.80	8.21	729.65	676.00	531.50	439.40
MS424	25.60	31.60	2.57	6.86	720.40	1025.00	1033.00	666.25
MS425	4.50	98.00	12.50	7.85	721.00	383.00	233.00	248.95
MS427	13.50	16.40	1.66	7.10	727.80	483.90	377.60	314.54
MS428	11.80	61.50	6.65	6.71	722.00	159.80	127.30	103.87
MS429	21.10	22.70	2.02	6.19	719.60	1411.00	1302.00	917.15
MS430	8.10	35.15	4.11	6.77	720.30	314.75	213.20	204.59
MS431	9.40	24.00	2.71	8.70	723.30	808.00	569.00	525.20

Appendix G: ICP-MS Water Chemistry Data

Sample	ICPMS Analysis Date	Li (mg/L)	B (mg/L)	Na (mg/L)	Mg (mg/L)	Al (mg/L)	Si (mg/L)	P (mg/L)	K (mg/L)	Ca (mg/L)
MS007	8/28/11	0.001	bdl	22.7	4.2	0.13	6.2	0.14	2.5	20.8
MS009	9/19/11	0.004	bdl	6.9	6	bdl	12.5	bdl	0.7	35.1
MS010	9/19/11	0.007	bdl	124.2	2.4	bdl	9.8	0.25	0.9	13.3
MS014	9/22/11	0.0045	bdl	6.8	6.7	bdl	10.3	0.009	0.74	36.1
MS015	10/22/11	0.0039	0.001	152.9	4.1	bdl	7.5	0.027	0.5	20.2
MS016	10/22/11	0.0006	0.011	6.5	1.2	bdl	3.8	0.001	1.15	2.1
MS017	10/22/11	0.0001	bdl	32.6	0.8	bdl	1.1	0.036	bdl	6.3
MS018	10/22/11	0.0097	bdl	10	14.5	bdl	7.4	0.027	0.81	60.7
MS019	10/22/11	0.0044	bdl	66.2	1.2	bdl	6.4	0.262	0.43	10
MS020	-	0.0092	bdl	10.4	14.2	bdl	6.9	bdl	2.67	61.8
MS021	-	bdl	bdl	91.8	bdl	bdl	9.9	0.265	bdl	bdl
MS022	-	0.008	bdl	112.5	2.1	bdl	8.2	0.318	0.74	11.7
MS023	11/26/11	0.0069	bdl	7.4	3.7	bdl	8.6	0.017	0.32	41.8
MS024	11/26/11	0.0069	bdl	7.9	3.8	bdl	9.2	0.036	0.38	42.9
MS026	1/17/12	0.0055	bdl	28.2	3.2	bdl	12.3	bdl	0.33	25.9
MS027	1/17/12	0.0057	bdl	28.8	3.2	bdl	12.6	bdl	0.42	24.6
MS032	5/12/12	0.0057	bdl	33.4	3.3	0.06	3.5	bdl	0.15	25
MS033	5/12/12	0.003	bdl	31.1	3.3	0.073	0.4	bdl	bdl	22.4
MS034	5/12/12	0.0053	bdl	34.4	3.8	0.084	1	bdl	0.43	24.5
MS050	9/17/12	0.00	bdl	161.30	3.50	bdl	7.50	0.11	0.40	27.90
MS051	9/17/12	0.00	bdl	6.30	6.80	bdl	8.20	bdl	0.60	45.90
MS052	9/17/12	0.01	bdl	7.60	5.90	bdl	7.60	bdl	0.40	62.60
MS053	9/17/12	0.00	bdl	147.50	0.30	bdl	8.80	0.06	0.10	11.30
MS054	9/17/12	0.01	bdl	5.30	4.10	bdl	14.40	bdl	0.40	41.60

MS055	9/17/12	0.01	bdl	6.20	3.90	bdl	12.70	0.01	0.30	49.60
MS056	9/17/12	0.00	bdl	7.10	3.30	bdl	12.80	0.05	0.70	28.90
MS057	9/17/12	0.01	bdl	7.50	10.60	bdl	14.70	bdl	0.70	60.80
MS058	9/17/12	0.01	bdl	139.20	2.60	bdl	11.30	bdl	1.30	30.40
MS064	10/18/12	0.01	0.04	56.49	10.61	0.00	1.42	0.01	1.98	32.42
MS065	12/14/12	0.01	0.03	16.42	13.46	0.01	7.74	0.00	1.36	88.96
MS066	12/14/12	0.01	0.03	14.58	10.60	0.00	0.99	0.00	1.50	39.12
MS067	12/14/12	0.01	0.03	11.71	8.22	0.01	10.80	0.00	1.25	60.39
MS068	12/14/12	0.01	0.03	19.26	18.21	0.00	7.66	0.02	1.56	116.33
MS071	12/14/12	0.01	0.02	6.32	8.09	0.01	0.81	0.01	1.24	35.09
MS072	12/14/12	0.01	0.02	9.21	11.64	0.00	1.29	0.01	1.43	35.99
MS073	10/18/12	0.01	0.02	7.09	7.72	0.00	2.31	0.01	1.24	39.63
MS074	12/14/12	0.01	0.02	9.00	6.60	0.00	2.72	0.00	1.08	39.16
MS085	11/27/12	0.00	bdl	6.04	8.57	bdl	11.89	bdl	0.11	48.57
MS086	11/27/12	0.01	bdl	23.56	20.98	bdl	10.53	0.01	0.43	126.24
MS087	11/27/12	0.01	0.01	8.46	8.04	bdl	14.42	bdl	bdl	47.22
MS088	11/27/12	0.01	0.01	13.33	9.92	bdl	14.24	bdl	0.08	61.90
MS089	11/27/12	0.00	0.01	33.14	6.89	bdl	13.04	0.04	0.19	50.84
MS090	11/27/12	0.01	0.01	35.29	8.79	bdl	13.14	0.08	0.36	61.99
MS091	11/27/12	0.01	0.15	217.02	3.52	bdl	8.98	0.05	bdl	26.42
MS092	11/27/12	0.00	bdl	8.84	7.75	bdl	12.43	0.06	0.04	58.25
MS093	11/27/12	0.00	bdl	12.24	9.27	bdl	11.64	bdl	0.20	61.44
MS098	12/14/12	0.01	0.01	7.97	7.93	bdl	9.30	0.14	1.46	52.32
MS099	1/30/13	0.01	0.01	171.21	2.09	bdl	5.31	0.07	1.54	12.27
MS100	1/30/13	0.01	0.01	13.88	10.04	bdl	10.62	0.02	1.53	79.29
MS101	1/30/13	0.01	0.01	16.79	14.72	bdl	8.84	0.03	1.63	106.73
MS102	1/30/13	0.01	0.01	10.31	14.55	bdl	10.54	0.02	1.46	71.70
MS103	1/30/13	0.00	0.01	10.29	7.68	bdl	6.19	0.03	1.72	22.11
MS104	12/14/12	0.01	0.05	6.89	6.08	bdl	8.37	bdl	1.14	25.92

MS105	12/14/12	0.02	0.03	5.95	6.56	bdl	11.91	bdl	1.08	16.19
MS106	12/14/12	0.01	0.05	13.75	7.25	bdl	10.83	bdl	1.21	32.18
MS107	12/14/12	0.00	0.12	9.29	5.75	bdl	4.26	bdl	1.92	12.15
MS108	12/14/12	0.01	0.06	8.94	7.77	bdl	8.91	bdl	1.93	46.52
MS113	1/30/13	0.00	0.02	22.14	6.98	bdl	4.96	0.00	1.54	21.92
MS114	1/30/13	0.01	0.01	7.26	8.40	bdl	8.88	0.00	1.31	51.99
MS115	1/30/13	0.01	0.10	176.02	3.17	bdl	5.81	0.07	0.88	16.03
MS116	1/30/13	0.01	0.02	17.12	16.31	bdl	9.57	0.02	1.55	113.43
MS117	1/30/13	0.00	0.23	S	bdl	bdl	7.30	0.07	0.15	0.42
MS118	1/30/13	0.01	0.01	5.92	8.35	bdl	8.33	bdl	1.27	42.74
MS119	1/30/13	0.00	0.04	34.53	4.49	0.01	4.24	0.02	2.50	16.97
MS120	1/30/13	0.01	0.00	8.66	7.74	bdl	9.87	bdl	1.15	75.18
MS121	1/30/13	0.00	0.01	8.12	6.02	bdl	10.16	bdl	1.07	46.82
MS124	1/30/13	0.01	0.01	99.60	16.56	bdl	10.79	0.01	1.83	117.41
MS125	1/30/13	0.01	0.03	54.69	11.33	bdl	7.95	0.01	1.63	43.87
MS126	1/30/13	0.01	0.02	10.69	9.49	bdl	8.68	0.01	1.49	61.48
MS127	1/30/13	0.01	0.02	13.26	15.24	bdl	7.93	0.01	1.76	68.74
MS128	1/30/13	0.01	0.00	8.46	4.24	bdl	10.59	0.05	0.90	44.19
MS143	1/30/13	0.01	0.01	7.52	8.62	0.01	9.06	0.01	1.32	49.32
MS145	1/30/13	0.01	0.01	12.74	9.87	0.01	9.42	0.02	1.20	64.93
MS157	3/12/13	0.01	0.02	7.51	8.11	0.02	8.23	0.03	1.23	47.33
MS158	3/12/13	0.00	0.02	16.92	5.35	bdl	1.65	0.29	1.82	22.85
MS159	3/12/13	0.01	0.04	49.47	3.64	0.00	8.75	0.04	0.93	35.33
MS160	3/12/13	0.01	0.08	137.31	1.24	bdl	6.67	0.07	0.46	5.89
MS161	3/12/13	0.01	0.02	19.00	14.85	bdl	7.69	0.04	1.34	99.23
MS164	3/26/13	0.01	0.02	6.82	8.06	bdl	11.89	0.01	0.84	33.41
MS165 1	3/20/13	0.01	0.02	8.27	8.50	bdl	8.83	0.02	1.23	48.44
MS165 2	3/20/13	0.01	0.02	7.49	8.37	bdl	8.74	0.01	1.15	45.43
MS169	5/14/13	0.00	0.18	S	0.24	0.00	4.11	0.15	0.94	1.11

MS171	5/14/13	0.01	0.04	18.81	11.02	bdl	5.31	0.03	1.83	34.43
MS172	5/14/13	0.00	0.02	4.59	5.73	0.01	4.19	0.07	1.09	11.08
MS173	5/14/13	0.00	0.02	3.60	4.01	0.01	3.97	0.07	1.12	7.37
MS174	5/14/13	0.01	0.04	22.30	12.45	bdl	5.55	0.05	1.89	41.31
MS175	5/14/13	0.01	0.02	9.98	6.77	bdl	10.96	0.06	1.14	42.04
MS182	5/14/13	0.01	0.10	S	3.06	bdl	5.30	0.11	0.86	13.41
MS183	5/14/13	0.01	0.02	121.98	19.28	bdl	10.13	0.05	1.87	106.08
MS184	5/24/13	0.01	0.11	S	0.25	bdl	6.93	0.16	0.57	1.30
MS186	5/14/13	0.01	0.03	21.47	18.86	bdl	7.84	0.05	1.52	110.98
MS187	5/14/13	0.01	0.01	8.14	7.77	bdl	10.06	0.04	1.09	60.14
MS188	7/22/13	0.01	0.03	7.32	9.81	0.00	7.28	0.03	0.94	31.34
MS190	7/11/13	0.01	0.03	7.95	10.38	bdl	6.47	0.01	1.17	39.63
MS192	7/12/13	0.01	0.13	87.04	9.49	bdl	5.13	0.04	1.33	32.54
MS193	7/12/13	0.01	0.09	55.29	16.65	bdl	5.04	0.01	1.98	50.56
MS194	7/12/13	0.01	0.10	12.31	11.71	bdl	5.54	0.01	1.72	39.00
MS195	7/12/13	0.00	0.11	13.00	12.11	bdl	6.16	bdl	1.67	40.64
MS198	8/21/13	0.01	0.01	8.61	6.85	bdl	8.78	0.00	0.98	43.52
MS199	8/21/13	0.01	0.01	5.47	7.89	bdl	7.96	0.00	0.98	35.62
MS200	8/21/13	0.01	0.02	19.68	13.26	0.00	6.95	0.00	1.38	53.71
MS201	8/21/13	0.01	0.02	18.20	14.72	bdl	7.24	bdl	1.23	86.27
MS202	8/21/13	0.01	0.10	185.15	6.05	0.00	4.97	0.06	0.84	26.20
MS203	8/21/13	0.01	0.00	5.99	4.09	bdl	9.05	0.01	0.60	36.07
MS204	8/21/13	0.01	bdl	7.20	4.91	bdl	9.38	bdl	0.69	43.41
MS205	8/21/13	0.01	bdl	7.61	6.37	bdl	8.67	bdl	0.82	55.93
MS206	8/21/13	0.01	0.09	159.06	0.43	bdl	6.05	0.05	0.37	1.86
MS207	8/21/13	0.01	bdl	4.58	3.56	bdl	11.42	bdl	0.60	13.70
MS209	8/21/13	0.03	0.05	11.69	8.30	0.01	4.82	bdl	1.41	43.37
MS210	8/21/13	0.01	0.02	31.02	17.70	bdl	8.14	0.19	4.74	5.71
MS211	8/21/13	0.01	0.01	11.09	9.00	bdl	7.57	bdl	1.28	38.27

MS212	8/21/13	0.02	0.05	31.67	22.85	0.08	6.25	bdl	1.85	78.78
MS213	8/21/13	0.01	0.04	9.03	12.99	bdl	5.36	0.04	1.88	38.18
MS214	8/21/13	0.02	0.04	18.79	17.01	bdl	6.12	bdl	2.01	52.50
MS215	8/21/13	0.01	0.01	41.69	11.72	bdl	5.38	bdl	1.77	37.53
MS221	9/25/13	0.01	0.02	22.83	11.26	0.01	7.47	bdl	1.52	49.49
MS222	9/25/13	0.00	0.05	19.83	14.49	bdl	3.55	bdl	2.02	41.19
MS223	9/25/13	0.01	0.02	5.76	9.89	0.00	3.92	bdl	1.26	58.45
MS224	9/25/13	0.01	0.02	6.42	7.76	0.02	7.57	bdl	3.12	34.96
MS225	9/25/13	0.01	0.01	4.88	6.99	0.00	6.55	bdl	2.51	31.60
MS226	10/16/13	0.01	0.05	22.16	10.00	bdl	7.01	bdl	1.56	43.82
MS227	10/16/13	0.01	0.05	14.29	10.68	bdl	5.68	bdl	1.33	36.97
MS228	10/16/13	0.00	0.01	52.81	8.26	bdl	5.01	bdl	2.08	12.70
MS229	10/16/13	0.01	0.01	5.84	33.84	bdl	4.04	bdl	2.13	127.87
MS230	11/13/13	0.008	0.005	25.87	21.43	bdl	8.97	0.01	1.354	90.68
MS231	11/13/13	0.006	0.014	21.25	16.74	bdl	7.30	0.00	1.440	102.69
MS232 1	11/13/13	0.008	bdl	5.42	4.98	bdl	10.04	0.03	0.711	10.26
MS232 2	11/13/13	0.008	bdl	5.16	4.83	0.002	9.64	0.03	0.655	9.78
MS233	11/13/13	0.01	0.01	5.82	7.58	bdl	7.50	0.03	1.09	35.11
MS234	11/13/13	0.00	0.01	8.85	6.33	bdl	8.33	0.01	1.03	43.32
MS235 1	11/13/13	0.01	bdl	7.08	4.64	bdl	8.91	0.02	0.78	42.86
MS235 2	11/13/13	0.01	bdl	6.73	4.41	bdl	8.61	0.01	0.74	40.30
MS249	12/17/13	0.01	0.06	76.31	29.05	0.01	8.61	bdl	2.80	115.63
MS253	1/30/14	0.015	0.051	74.39	28.55	0.009	8.24	bdl	2.53	118.67
MS254	1/30/14	0.032	0.048	207.30	40.87	bdl	6.21	0.03	4.04	120.00
MS255	1/30/14	0.008	0.017	6.79	7.52	0.011	7.74	bdl	1.07	40.97
MS256	1/30/14	0.009	0.032	25.55	16.25	0.009	6.28	bdl	1.44	98.29
MS257	1/30/14	0.008	bdl	5.42	4.98	bdl	10.04	0.03	0.711	10.26
MS269	3/24/14	0.008	0.135	17.06	11.91	0.011	4.85	0.01	0.78	59.68
MS270	3/24/14	0.017	0.066	9.46	14.26	0.036	5.99	0.04	0.64	36.00

MS271	3/24/14	0.011	0.025	5.81	4.78	0.002	6.11	0.04	0.41	8.42
MS272	3/24/14	0.013	0.053	7.23	5.06	0.004	6.31	0.05	0.57	19.90
MS273	3/24/14	0.008	0.116	14.89	7.68	0.004	4.93	0.02	0.83	31.29
MS274	3/24/14	0.005	0.071	3.63	9.30	0.018	3.50	0.04	0.76	23.09
MS275	3/24/14	0.007	0.080	6.71	11.07	0.015	3.73	0.03	0.95	32.49
MS276	3/24/14	0.009	0.166	9.52	14.70	0.008	3.82	0.04	1.73	44.71
MS277	3/24/14	0.003	0.026	35.03	9.30	0.023	2.96	0.16	1.35	27.15
MS297	3/24/14	0.012	0.096	6.10	11.10	0.002	3.57	0.10	1.28	30.96
MS298	4/10/14	0.001	0.023	91.82	0.11	0.015	9.92	0.03	0.35	1.02
MS299	4/10/14	0.006	0.109	170.12	0.38	0.034	5.81	0.11	0.55	2.68
MS300	4/10/14	0.012	0.010	7.98	6.39	0.013	8.79	0.05	0.99	58.68
MS301	4/10/14	0.013	0.016	9.22	10.56	0.018	11.46	0.02	1.33	49.69
MS302	4/10/14	0.008	0.025	29.55	21.66	0.023	6.98	0.03	1.68	128.09
MS303	4/10/14	0.011	0.000	6.16	5.34	0.014	10.51	0.08	0.67	11.38
MS304	4/10/14	0.001	0.019	3.92	4.26	0.102	4.31	0.04	1.30	10.94
MS318	5/20/14	0.005	0.013	18.57	9.01	0.019	9.43	0.09	1.04	41.31
MS319	5/20/14	0.009	0.005	8.15	9.67	0.015	7.33	0.08	1.27	57.91
MS320	5/20/14	0.008	0.018	24.89	16.09	0.011	6.90	0.06	1.54	92.62
MS321	5/20/14	0.015	0.001	10.14	15.82	0.156	12.61	0.12	1.09	48.17
MS322	5/20/14	0.011	bdl	6.00	5.58	0.030	11.80	0.30	0.69	14.86
MS323	5/20/14	0.024	bdl	6.51	6.84	0. 015	11.22	0.12	0.97	23.43
MS324	5/20/14	0.013	0.006	9.33	11.23	0.014	11.61	0.05	1.28	52.32
MS333	7/17/14	0.007	0.033	9.04	9.13	0.045	8.78	0.03	1.58	50.66
MS334	7/17/14	0.007	0.065	25.00	20.69	0.078	6.65	0.04	1.63	122.59
MS335	7/17/14	0.006	0.064	12.38	7.33	0.117	9.94	0.06	1.18	51.50
MS336	7/17/14	0.008	0.084	18.73	7.18	0.108	9.37	0.06	1.27	36.06
MS337	7/17/14	0.010	0.078	6.74	8.74	0.109	7.50	0.04	1.28	42.77
MS338	7/17/14	0.012	0.188	9.57	12.24	0.257	19.73	0.15	1.77	53.61
MS344	7/28/14	0.011	0.063	9.49	7.70	0.535	9.11	0.24	1.74	96.60

MS345	7/28/14	0.005	0.113	171.59	0.48	0.044	5.09	0.12	0.43	3.11
MS346	7/28/14	0.009	0.038	9.24	4.57	0.058	8.35	0.07	0.81	40.89
MS350	7/30/14	0.006	0.055	58.26	34.50	0.004	4.65	0.07	2.43	49.72
MS351	8/12/14	0.006	0.013	15.89	6.85	0.007	7.37	0.08	1.39	27.02
MS352	8/12/14	0.007	0.020	8.44	8.77	0.014	7.65	0.13	1.52	34.97
MS353	8/12/14	0.006	0.009	8.11	6.06	0.153	8.17	0.20	1.28	40.07
MS354	8/12/14	0.004	0.106	98.38	0.35	0.016	3.92	0.12	0.59	1.81
MS355	8/12/14	0.008	0.012	11.22	4.88	0.012	6.90	0.23	0.94	17.62
MS356	8/12/14	0.009	0.002	6.51	5.51	0.006	6.01	0.17	0.84	17.58
MS357	8/12/14	0.013	0.010	9.79	11.36	0.013	11.57	0.07	1.35	54.95
MS358	8/12/14	0.003	0.024	13.65	5.62	0.016	3.78	0.12	1.87	19.55
MS360	8/26/14	0.007	0.027	104.47	0.080	bdl	5.93	0.05	0.110	0.44
MS361	8/26/14	0.008	0.117	>100	2.760	0.043	5.79	0.09	1.43	8.59
MS375	9/2/14	0.010	0.021	17.87	14.40	0.028	5.93	0.02	2.36	75.45
MS376	9/2/14	0.007	0.067	79.09	7.35	0.328	4.26	0.09	2.08	84.95
MS377	9/2/14	0.007	0.012	22.71	8.28	0.029	4.92	0.01	1.42	34.10
MS378	9/2/14	0.016	0.029	37.35	17.16	0.054	5.37	bdl	3.17	98.93
MS379	9/2/14	0.007	0.016	21.09	12.63	bdl	4.70	bdl	1.98	52.93
MS380	9/2/14	0.012	0.024	44.39	14.47	bdl	4.60	bdl	2.64	58.92
MS381	9/2/14	0.015	0.053	102.60	4.90	bdl	6.20	0.01	1.83	28.61
MS382	9/2/14	0.013	0.001	10.67	10.58	0.050	7.04	0.03	1.81	79.74
MS383	9/2/14	0.013	0.024	102.40	8.77	bdl	4.29	bdl	1.92	36.57
MS384	9/2/14	0.011	0.021	31.87	12.91	0.097	6.03	bdl	1.84	92.46
MS385	9/2/14	0.005	bdl	3.71	7.67	0.001	3.91	bdl	1.38	41.48
MS386	9/2/14	0.002	bdl	12.45	5.24	bdl	3.99	bdl	1.66	20.48
MS388	9/15/14	0.006	0.014	10.00	17.38	bdl	6.67	0.01	1.69	42.84
MS389	9/15/14	0.006	0.004	9.56	5.24	0.005	5.01	0.08	1.10	27.84
MS390	9/15/14	0.005	0.021	48.19	7.63	bdl	3.79	bdl	2.48	35.91
MS391	9/30/14	0.014	0.005	6.08	10.80	0.036	4.97	0.02	1.97	32.69

MS392	9/30/14	0.023	0.004	9.80	5.98	0.064	8.29	0.09	1.59	13.12
MS393	9/30/14	0.007	bdl	13.29	7.00	0.008	5.81	0.01	2.08	31.09
MS394	9/30/14	0.011	0.010	54.02	20.26	0.020	6.35	0.02	2.39	84.77
MS395	9/30/14	bdl	0.038	109.84	0.09	0.041	8.31	0.03	0.09	0.41
MS396	9/30/14	0.009	0.006	17.15	7.61	0.012	7.46	0.02	1.15	24.58
MS397	9/30/14	0.008	0.065	119.78	3.56	0.054	5.03	0.07	1.99	14.46
MS398	9/30/14	0.008	0.059	55.64	12.09	0.019	4.94	0.03	2.01	51.79
MS399	9/30/14	0.008	0.010	21.23	15.31	0.046	3.26	0.04	1.29	86.47
MS400	9/30/14	0.008	0.099	45.92	16.75	0.014	6.19	0.02	1.63	47.35
MS401	9/30/14	0.007	0.013	18.55	14.66	0.014	6.78	0.03	1.31	92.09
MS402	9/30/14	0.009	bdl	5.88	5.04	0.007	10.68	0.22	0.60	11.18
MS403	9/30/14	0.021	bdl	6.05	6.56	0.018	10.73	0.09	0.89	22.50
MS404	10/21/14	0.007	bdl	9.03	13.41	0.012	5.86	bdl	0.83	117.99
MS405	10/21/14	0.034	bdl	6.43	10.62	bdl	3.76	0.01	2.27	65.07
MS406	10/21/14	0.006	bdl	7.87	5.98	0.003	9.78	0.01	0.89	52.47
MS407	10/21/14	0.007	bdl	7.53	7.39	bdl	7.78	bdl	1.17	53.74
MS408	10/21/14	0.010	bdl	5.89	6.51	0.022	7.30	bdl	0.83	40.46
MS409	10/21/14	0.010	0.001	20.06	10.02	0.080	4.95	0.04	1.72	57.03
MS410	10/29/14	0.007	0.021	8.71	8.52	0.020	8.48	0.01	1.49	47.08
MS411	10/29/14	0.001	0.021	14.65	6.69	0.059	2.18	0.21	2.58	37.63
MS412	10/29/14	0.012	0.018	10.27	12.04	0.015	12.30	0.01	1.67	57.71
MS413	10/29/14	0.007	0.017	23.70	21.25	0.009	7.75	0.03	1.63	130.25
MS414	10/29/14	0.006	0.097	183.33	4.85	0.043	6.07	0.08	1.07	22.85
MS415	10/29/14	0.011	0.018	20.93	13.73	0.012	7.78	0.01	1.78	62.83
MS416	10/29/14	0.006	0.077	140.70	1.19	0.014	7.79	0.07	0.61	6.68
MS417	10/29/14	0.007	0.009	29.61	7.99	0.012	10.33	0.02	1.34	55.88
MS418	10/29/14	0.007	0.010	45.91	10.56	0.006	9.70	0.05	1.44	70.66
MS419	10/29/14	0.010	bdl	8.15	4.78	0.008	10.19	0.09	0.86	42.46
MS420	11/9/14	0.006	0.012	7.62	8.38	0.048	9.59	0.04	1.61	56.10

MS421	11/12/14	0.008	0.045	38.45	16.39	0.034	6.42	0.02	2.30	44.53
MS422	11/12/14	0.010	0.030	21.94	11.64	0.035	6.96	0.09	1.92	39.83
MS423	12/3/14	0.009	0.223	168.36	0.28	0.017	4.75	0.12	1.32	1.28
MS424	12/19/14	0.006	bdl	20.62	16.47	bdl	6.82	0.07	1.38	93.45
MS425	12/19/14	0.001	bdl	14.57	5.82	bdl	2.10	0.24	1.85	25.62
MS426	12/19/14	0.001	bdl	14.64	5.82	bdl	2.09	0.23	1.92	25.07
MS427	12/19/14	0.001	bdl	83.05	0.12	bdl	4.86	0.22	0.66	2.57
MS428	12/19/14	0.004	bdl	4.98	3.49	bdl	10.68	0.10	0.63	12.63
MS429	12/19/14	0.009	0.016	134.48	14.31	0.457	5.32	0.09	1.30	39.53
MS430	12/19/14	0.009	bdl	4.86	6.96	bdl	8.15	0.10	0.99	22.63
MS431	12/19/14	0.01	0.11	155.93	0.22	bdl	3.62	0.20	1.15	0.96

Sample	ICPMS Analysis Date	Ti (mg/L)	V (mg/L)	Cr (mg/L)	Mn (mg/L)	Fe (mg/L)	Co (mg/L)	Ni (mg/L)	Cu (mg/L)	Zn (mg/L)
MS007	8/28/11	0.01	bdl	bdl	0.005	bdl	bdl	0.003	0	bdl
MS009	9/19/11	0.003	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MS010	9/19/11	0.001	bdl	bdl	bdl	bdl	bdl	bdl	0.01	bdl
MS014	9/22/11	0.0021	bdl	bdl	bdl	0.09	bdl	bdl	0.0007	bdl
MS015	10/22/11	0.0009	bdl	bdl	0.009	bdl	bdl	bdl	bdl	bdl
MS016	10/22/11	0.0007	bdl	bdl	0.003	bdl	bdl	0.0021	0.1692	0.0159
MS017	10/22/11	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MS018	10/22/11	0.0017	bdl	bdl	0.238	0.205	0.0005	0.0015	0.0055	bdl
MS019	10/22/11	0.0019	bdl	bdl	0.002	bdl	bdl	bdl	0.008	bdl
MS020	-	0.0014	bdl	bdl	bdl	0.135	bdl	bdl	0.0164	bdl
MS021	-	0.0027	bdl	bdl	0.085	1.462	bdl	bdl	0.068	bdl
MS022	-	0.002	bdl	bdl	bdl	bdl	bdl	bdl	0.0075	bdl
MS023	11/26/11	0.0019	bdl	bdl	bdl	0.069	bdl	bdl	bdl	bdl
MS024	11/26/11	0.0016	bdl	bdl	bdl	0.191	bdl	bdl	bdl	bdl
MS026	1/17/12	0.0023	bdl	bdl	bdl	0.04	bdl	bdl	0.0017	bdl
MS027	1/17/12	0.0019	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MS032	5/12/12	bdl	bdl	bdl	0.015	bdl	0.0021	bdl	0.0499	0.3915
MS033	5/12/12	bdl	bdl	bdl	0.079	bdl	0.0015	bdl	0.0556	0.057
MS034	5/12/12	bdl	bdl	bdl	0.311	bdl	0.0019	bdl	0.0183	bdl
MS050	9/17/12	0.00	bdl	bdl	0.01	bdl	bdl	bdl	bdl	bdl
MS051	9/17/12	0.00	bdl	bdl	0.09	bdl	bdl	bdl	bdl	bdl
MS052	9/17/12	0.00	bdl	bdl	0.04	bdl	bdl	0.00	0.02	0.04
MS053	9/17/12	0.00	bdl	0.00	bdl	bdl	bdl	bdl	bdl	bdl
MS054	9/17/12	0.00	bdl	bdl	0.25	bdl	bdl	bdl	bdl	bdl
MS055	9/17/12	0.00	bdl	bdl	0.37	0.13	0.00	bdl	bdl	bdl
MS056	9/17/12	0.00	bdl	0.00	0.04	0.11	bdl	0.00	bdl	bdl
MS057	9/17/12	0.00	bdl	0.00	0.12	bdl	bdl	0.00	bdl	bdl

MS058	9/17/12	0.00	bdl	0.00	2.63	bdl	0.00	0.00	bdl	bdl
MS064	10/18/12	0.00	0.00	0.00	0.16	0.12	0.00	0.00	0.00	0.01
MS065	12/14/12	0.00	0.00	0.00	<0.01	0.22	<0.001	0.00	0.00	0.01
MS066	12/14/12	<0.001	<0.001	0.00	0.24	0.14	0.00	0.00	0.00	0.01
MS067	12/14/12	0.00	<0.001	0.00	0.43	0.17	0.00	0.00	0.00	<0.01
MS068	12/14/12	0.00	0.00	0.00	<0.01	0.41	<0.001	0.00	0.00	<0.01
MS071	12/14/12	<0.001	<0.001	0.00	0.28	0.16	0.00	0.00	0.01	0.01
MS072	12/14/12	0.00	<0.001	0.00	0.07	0.15	<0.001	0.00	<0.001	<0.01
MS073	10/18/12	0.00	<0.001	0.00	0.05	0.15	<0.001	0.00	0.00	<0.01
MS074	12/14/12	0.00	<0.001	0.00	0.24	0.12	<0.001	0.00	<0.001	<0.01
MS085	11/27/12	0.00	bdl	0.03	0.10	bdl	bdl	0.01	0.01	bdl
MS086	11/27/12	0.00	0.00	0.04	0.13	bdl	0.00	0.02	0.01	bdl
MS087	11/27/12	0.00	0.00	0.04	0.02	bdl	bdl	0.01	0.01	bdl
MS088	11/27/12	0.00	0.00	0.03	0.05	bdl	0.00	0.01	0.02	0.01
MS089	11/27/12	0.00	0.00	0.03	0.01	bdl	bdl	0.01	0.02	bdl
MS090	11/27/12	0.00	0.00	0.04	0.06	bdl	bdl	0.01	0.02	bdl
MS091	11/27/12	0.00	0.00	0.04	0.02	bdl	0.00	0.01	0.02	bdl
MS092	11/27/12	0.00	bdl	0.04	0.41	bdl	0.00	0.01	0.01	bdl
MS093	11/27/12	bdl	bdl	0.03	0.07	bdl	<0.0001	0.01	0.02	0.13
MS098	12/14/12	0.00	bdl	0.00	0.05	0.21	0.00	0.00	0.00	0.01
MS099	1/30/13	<0.001	0.00	<0.001	1.95	0.09	0.00	0.01	0.01	<0.01
MS100	1/30/13	0.00	bdl	0.00	1.12	0.30	0.00	0.00	0.00	0.00
MS101	1/30/13	0.00	bdl	<0.001	0.09	0.42	0.00	0.00	0.00	0.03
MS102	1/30/13	0.00	bdl	<0.001	1.32	0.28	0.01	0.01	0.00	0.03
MS103	1/30/13	0.00	bdl	<0.001	0.02	0.11	0.00	0.01	0.17	0.16
MS104	12/14/12	0.00	0.00	0.00	0.01	bdl	0.00	0.00	0.01	0.25
MS105	12/14/12	0.00	0.00	0.00	0.01	bdl	0.00	0.00	0.34	0.04
MS106	12/14/12	0.01	0.00	0.00	0.01	bdl	0.00	0.00	0.02	0.07
MS107	12/14/12	0.01	0.00	bdl	0.01	bdl	0.00	0.01	0.04	0.09

MS108	12/14/12	0.01	0.00	0.00	0.01	bdl	0.00	0.00	0.02	0.10
MS113	1/30/13	0.00	0.00	0.00	0.07	0.09	0.00	0.00	0.03	1.51
MS114	1/30/13	0.00	bdl	0.00	0.02	0.18	0.00	0.00	0.00	0.01
MS115	1/30/13	0.00	0.00	0.00	0.01	0.05	0.00	0.00	0.03	0.00
MS116	1/30/13	0.00	0.00	0.00	0.15	0.43	0.00	0.00	0.00	0.01
MS117	1/30/13	0.00	0.00	0.00	<0.01	0.02	0.00	0.00	0.01	0.00
MS118	1/30/13	0.00	bdl	0.00	0.29	0.19	0.00	0.00	0.01	0.07
MS119	1/30/13	0.00	bdl	0.00	0.03	0.10	0.00	0.01	0.00	0.02
MS120	1/30/13	0.00	bdl	0.00	0.13	0.27	0.00	0.01	0.05	0.18
MS121	1/30/13	0.00	bdl	0.00	0.31	0.16	0.00	0.00	0.00	0.00
MS124	1/30/13	0.00	0.00	0.00	0.66	1.92	0.00	0.00	0.00	0.01
MS125	1/30/13	0.00	bdl	0.00	0.35	0.17	0.00	0.00	0.00	0.00
MS126	1/30/13	0.00	bdl	0.00	1.80	2.20	0.01	0.01	0.00	0.01
MS127	1/30/13	0.00	bdl	0.00	0.85	0.25	0.00	0.01	0.02	0.12
MS128	1/30/13	0.00	bdl	0.00	0.06	0.17	0.00	0.00	0.00	0.02
MS143	1/30/13	0.00	bdl	0.00	0.02	0.26	0.00	0.00	0.00	bdl
MS145	1/30/13	0.00	bdl	0.00	0.11	0.37	0.00	0.00	0.00	bdl
MS157	3/12/13	0.00	bdl	0.00	0.04	0.25	0.00	0.00	0.00	0.06
MS158	3/12/13	0.00	bdl	0.00	0.00	0.14	bdl	0.00	0.00	0.10
MS159	3/12/13	0.00	bdl	0.00	0.00	0.19	<0.0001	0.00	0.01	0.48
MS160	3/12/13	0.00	bdl	0.00	0.00	0.05	bdl	bdl	0.01	0.06
MS161	3/12/13	0.00	bdl	0.00	0.33	0.53	0.00	0.00	0.00	0.09
MS164	3/26/13	0.00	0.00	0.00	0.34	0.58	0.00	0.00	0.00	0.02
MS165 1	3/20/13	0.00	0.00	0.00	0.06	0.40	0.00	0.00	0.00	0.01
MS165 2	3/20/13	0.00	0.00	0.00	0.10	0.32	0.00	0.00	0.00	bdl
MS169	5/14/13	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.08	bdl
MS171	5/14/13	0.00	0.00	0.00	0.53	0.95	0.00	0.00	0.00	bdl
MS172	5/14/13	0.00	0.00	0.00	0.01	0.06	0.00	0.01	0.00	0.13
MS173	5/14/13	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.00	bdl

MS174	5/14/13	0.00	0.00	0.00	0.55	0.77	0.00	0.00	0.00	bdl
MS175	5/14/13	0.00	0.00	0.00	0.28	0.55	0.00	0.00	0.00	bdl
MS182	5/14/13	0.00	0.00	0.00	0.02	0.07	0.00	0.00	0.01	bdl
MS183	5/14/13	0.00	0.00	0.00	0.64	1.62	0.00	0.00	0.00	bdl
MS184	5/24/13	0.00	0.00	0.00	0.00	0.02	0.00	<0.001	0.00	0.00
MS186	5/14/13	0.00	0.00	0.00	0.15	0.66	0.00	0.00	0.00	0.01
MS187	5/14/13	0.00	0.00	<0.001	0.25	0.32	0.00	0.01	0.05	0.08
MS188	7/22/13	0.00	bdl	0.00	0.07	0.15	0.00	0.00	0.00	0.02
MS190	7/11/13	0.00	bdl	0.00	0.09	0.20	0.00	0.00	0.00	bdl
MS192	7/12/13	0.00	bdl	0.00	0.02	0.15	0.00	0.00	0.00	0.02
MS193	7/12/13	0.00	bdl	0.00	0.05	0.27	0.00	0.00	0.01	bdl
MS194	7/12/13	0.00	bdl	0.00	0.07	0.18	0.00	0.00	0.00	0.01
MS195	7/12/13	0.00	bdl	0.00	0.04	0.19	0.00	0.00	0.00	bdl
MS198	8/21/13	0.00	bdl	0.00	0.44	0.18	0.00	0.00	0.00	0.00
MS199	8/21/13	0.00	bdl	0.00	0.21	0.13	0.00	0.00	0.00	0.03
MS200	8/21/13	0.00	bdl	0.00	0.01	0.21	0.00	0.00	0.02	0.03
MS201	8/21/13	0.00	bdl	0.00	0.19	0.33	0.00	0.00	0.00	0.01
MS202	8/21/13	0.00	bdl	0.00	0.02	0.10	0.00	<0.001	0.01	0.00
MS203	8/21/13	0.00	bdl	0.00	0.04	0.14	0.00	0.00	0.00	0.00
MS204	8/21/13	0.00	bdl	0.00	0.80	0.20	0.00	0.00	0.01	0.08
MS205	8/21/13	0.00	bdl	<0.001	0.06	0.20	0.00	0.00	0.02	0.08
MS206	8/21/13	0.00	bdl	0.00	0.00	0.01	0.00	<0.001	0.00	bdl
MS207	8/21/13	0.00	bdl	bdl	0.55	0.08	0.00	0.00	0.00	0.02
MS209	8/21/13	bdl	bdl	0.00	0.14	0.15	0.00	0.00	0.03	0.02
MS210	8/21/13	0.00	bdl	0.00	0.04	0.02	0.00	<0.001	0.00	0.00
MS211	8/21/13	0.08	bdl	0.00	0.52	1.03	0.00	0.00	0.01	0.17
MS212	8/21/13	0.01	bdl	0.00	1.25	1.36	0.00	0.00	0.00	0.03
MS213	8/21/13	bdl	bdl	0.00	0.25	0.14	0.00	0.00	0.00	0.03
MS214	8/21/13	bdl	bdl	bdl	0.14	0.14	0.00	0.00	0.00	0.01

MS215	8/21/13	bdl	bdl	0.00	0.00	0.14	0.00	0.00	0.08	0.02
MS221	9/25/13	0.00	0.00	bdl	0.39	0.13	0.00	0.00	0.00	0.01
MS222	9/25/13	0.00	0.00	bdl	0.12	bdl	0.00	0.00	0.00	0.00
MS223	9/25/13	0.00	0.00	bdl	0.00	0.04	0.00	0.00	0.00	0.01
MS224	9/25/13	0.00	0.00	bdl	0.17	bdl	0.00	0.00	0.01	0.02
MS225	9/25/13	0.00	0.00	bdl	0.05	bdl	0.00	0.00	0.01	0.03
MS226	10/16/13	0.00	bdl	0.00	0.03	0.22	0.00	0.00	0.00	0.01
MS227	10/16/13	0.00	bdl	0.00	0.11	0.18	0.00	0.00	0.01	0.01
MS228	10/16/13	0.00	bdl	bdl	0.08	0.06	0.00	0.01	0.01	0.01
MS229	10/16/13	<0.001	bdl	0.00	0.32	0.99	0.00	0.00	bdl	0.00
MS230	11/13/13	0.002	0.0011	<0.001	0.050	0.25	0.0001	0.004	0.014	0.0032
MS231	11/13/13	0.001	0.0010	0.001	0.236	0.30	0.0003	0.003	0.002	0.0051
MS232 1	11/13/13	0.002	bdl	bdl	0.247	bdl	0.0005	0.002	0.088	0.0515
MS232 2	11/13/13	0.002	bdl	bdl	0.241	0.01	0.0005	0.002	0.112	0.0571
MS233	11/13/13	0.00	bdl	<0.001	0.23	0.04	0.00	0.00	0.01	0.01
MS234	11/13/13	0.00	bdl	<0.001	0.30	0.06	0.00	0.00	0.00	0.00
MS235 1	11/13/13	0.00	0.00	<0.001	0.56	0.08	0.00	0.00	0.00	0.06
MS235 2	11/13/13	0.00	0.00	0.00	0.53	0.26	0.00	0.00	0.01	0.07
MS249	12/17/13	0.00	bdl	0.00	0.48	0.67	0.00	0.00	0.01	0.03
MS253	1/30/14	0.002	0.0002	0.001	0.49	1.70	0.0006	0.005	0.009	0.043
MS254	1/30/14	0.001	0.0009	0.003	bdl	0.64	0.0002	0.002	0.028	0.012
MS255	1/30/14	0.002	bdl	bdl	0.25	1.54	0.0002	0.004	0.029	0.011
MS256	1/30/14	0.002	0.0001	0.001	0.22	0.97	0.0004	0.005	0.008	0.020
MS257	1/30/14	0.002	bdl	bdl	0.247	bdl	0.0005	0.002	0.088	0.051
MS269	3/24/14	0.003	bdl	0.0009	0.122	4.52	0.0011	0.002	0.036	0.020
MS270	3/24/14	0.004	bdl	0.0046	1.111	5.79	0.0067	0.012	0.042	0.022
MS271	3/24/14	0.004	bdl	0.0001	0.179	1.62	0.0010	0.003	0.174	0.030
MS272	3/24/14	0.004	bdl	bdl	0.024	2.46	0.0007	0.001	0.026	0.008
MS273	3/24/14	0.003	bdl	0.0005	0.022	0.74	0.0008	0.001	0.031	0.005

MS274	3/24/14	0.002	bdl	bdl	0.006	0.57	0.0007	0.003	0.029	0.005
MS275	3/24/14	0.002	bdl	0.0008	0.004	0.75	0.0006	0.002	0.028	0.043
MS276	3/24/14	0.002	bdl	0.0007	0.094	1.63	0.0006	0.001	0.019	0.012
MS277	3/24/14	0.002	bdl	0.0022	0.006	0.70	0.0005	0.004	0.053	0.050
MS297	3/24/14	0.002	bdl	bdl	0.001	0.73	0.0003	0.009	0.023	0.004
MS298	4/10/14	0.003	0.0003	0.0007	0.002	0.01	0.0001	bdl	0.019	0.01
MS299	4/10/14	0.002	0.0003	0.0011	0.003	0.02	0.0001	bdl	0.021	0.01
MS300	4/10/14	0.003	0.0003	0.0007	0.076	1.20	0.0002	<0.001	0.035	0.06
MS301	4/10/14	0.004	0.0001	0.0013	0.157	0.44	0.0001	bdl	0.011	0.010
MS302	4/10/14	0.002	0.0007	0.0010	0.167	2.13	0.0004	0.002	0.009	0.01
MS303	4/10/14	0.003	0.0002	0.0004	0.283	2.93	0.0006	0.001	0.117	0.033
MS304	4/10/14	0.004	0.0003	0.0004	0.004	0.10	0.0001	bdl	0.085	0.074
MS318	5/20/14	0.003	bdl	bdl	0.263	0.59	0.0001	<0.001	0.008	0.01
MS319	5/20/14	0.002	bdl	0.001	0.138	2.41	0.0002	0.002	0.057	0.02
MS320	5/20/14	0.002	bdl	0.001	0.269	1.94	0.0004	0.002	0.008	0.01
MS321	5/20/14	0.004	bdl	0.015	0.958	19.81	0.0056	0.009	0.021	0.05
MS322	5/20/14	0.004	bdl	bdl	0.362	17.96	0.0009	0.003	0.168	0.10
MS323	5/20/14	0.004	bdl	bdl	0.027	3.01	0.0001	<0.001	0.021	0.03
MS324	5/20/14	0.003	bdl	0.001	0.146	0.38	0.0001	0.001	0.001	0.01
MS333	7/17/14	bdl	0.0010	0.001	0.05	0.51	0.0002	0.004	0.006	0.01
MS334	7/17/14	0.003	0.0008	0.001	0.05	0.66	0.0004	0.002	0.012	0.03
MS335	7/17/14	0.003	0.0004	0.001	0.36	1.49	0.0010	0.002	0.007	0.05
MS336	7/17/14	0.004	0.0011	<0.001	0.56	2.60	0.0006	0.001	0.015	0.02
MS337	7/17/14	0.004	0.0007	<0.001	0.54	0.64	0.0029	0.004	0.014	0.16
MS338	7/17/14	0.011	0.0030	0.003	0.16	0.38	0.0010	0.001	0.034	0.06
MS344	7/28/14	0.004	0.0011	0.002	0.18	4.37	0.0005	0.002	0.060	0.60
MS345	7/28/14	bdl	bdl	0.001	<0.01	0.03	0.0001	<0.001	0.005	0.02
MS346	7/28/14	0.001	bdl	bdl	0.51	3.64	0.0012	0.003	0.023	0.09
MS350	7/30/14	bdl	0.0001	0.002	<0.01	0.27	0.0002	0.004	0.045	0.10

MS351	8/12/14	bdl	bdl	bdl	0.23	0.13	0.0001	0.001	0.001	<0.01
MS352	8/12/14	bdl	bdl	0.001	0.22	1.27	0.0003	0.004	0.012	0.12
MS353	8/12/14	bdl	0.0002	bdl	0.34	2.78	0.0002	0.002	0.015	0.31
MS354	8/12/14	bdl	bdl	0.001	0.03	0.03	0.0002	bdl	0.028	<0.01
MS355	8/12/14	bdl	bdl	bdl	0.77	3.52	0.0001	0.001	0.002	<0.01
MS356	8/12/14	bdl	bdl	bdl	0.53	3.05	0.0002	<0.001	0.002	0.01
MS357	8/12/14	bdl	bdl	bdl	0.15	0.31	0.0002	0.001	0.003	0.01
MS358	8/12/14	bdl	bdl	0.002	<0.01	0.09	0.0001	0.007	0.006	0.01
MS360	8/26/14	bdl	bdl	0.000	<0.01	0.000	0.0002	<0.001	0.008	bdl
MS361	8/26/14	bdl	0.0001	0.003	0.020	0.170	0.0003	0.004	0.045	0.09
MS375	9/2/14	bdl	bdl	bdl	0.34	2.70	bdl	0.001	0.005	0.01
MS376	9/2/14	0.001	0.0007	bdl	0.08	0.75	0.0002	0.001	0.020	0.96
MS377	9/2/14	bdl	bdl	bdl	0.11	0.95	bdl	<0.001	0.003	bdl
MS378	9/2/14	bdl	0.0001	bdl	0.04	0.61	0.0002	0.007	0.074	0.19
MS379	9/2/14	bdl	bdl	bdl	bdl	0.24	bdl	0.002	0.047	bdl
MS380	9/2/14	bdl	bdl	bdl	0.25	1.49	0.0003	0.001	0.020	bdl
MS381	9/2/14	bdl	bdl	bdl	0.01	0.20	0.0002	0.002	0.019	bdl
MS382	9/2/14	0.001	bdl	bdl	0.25	1.97	0.0002	0.004	0.036	0.11
MS383	9/2/14	bdl	bdl	bdl	0.20	1.28	bdl	<0.001	0.017	bdl
MS384	9/2/14	bdl	bdl	bdl	0.68	1.08	bdl	0.002	0.011	0.69
MS385	9/2/14	bdl	bdl	bdl	bdl	0.17	bdl	0.008	0.034	0.02
MS386	9/2/14	bdl	bdl	bdl	bdl	0.08	bdl	0.003	0.006	bdl
MS388	9/15/14	bdl	bdl	bdl	0.02	0.23	bdl	0.001	0.027	0.06
MS389	9/15/14	bdl	bdl	bdl	0.23	1.65	bdl	bdl	0.003	0.06
MS390	9/15/14	bdl	bdl	bdl	0.16	0.28	0.0002	0.001	0.022	0.07
MS391	9/30/14	0.002	0.0001	bdl	0.64	4.49	0.0009	0.003	0.014	0.01
MS392	9/30/14	0.003	0.0001	0.001	1.10	20.10	0.0083	0.014	0.275	0.14
MS393	9/30/14	0.002	bdl	bdl	0.02	0.21	0.0003	0.002	0.055	0.03
MS394	9/30/14	0.002	0.0007	0.002	<0.01	0.47	0.0002	0.006	0.010	0.14

MS395	9/30/14	0.003	0.0003	0.001	<0.01	0.01	0.0001	bdl	0.005	0.01
MS396	9/30/14	0.002	0.0001	bdl	0.01	0.21	0.0001	0.001	0.011	0.02
MS397	9/30/14	0.002	0.0002	0.001	0.03	0.11	0.0002	0.002	0.013	0.02
MS398	9/30/14	0.002	bdl	0.001	0.03	0.31	0.0003	0.001	0.003	0.01
MS399	9/30/14	0.001	0.0007	bdl	<0.01	0.45	0.0002	0.003	0.008	0.03
MS400	9/30/14	0.002	bdl	<0.001	0.13	0.24	0.0002	0.001	0.009	0.01
MS401	9/30/14	0.002	0.0004	bdl	0.19	1.53	0.0004	0.003	0.005	0.01
MS402	9/30/14	0.004	bdl	bdl	0.26	18.53	0.0006	0.003	0.183	0.05
MS403	9/30/14	0.003	bdl	bdl	0.03	3.21	0.0002	0.001	0.037	0.04
MS404	10/21/14	0.002	bdl	0.002	0.01	0.99	0.0007	0.005	0.108	0.03
MS405	10/21/14	0.001	bdl	bdl	1.23	16.29	0.0022	0.004	0.002	0.00
MS406	10/21/14	0.007	bdl	bdl	0.42	1.87	0.0005	0.007	0.011	0.05
MS407	10/21/14	0.003	bdl	bdl	0.13	0.74	0.0005	0.001	0.012	0.01
MS408	10/21/14	0.003	bdl	bdl	0.11	0.93	0.0010	0.002	0.014	0.01
MS409	10/21/14	0.002	bdl	0.001	0.57	2.73	0.0006	0.004	0.010	0.12
MS410	10/29/14	0.002	bdl	bdl	0.12	0.61	0.0004	0.001	0.014	0.01
MS411	10/29/14	0.002	bdl	0.001	<0.01	0.27	0.0004	0.002	0.011	0.02
MS412	10/29/14	0.003	bdl	0.001	0.14	0.40	0.0004	0.001	0.020	0.01
MS413	10/29/14	0.002	0.001	bdl	0.15	1.99	0.0007	0.002	0.006	0.01
MS414	10/29/14	0.002	0.001	bdl	0.02	0.20	0.0005	0.002	0.064	0.02
MS415	10/29/14	0.002	bdl	0.001	0.04	0.37	0.0004	0.003	0.015	0.02
MS416	10/29/14	0.002	bdl	bdl	<0.01	0.07	0.0005	bdl	0.006	<0.01
MS417	10/29/14	0.002	bdl	bdl	0.33	1.04	0.0014	0.002	0.022	0.03
MS418	10/29/14	0.003	bdl	bdl	0.56	4.79	0.0016	0.003	0.003	<0.01
MS419	10/29/14	0.002	bdl	bdl	0.51	4.08	0.0015	0.002	0.011	0.06
MS420	11/9/14	0.003	bdl	bdl	0.16	0.72	0.0006	0.001	0.006	0.06
MS421	11/12/14	0.002	bdl	0.001	0.01	0.31	0.0006	0.001	0.023	0.02
MS422	11/12/14	0.002	bdl	0.001	0.47	2.35	0.0007	bdl	0.008	0.02
MS423	12/3/14	0.001	bdl	bdl	0.00	0.02	0.0007	0.0002	0.003	<0.01

MS424	12/19/14	0.001	0.002	0.001	0.14	1.35	0.0005	0.003	0.010	bdl
MS425	12/19/14	bdl	0.001	0.001	<0.01	0.23	0.0003	0.007	0.013	bdl
MS426	12/19/14	bdl	0.001	0.001	<0.01	0.25	0.0003	0.003	0.013	bdl
MS427	12/19/14	0.001	bdl	0.001	<0.01	0.06	0.0002	0.000	0.010	0.05
MS428	12/19/14	0.002	bdl	0.001	0.43	2.75	0.0020	0.004	bdl	bdl
MS429	12/19/14	bdl	0.001	0.004	4.64	10.05	0.0163	0.017	0.079	0.06
MS430	12/19/14	0.001	bdl	bdl	0.75	9.81	0.0041	0.005	bdl	0.04
MS431	12/19/14	bdl	bdl	0.00	<0.01	0.05	0.00	<0.001	0.00	bdl

Sample	ICPMS Analysis Date	As (mg/L)	Se (mg/L)	Rb (mg/L)	Sr (mg/L)	Mo (mg/L)	Ag (mg/L)	Cd (mg/L)	Sn (mg/L)	Sb (mg/L)
MS007	8/28/11	bdl	bdl	0.0014	0.07	0.0001	bdl	bdl	bdl	bdl
MS009	9/19/11	bdl	bdl	0.0006	0.15	bdl	bdl	0.0001	bdl	bdl
MS010	9/19/11	bdl	bdl	0.0018	0.16	bdl	bdl	0.0001	bdl	bdl
MS014	9/22/11	bdl	0.0057	0.0004	0.15	0.00296	bdl	bdl	bdl	bdl
MS015	10/22/11	bdl	0.0045	0.0005	0.62	bdl	bdl	bdl	0.002	bdl
MS016	10/22/11	bdl	0.0003	0.0005	0.04	0.00003	bdl	bdl	bdl	bdl
MS017	10/22/11	bdl	0.002	bdl	0.2	bdl	bdl	bdl	bdl	bdl
MS018	10/22/11	bdl	bdl	0.0006	0.23	bdl	bdl	bdl	bdl	bdl
MS019	10/22/11	bdl	bdl	0.0009	0.07	bdl	bdl	bdl	bdl	bdl
MS020	-	bdl	bdl	0.0015	0.22	bdl	bdl	bdl	bdl	bdl
MS021	-	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
MS022	-	bdl	bdl	0.0019	0.11	bdl	bdl	bdl	bdl	bdl
MS023	11/26/11	bdl	0.0021	0.0006	0.09	bdl	bdl	bdl	bdl	bdl
MS024	11/26/11	bdl	0.0025	0.0007	0.08	bdl	bdl	bdl	bdl	bdl
MS026	1/17/12	bdl	0.0014	0.0009	0.17	bdl	bdl	bdl	bdl	bdl
MS027	1/17/12	bdl	bdl	0.0009	0.17	bdl	bdl	bdl	bdl	bdl
MS032	5/12/12	bdl	0.0004	0.0009	0.16	0.00019	bdl	0.00006	bdl	0.00018
MS033	5/12/12	bdl	bdl	0.0006	0.12	bdl	bdl	bdl	bdl	0.00005
MS034	5/12/12	bdl	0.0007	0.0009	0.14	bdl	bdl	0.00001	bdl	0.00012
MS050	9/17/12	bdl	0.00	0.00	0.54	bdl	bdl	bdl	bdl	bdl
MS051	9/17/12	bdl	0.00	0.00	0.15	bdl	bdl	bdl	bdl	bdl
MS052	9/17/12	bdl	bdl	0.00	0.10	bdl	bdl	bdl	bdl	bdl
MS053	9/17/12	bdl	0.00	0.00	0.03	bdl	bdl	bdl	bdl	bdl
MS054	9/17/12	bdl	bdl	0.00	0.08	bdl	bdl	bdl	bdl	bdl
MS055	9/17/12	bdl	0.00	0.00	0.08	bdl	bdl	bdl	bdl	bdl

MS056	9/17/12	bdl	0.00	bdl	0.05	bdl	bdl	bdl	bdl	0.00
MS057	9/17/12	bdl	bdl	0.00	0.21	bdl	bdl	bdl	bdl	bdl
MS058	9/17/12	bdl	0.00	0.00	0.16	bdl	bdl	bdl	bdl	bdl
MS064	10/18/12	0.00	0.00	0.00	0.35	<0.001	bdl	bdl	<0.0001	bdl
MS065	12/14/12	0.00	0.00	0.00	0.36	<0.001	<0.0001	bdl	<0.0001	bdl
MS066	12/14/12	0.00	0.00	0.00	0.23	<0.001	bdl	bdl	<0.0001	bdl
MS067	12/14/12	0.00	0.00	0.00	0.28	<0.001	bdl	bdl	<0.0001	bdl
MS068	12/14/12	0.00	0.00	0.00	0.45	<0.001	bdl	bdl	<0.0001	bdl
MS071	12/14/12	<0.001	<0.001	0.00	0.08	<0.001	bdl	bdl	<0.0001	bdl
MS072	12/14/12	<0.001	0.00	0.00	0.16	<0.001	0.00	bdl	<0.0001	bdl
MS073	10/18/12	0.00	bdl	0.00	0.16	<0.001	<0.0001	0.00	bdl	bdl
MS074	12/14/12	0.00	<0.001	0.00	0.22	<0.001	<0.0001	bdl	bdl	bdl
MS085	11/27/12	bdl	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl
MS086	11/27/12	bdl	0.00	bdl	0.49	bdl	bdl	bdl	bdl	bdl
MS087	11/27/12	0.00	bdl	bdl	0.16	bdl	bdl	bdl	bdl	bdl
MS088	11/27/12	bdl	bdl	bdl	0.36	bdl	bdl	bdl	bdl	bdl
MS089	11/27/12	0.00	bdl	bdl	0.32	bdl	bdl	bdl	bdl	bdl
MS090	11/27/12	0.00	bdl	bdl	0.47	bdl	bdl	bdl	bdl	bdl
MS091	11/27/12	0.00	bdl	bdl	0.27	<0.001	bdl	bdl	bdl	bdl
MS092	11/27/12	0.00	bdl	bdl	0.26	bdl	bdl	bdl	bdl	bdl
MS093	11/27/12	bdl	bdl	bdl	0.40	bdl	bdl	<0.0001	bdl	bdl
MS098	12/14/12	0.00	0.00	0.00	0.19	0.00	<0.0001	<0.0001	bdl	<0.0001
MS099	1/30/13	0.00	0.00	0.00	0.09	0.00	<0.0001	<0.0001	bdl	0.00
MS100	1/30/13	0.00	0.00	0.00	0.33	0.00	bdl	<0.0001	bdl	<0.0001
MS101	1/30/13	0.00	0.00	0.00	0.45	0.00	bdl	<0.0001	bdl	<0.0001
MS102	1/30/13	0.00	0.00	0.00	0.31	0.00	bdl	<0.0001	bdl	<0.0001
MS103	1/30/13	0.00	0.00	0.00	0.16	0.00	<0.0001	<0.0001	bdl	<0.0001
MS104	12/14/12	0.00	bdl	0.00	0.11	0.00	bdl	bdl	0.00	0.00
MS105	12/14/12	0.00	bdl	0.00	0.12	0.00	bdl	0.00	0.00	0.00

MS106	12/14/12	0.01	0.01	0.00	0.14	0.00	0.00	0.00	0.00	0.00
MS107	12/14/12	0.01	bdl	0.00	0.09	0.00	bdl	0.00	0.00	0.00
MS108	12/14/12	0.01	0.01	0.00	0.20	0.00	0.00	bdl	0.00	0.00
MS113	1/30/13	0.00	0.00	0.00	0.31	0.00	bdl	0.00	0.00	0.00
MS114	1/30/13	0.00	0.00	0.00	0.19	0.00	bdl	<0.0001	0.00	0.00
MS115	1/30/13	0.01	0.00	0.00	0.49	0.00	bdl	<0.0001	0.00	0.00
MS116	1/30/13	0.01	0.01	0.00	0.48	0.00	bdl	<0.0001	0.00	0.00
MS117	1/30/13	0.00	0.00	<0.001	0.00	0.00	bdl	<0.0001	<0.0001	0.00
MS118	1/30/13	0.00	bdl	0.00	0.09	0.00	bdl	<0.0001	<0.0001	0.00
MS119	1/30/13	0.00	<0.001	0.00	0.11	<0.0001	bdl	0.00	<0.0001	0.00
MS120	1/30/13	0.00	bdl	0.00	0.14	<0.0001	bdl	0.00	<0.0001	<0.0001
MS121	1/30/13	0.00	<0.001	0.00	0.25	0.00	bdl	<0.0001	<0.0001	0.00
MS124	1/30/13	0.01	0.01	0.00	0.51	0.00	0.00	<0.0001	bdl	0.00
MS125	1/30/13	0.00	0.00	0.00	0.45	<0.0001	bdl	<0.0001	bdl	<0.0001
MS126	1/30/13	0.00	0.00	0.00	0.23	<0.0001	0.00	<0.0001	bdl	<0.0001
MS127	1/30/13	0.00	0.00	0.00	0.22	<0.0001	bdl	0.00	bdl	0.00
MS128	1/30/13	0.00	0.00	0.00	0.15	0.00	0.00	<0.0001	bdl	0.00
MS143	1/30/13	bdl	0.00	0.00	0.19	0.00	bdl	bdl	0.00	0.00
MS145	1/30/13	bdl	0.00	0.00	0.35	<0.0001	bdl	bdl	0.00	0.00
MS157	3/12/13	bdl	0.00	0.00	0.19	bdl	bdl	bdl	bdl	bdl
MS158	3/12/13	bdl	<0.001	0.00	0.08	bdl	bdl	bdl	bdl	bdl
MS159	3/12/13	bdl	0.00	0.00	0.15	bdl	bdl	bdl	bdl	0.00
MS160	3/12/13	bdl	0.00	0.00	0.08	bdl	bdl	bdl	bdl	bdl
MS161	3/12/13	bdl	0.01	0.00	0.47	bdl	bdl	bdl	bdl	bdl
MS164	3/26/13	0.00	0.00	0.00	0.14	0.00	0.00	bdl	0.00	0.00
MS165 1	3/20/13	0.00	0.00	0.00	0.23	<0.0001	bdl	0.00	0.00	0.00
MS165 2	3/20/13	0.00	0.00	0.00	0.22	bdl	bdl	bdl	0.00	0.00
MS169	5/14/13	0.00	bdl	0.00	0.03	0.00	bdl	<0.0001	0.00	0.00
MS171	5/14/13	0.00	bdl	0.00	0.38	0.00	bdl	bdl	0.00	0.00

MS172	5/14/13	0.00	0.00	<0.001	0.05	<0.0001	bdl	<0.0001	0.00	0.00
MS173	5/14/13	bdl	bdl	<0.001	0.04	0.00	bdl	<0.0001	0.00	0.00
MS174	5/14/13	<0.001	bdl	0.00	0.44	0.00	bdl	<0.0001	0.00	0.00
MS175	5/14/13	<0.001	bdl	0.00	0.19	0.00	bdl	<0.0001	0.00	0.00
MS182	5/14/13	0.00	0.00	0.00	0.50	0.00	bdl	<0.0001	0.00	0.00
MS183	5/14/13	0.01	0.01	0.00	0.45	0.00	bdl	<0.0001	<0.0001	<0.0001
MS184	5/24/13	0.00	<0.001	0.00	0.03	0.00	bdl	bdl	0.00	0.00
MS186	5/14/13	0.00	0.00	0.00	0.54	<0.0001	bdl	<0.0001	0.00	0.00
MS187	5/14/13	0.00	bdl	0.00	0.14	bdl	bdl	0.00	<0.0001	<0.0001
MS188	7/22/13	0.00	0.00	0.00	0.35	0.00	0.00	0.00	0.00	0.00
MS190	7/11/13	0.00	0.00	0.00	0.84	0.00	bdl	0.00	0.00	0.00
MS192	7/12/13	0.00	0.00	0.00	1.25	0.00	bdl	bdl	0.00	0.00
MS193	7/12/13	0.00	0.00	0.00	1.33	<0.0001	bdl	bdl	0.00	0.00
MS194	7/12/13	0.00	0.00	0.00	2.31	<0.0001	bdl	bdl	0.00	<0.0001
MS195	7/12/13	0.00	bdl	0.00	2.49	<0.0001	bdl	bdl	0.00	<0.0001
MS198	8/21/13	bdl	bdl	0.00	0.32	0.00	0.00	<0.0001	0.00	0.00
MS199	8/21/13	bdl	0.00	0.00	0.11	0.00	bdl	<0.0001	0.00	0.00
MS200	8/21/13	bdl	bdl	0.00	0.26	0.00	0.00	<0.0001	0.00	0.00
MS201	8/21/13	bdl	bdl	0.00	0.52	0.00	0.00	<0.0001	0.00	<0.0001
MS202	8/21/13	<0.001	0.00	0.00	1.14	0.00	bdl	<0.0001	0.00	<0.0001
MS203	8/21/13	bdl	0.00	0.00	0.14	0.00	0.00	bdl	0.00	0.00
MS204	8/21/13	bdl	bdl	0.00	0.14	<0.0001	bdl	<0.0001	0.00	<0.0001
MS205	8/21/13	bdl	bdl	0.00	0.15	<0.0001	bdl	<0.0001	0.00	<0.0001
MS206	8/21/13	bdl	bdl	0.00	0.04	0.00	bdl	bdl	0.00	<0.0001
MS207	8/21/13	bdl	bdl	0.00	0.06	0.00	bdl	bdl	0.00	<0.0001
MS209	8/21/13	bdl	bdl	0.00	0.10	0.00	0.00	<0.0001	<0.0001	0.00
MS210	8/21/13	bdl	0.00	0.00	0.02	0.00	bdl	bdl	<0.0001	<0.0001
MS211	8/21/13	bdl	bdl	0.00	0.27	0.00	bdl	bdl	<0.0001	<0.0001
MS212	8/21/13	bdl	bdl	0.00	1.25	<0.0001	bdl	bdl	<0.0001	<0.0001

MS213	8/21/13	bdl	bdl	0.00	1.33	bdl	bdl	bdl	<0.0001	<0.0001
MS214	8/21/13	bdl	bdl	0.00	1.46	bdl	bdl	bdl	bdl	bdl
MS215	8/21/13	bdl	bdl	0.00	0.40	0.00	bdl	0.00	<0.0001	<0.0001
MS221	9/25/13	bdl	bdl	0.00	0.28	0.00	bdl	0.00	0.00	0.00
MS222	9/25/13	0.00	bdl	0.00	0.69	0.00	bdl	0.00	0.00	0.00
MS223	9/25/13	0.00	bdl	0.00	0.33	0.00	bdl	0.00	0.00	0.00
MS224	9/25/13	bdl	bdl	0.00	0.19	0.00	bdl	0.00	0.00	0.00
MS225	9/25/13	bdl	bdl	0.00	0.12	0.00	bdl	0.00	0.00	0.00
MS226	10/16/13	bdl	bdl	0.00	0.85	0.00	bdl	bdl	0.00	<0.0001
MS227	10/16/13	bdl	<0.001	0.00	0.92	<0.0001	bdl	0.00	<0.0001	<0.0001
MS228	10/16/13	0.00	<0.001	0.00	0.07	<0.0001	bdl	0.00	0.00	0.00
MS229	10/16/13	0.00	<0.001	0.00	0.72	0.00	bdl	bdl	<0.0001	<0.0001
MS230	11/13/13	0.002	0.004	0.000	0.20	0.0001	0.0001	0.0001	0.0001	0.0001
MS231	11/13/13	0.002	0.004	0.001	0.45	0.0001	bdl	<0.0001	0.0001	<0.0001
MS232 1	11/13/13	bdl	bdl	<0.001	0.04	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
MS232 2	11/13/13	bdl	0.001	<0.001	0.04	0.0001	bdl	<0.0001	<0.0001	<0.0001
MS233	11/13/13	bdl	bdl	0.00	0.08	<0.0001	bdl	<0.0001	<0.0001	<0.0001
MS234	11/13/13	bdl	bdl	0.00	0.25	0.00	bdl	<0.0001	<0.0001	<0.0001
MS235 1	11/13/13	bdl	0.00	0.00	0.09	<0.0001	bdl	0.00	<0.0001	<0.0001
MS235 2	11/13/13	bdl	0.00	0.00	0.09	<0.0001	bdl	<0.0001	<0.0001	<0.0001
MS249	12/17/13	0.00	0.00	0.00	1.66	0.00	bdl	0.00	0.00	0.00
MS253	1/30/14	0.002	bdl	0.004	1.67	0.0001	bdl	bdl	0.0197	0.0001
MS254	1/30/14	0.002	0.002	bdl	0.53	bdl	bdl	bdl	bdl	bdl
MS255	1/30/14	0.002	bdl	0.001	0.22	bdl	0.0003	0.0001	0.0125	0.0001
MS256	1/30/14	bdl	0.005	0.001	0.59	0.0001	0.0003	bdl	0.0178	bdl
MS257	1/30/14	bdl	bdl	<0.001	0.04	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
MS269	3/24/14	bdl	0.002	0.001	0.39	0.0009	0.0050	0.00006	0.042	0.0008
MS270	3/24/14	bdl	0.002	0.001	0.16	0.0008	0.0051	0.00005	0.020	0.0008
MS271	3/24/14	bdl	0.000	<0.001	0.04	0.0005	0. 0054	0.00005	0.032	0.0006

MS272	3/24/14	bdl	0.001	0.001	0.13	0.0005	0.0047	0.00004	0.018	0.0005
MS273	3/24/14	bdl	bdl	0.001	0.36	0.0005	0.0035	0.00002	0.044	0.0004
MS274	3/24/14	bdl	0.003	<0.001	0.07	0.0004	0.0040	<0.00001	0.012	0.0003
MS275	3/24/14	bdl	0.002	0.002	0.22	0.0004	0.0035	0.00003	0.064	0.0003
MS276	3/24/14	bdl	bdl	0.002	0.65	0.0004	0.1023	0.00001	0.019	0.0002
MS277	3/24/14	bdl	bdl	0.001	0.14	0.0003	0.0031	0.00003	0.037	0.0001
MS297	3/24/14	bdl	bdl	0.001	0.37	0.0002	0.0034	bdl	<0.001	0.0001
MS298	4/10/14	bdl	0.001	<0.001	0.00	0.0009	0.0006	0.00002	0.005	0.0004
MS299	4/10/14	bdl	0.002	0.001	0.03	0.0008	0.0004	<0.00001	0.005	0.0003
MS300	4/10/14	bdl	0.000	0.002	0.14	0.0004	0.0003	0.00001	0.045	0.0002
MS301	4/10/14	bdl	0.000	0.001	0.24	0.0003	0.0003	bdl	0.003	0.0002
MS302	4/10/14	bdl	0.008	0.001	0.64	0.0003	0.0001	bdl	0.003	0.0002
MS303	4/10/14	bdl	0.000	0.001	0.05	0.0002	0.0001	0.00001	0.002	0.0003
MS304	4/10/14	bdl	0.001	0.000	0.04	0.0002	0.0001	bdl	0.007	0.0001
MS318	5/20/14	bdl	0.002	0.001	0.92	0.0001	0.0003	bdl	0.002	0.0001
MS319	5/20/14	bdl	<0.001	0.001	0.22	0.0001	0.0002	<0.00001	0.003	0.0002
MS320	5/20/14	bdl	0.004	0.001	0.56	0.0001	0.0006	bdl	0.004	0.0001
MS321	5/20/14	bdl	0.003	0.001	0.19	<0.0001	0.0006	0.00003	0.001	0.0001
MS322	5/20/14	bdl	0.001	0.001	0.05	0.0001	0.0004	0.00002	0.006	0.0001
MS323	5/20/14	bdl	0.001	0.001	0.15	0.0001	0.0001	bdl	0.003	<0.0001
MS324	5/20/14	bdl	<0.001	0.001	0.28	0.0001	0.0005	bdl	0.004	<0.0001
MS333	7/17/14	0.001	0.005	0.001	0.18	0.0002	0.0015	0.00053	0.005	0.0010
MS334	7/17/14	0.003	0.007	0.001	0.57	0.0013	0.0007	0.00015	0.008	0.0004
MS335	7/17/14	0.003	0.002	0.001	0.28	0.0009	0.0007	0.00017	0.093	0.0002
MS336	7/17/14	0.007	0.004	0.001	0.19	0.0009	0.0006	0.00011	0.011	0.0003
MS337	7/17/14	0.004	0.003	0.001	0.10	0.0007	0.0006	0.00012	0.010	0.0002
MS338	7/17/14	0.026	0.020	0.001	0.24	0.0022	0.0021	0.00016	0.093	0.0005

MS344	7/28/14	0.004	0.005	0.002	0.17	0.0006	0.0007	0.0001	0.010	0.0001
MS345	7/28/14	bdl	0.002	0.001	0.03	0.0002	bdl	<0.00001	0.003	bdl
MS346	7/28/14	bdl	0.002	0.001	0.10	0.0001	<0.0001	0.0001	0.004	<0.0001
MS350	7/30/14	bdl	0.003	0.001	0.67	0.0011	0.0002	bdl	0.004	0.0002
MS351	8/12/14	bdl	0.003	0.001	0.41	0.0003	bdl	bdl	0.004	0.0001
MS352	8/12/14	bdl	0.002	0.002	0.44	0.0002	bdl	bdl	0.002	0.0001
MS353	8/12/14	bdl	0.003	0.002	0.29	0.0002	0.0002	0.0001	0.008	0.0001
MS354	8/12/14	bdl	0.003	0.001	0.05	0.0003	0.0001	bdl	0.003	0.0002
MS355	8/12/14	bdl	0.002	0.001	0.17	0.0002	0.0004	bdl	0.007	bdl
MS356	8/12/14	bdl	0.002	0.001	0.15	0.0002	0.0003	bdl	0.002	bdl
MS357	8/12/14	bdl	0.003	0.001	0.28	0.0001	0.0001	bdl	0.002	bdl
MS358	8/12/14	bdl	0.002	0.001	0.10	0.0003	0.0001	0.0001	0.001	0.0001
MS360	8/26/14	0.001	0.002	<0.001	0.000	0.0014	0.0002	0.0001	0.005	0.001
MS361	8/26/14	0.004	0.004	0.002	0.240	0.002	0.0004	0.0001	0.004	0.001
MS375	9/2/14	0.001	<0.001	0.002	0.97	bdl	bdl	bdl	<0.001	bdl
MS376	9/2/14	0.002	<0.001	0.003	0.74	bdl	bdl	bdl	0.018	bdl
MS377	9/2/14	0.002	bdl	0.001	0.42	bdl	bdl	bdl	bdl	bdl
MS378	9/2/14	0.002	bdl	0.003	1.27	bdl	bdl	bdl	0.008	bdl
MS379	9/2/14	0.001	<0.001	0.003	0.64	bdl	bdl	bdl	bdl	bdl
MS380	9/2/14	0.002	bdl	0.003	1.33	bdl	bdl	bdl	0.002	0.0022
MS381	9/2/14	0.004	<0.001	0.003	0.46	bdl	bdl	bdl	bdl	bdl
MS382	9/2/14	0.002	bdl	0.002	0.54	bdl	bdl	bdl	0.006	bdl
MS383	9/2/14	0.002	bdl	0.003	0.54	bdl	bdl	bdl	bdl	bdl
MS384	9/2/14	0.002	<0.001	0.002	0.95	bdl	bdl	bdl	0.003	bdl
MS385	9/2/14	0.003	bdl	0.001	0.13	bdl	bdl	bdl	bdl	bdl
MS386	9/2/14	0.001	bdl	<0.001	0.11	bdl	bdl	bdl	bdl	bdl
MS388	9/15/14	0.002	bdl	<0.001	0.53	0.0004	bdl	bdl	bdl	bdl
MS389	9/15/14	0.001	bdl	0.001	0.34	0.0003	bdl	bdl	bdl	bdl
MS390	9/15/14	0.002	bdl	0.001	0.41	0.0004	bdl	bdl	bdl	bdl

MS391	9/30/14	0.006	0.001	0.003	0.21	0.0003	bdl	bdl	0.002	0.0001
MS392	9/30/14	0.001	<0.001	0.002	0.09	0.0002	bdl	bdl	0.003	0.0002
MS393	9/30/14	0.001	0.001	0.002	0.34	0.0004	bdl	bdl	0.002	0.0001
MS394	9/30/14	0.001	0.001	0.001	0.35	0.0006	bdl	0.0001	0.003	0.0002
MS395	9/30/14	0.002	0.001	<0.001	0.00	0.0002	bdl	<0.0001	0.002	0.0001
MS396	9/30/14	<0.001	<0.001	0.002	0.31	0.0002	bdl	<0.0001	0.003	0.0001
MS397	9/30/14	0.001	0.002	0.003	0.43	0.0003	0.0002	0.0001	0.003	<0.0001
MS398	9/30/14	0.001	0.001	0.002	1.08	0.0005	bdl	<0.0001	0.003	<0.0001
MS399	9/30/14	0.002	0.001	0.001	0.71	0.0005	0.0001	0.0001	0.003	0.0001
MS400	9/30/14	0.001	0.001	0.001	1.07	0.0005	bdl	bdl	0.003	<0.0001
MS401	9/30/14	0.001	0.004	0.001	0.47	0.0001	0.0005	bdl	0.001	<0.0001
MS402	9/30/14	0.002	0.001	0.001	0.05	0.0001	0.0001	<0.0001	0.001	0.0001
MS403	9/30/14	<0.001	0.001	0.001	0.12	0.0003	bdl	<0.0001	0.001	0.0001
MS404	10/21/14	<0.01	0.005	0.002	0.28	0.0003	0.0023	bdl	0.005	0.0001
MS405	10/21/14	<0.01	0.005	0.004	0.30	0.0001	0.0012	bdl	0.004	bdl
MS406	10/21/14	<0.01	0.006	0.001	0.21	0.0002	0.0014	bdl	0.002	bdl
MS407	10/21/14	<0.01	0.005	0.001	0.21	0.0001	0.0029	bdl	0.002	bdl
MS408	10/21/14	<0.01	0.004	0.001	0.10	0.0001	0.0017	bdl	0.004	0.0001
MS409	10/21/14	<0.01	0.004	0.003	0.49	0.0003	0.0014	0.0001	0.007	bdl
MS410	10/29/14	0.004	0.003	0.001	0.19	0.0012	0.0009	bdl	0.005	0.0002
MS411	10/29/14	0.002	0.004	0.002	0.14	0.0007	0.0006	0.0001	0.004	0.0002
MS412	10/29/14	0.003	0.003	0.001	0.25	0.0002	0.0004	bdl	0.003	0.0001
MS413	10/29/14	0.005	0.009	0.001	0.58	0.0002	0.0008	bdl	0.003	0.0001
MS414	10/29/14	<0.01	0.007	0.001	0.75	0.0002	0.0010	bdl	0.003	0.0001
MS415	10/29/14	<0.01	0.002	0.001	0.23	bdl	0.0010	bdl	0.004	0.0001
MS416	10/29/14	<0.01	0.002	0.001	0.06	0.0001	0.0008	bdl	0.003	0.0001
MS417	10/29/14	<0.01	0.005	0.002	0.35	bdl	0.0009	bdl	0.004	0.0001
MS418	10/29/14	<0.01	0.007	0.002	0.53	bdl	0.0003	bdl	0.003	0.0002
MS419	10/29/14	<0.01	0.004	0.001	0.09	bdl	0.0008	bdl	0.004	bdl

MS420	11/9/14	<0.01	0.004	0.001	0.21	bdl	0.0016	bdl	0.003	bdl
MS421	11/12/14	<0.01	0.010	0.001	0.70	0.0007	0.0008	bdl	0.005	0.0002
MS422	11/12/14	<0.01	0.005	0.002	0.41	0.0006	0.0008	bdl	0.006	0.0003
MS423	12/3/14	0.005	0.006	0.002	0.03	bdl	0.0003	bdl	0.001	0.0004
MS424	12/19/14	0.004	0.011	0.001	0.50	bdl	bdl	bdl	0.002	bdl
MS425	12/19/14	0.004	0.007	0.001	0.11	bdl	bdl	0.0003	0.002	0.0001
MS426	12/19/14	0.003	0.007	0.001	0.11	bdl	bdl	0.0002	0.002	0.0001
MS427	12/19/14	0.003	0.007	0.001	<0.01	bdl	bdl	bdl	0.003	bdl
MS428	12/19/14	0.003	0.006	0.000	0.05	bdl	bdl	bdl	0.001	bdl
MS429	12/19/14	0.003	0.010	0.002	0.31	bdl	bdl	bdl	0.001	bdl
MS430	12/19/14	0.001	0.006	0.001	0.06	bdl	bdl	bdl	0.001	bdl
MS431	12/19/14	0.00	0.01	0.00	0.02	bdl	bdl	bdl	0.00	bdl

Sample	ICPMS Analysis Date	Ba (mg/L)	W (mg/L)	Pb (mg/L)	U (mg/L)
MS007	8/28/11	0.03	bdl	0.006	bdl
MS009	9/19/11	0.12	bdl	0.006	bdl
MS010	9/19/11	0.07	bdl	bdl	0.0004
MS014	9/22/11	0.12	bdl	bdl	bdl
MS015	10/22/11	0.28	bdl	bdl	bdl
MS016	10/22/11	0.06	bdl	0.0016	bdl
MS017	10/22/11	0.22	bdl	bdl	bdl
MS018	10/22/11	0.03	bdl	bdl	bdl
MS019	10/22/11	0.09	bdl	bdl	bdl
MS020	-	0.04	bdl	bdl	bdl
MS021	-	0.01	bdl	0.0085	bdl
MS022	-	0.1	bdl	bdl	bdl
MS023	11/26/11	0.06	bdl	bdl	bdl
MS024	11/26/11	0.06	bdl	bdl	bdl
MS026	1/17/12	0.08	bdl	bdl	bdl
MS027	1/17/12	0.08	bdl	bdl	bdl
MS032	5/12/12	0.07	0.00019	bdl	bdl
MS033	5/12/12	0.06	0.00009	bdl	bdl
MS034	5/12/12	0.09	0.00006	bdl	bdl
MS050	9/17/12	0.39	bdl	bdl	bdl
MS051	9/17/12	0.20	bdl	bdl	bdl
MS052	9/17/12	0.22	bdl	bdl	bdl
MS053	9/17/12	0.12	bdl	bdl	bdl
MS054	9/17/12	0.18	bdl	bdl	bdl
MS055	9/17/12	0.26	bdl	bdl	bdl
MS056	9/17/12	0.14	bdl	bdl	bdl
MS057	9/17/12	0.17	bdl	bdl	bdl
MS058	9/17/12	0.22	bdl	bdl	bdl
MS064	10/18/12	0.06	<0.001	<0.0001	<0.0001
MS065	12/14/12	0.22	<0.001	<0.0001	<0.0001
MS066	12/14/12	0.03	<0.001	bdl	bdl
MS067	12/14/12	0.05	<0.001	bdl	bdl
MS068	12/14/12	0.32	<0.001	<0.0001	<0.0001
MS071	12/14/12	0.06	<0.001	<0.0001	<0.0001
MS072	12/14/12	0.05	<0.001	bdl	bdl
MS073	10/18/12	0.10	<0.001	<0.0001	<0.0001
MS074	12/14/12	0.05	<0.001	bdl	bdl
MS085	11/27/12	bdl	bdl	bdl	bdl
MS086	11/27/12	bdl	bdl	bdl	bdl
MS087	11/27/12	bdl	bdl	bdl	bdl

MS088	11/27/12	bdl	bdl	bdl	bdl
MS089	11/27/12	bdl	bdl	bdl	bdl
MS090	11/27/12	bdl	bdl	bdl	bdl
MS091	11/27/12	bdl	bdl	bdl	bdl
MS092	11/27/12	bdl	bdl	bdl	bdl
MS093	11/27/12	bdl	bdl	bdl	bdl
MS098	12/14/12	0.14	<0.0001	<0.0001	bdl
MS099	1/30/13	0.05	<0.0001	<0.0001	0.00
MS100	1/30/13	0.03	<0.0001	<0.0001	bdl
MS101	1/30/13	0.42	<0.0001	<0.0001	bdl
MS102	1/30/13	0.16	<0.0001	<0.0001	bdl
MS103	1/30/13	0.05	0.00	0.00	bdl
MS104	12/14/12	0.06	0.00	0.01	bdl
MS105	12/14/12	0.02	0.00	0.00	bdl
MS106	12/14/12	0.05	0.00	0.01	0.00
MS107	12/14/12	bdl	0.00	0.00	bdl
MS108	12/14/12	0.08	0.00	0.00	bdl
MS113	1/30/13	0.32	0.00	0.00	bdl
MS114	1/30/13	0.14	0.00	bdl	0.00
MS115	1/30/13	0.32	0.00	0.00	bdl
MS116	1/30/13	0.40	0.00	<0.0001	bdl
MS117	1/30/13	0.00	0.00	<0.0001	bdl
MS118	1/30/13	0.08	0.00	0.00	bdl
MS119	1/30/13	0.07	0.00	0.00	bdl
MS120	1/30/13	0.21	0.00	<0.0001	bdl
MS121	1/30/13	0.07	0.00	<0.0001	bdl
MS124	1/30/13	0.21	<0.0001	0.00	bdl
MS125	1/30/13	0.14	<0.0001	<0.0001	<0.0001
MS126	1/30/13	0.05	<0.0001	<0.0001	bdl
MS127	1/30/13	0.07	<0.0001	<0.0001	bdl
MS128	1/30/13	0.27	<0.0001	<0.0001	bdl
MS143	1/30/13	0.16	bdl	bdl	0.00
MS145	1/30/13	0.23	bdl	bdl	<0.0001
MS157	3/12/13	0.13	bdl	bdl	bdl
MS158	3/12/13	0.02	bdl	bdl	bdl
MS159	3/12/13	0.12	bdl	bdl	bdl
MS160	3/12/13	0.15	bdl	bdl	bdl
MS161	3/12/13	0.33	bdl	bdl	bdl
MS164	3/26/13	0.34	0.00	0.00	<0.0001
MS165 1	3/20/13	0.17	<0.0001	0.00	0.00
MS165 2	3/20/13	0.17	bdl	bdl	0.00
MS169	5/14/13	0.07	0.00	0.00	<0.0001
MS171	5/14/13	0.23	0.00	bdl	bdl
MS172	5/14/13	0.03	0.00	0.00	bdl

MS173	5/14/13	0.04	0.00	0.00	bdl
MS174	5/14/13	0.27	0.00	0.00	bdl
MS175	5/14/13	0.20	0.00	<0.0001	bdl
MS182	5/14/13	0.32	<0.0001	0.00	bdl
MS183	5/14/13	0.24	<0.0001	<0.0001	bdl
MS184	5/24/13	0.05	0.00	0.00	bdl
MS186	5/14/13	0.47	<0.0001	0.00	bdl
MS187	5/14/13	0.20	<0.0001	bdl	bdl
MS188	7/22/13	0.34	0.00	0.00	bdl
MS190	7/11/13	0.14	0.00	bdl	bdl
MS192	7/12/13	0.95	0.00	bdl	0.00
MS193	7/12/13	3.64	<0.0001	0.00	<0.00001
MS194	7/12/13	4.58	0.00	0.00	bdl
MS195	7/12/13	7.03	bdl	bdl	bdl
MS198	8/21/13	0.10	0.00	0.00	<0.00001
MS199	8/21/13	0.10	0.00	<0.0001	0.00
MS200	8/21/13	0.07	0.00	0.00	<0.00001
MS201	8/21/13	0.38	0.00	<0.0001	<0.00001
MS202	8/21/13	0.63	0.00	0.00	<0.00001
MS203	8/21/13	0.22	0.00	bdl	0.00
MS204	8/21/13	0.25	0.00	0.00	<0.00001
MS205	8/21/13	0.23	0.00	<0.0001	<0.00001
MS206	8/21/13	0.07	0.00	0.00	<0.00001
MS207	8/21/13	0.04	0.00	0.00	bdl
MS209	8/21/13	0.19	0.00	0.00	0.00
MS210	8/21/13	0.00	0.00	<0.0001	<0.00001
MS211	8/21/13	0.22	0.00	<0.0001	bdl
MS212	8/21/13	0.29	0.00	0.00	bdl
MS213	8/21/13	3.74	0.00	0.00	bdl
MS214	8/21/13	5.54	0.00	<0.0001	bdl
MS215	8/21/13	0.15	0.00	0.00	0.00
MS221	9/25/13	0.26	0.00	0.00	0.00
MS222	9/25/13	0.10	0.00	0.00	0.00
MS223	9/25/13	0.04	0.00	0.00	0.00
MS224	9/25/13	0.54	0.00	0.00	0.00
MS225	9/25/13	0.20	0.00	0.00	0.00
MS226	10/16/13	0.49	0.00	bdl	0.00
MS227	10/16/13	3.01	0.00	bdl	<0.00001
MS228	10/16/13	0.02	0.00	0.00	bdl
MS229	10/16/13	0.36	0.00	bdl	0.00
MS230	11/13/13	0.10	0.00060	bdl	0.00004
MS231	11/13/13	0.43	0.00047	bdl	0.00001
MS232 1	11/13/13	0.07	0.00039	bdl	bdl
MS232 2	11/13/13	0.07	0.00033	0.0007	bdl

MS233	11/13/13	0.08	0.00	bdl	0.00
MS234	11/13/13	0.08	0.00	bdl	bdl
MS235 1	11/13/13	0.20	0.00	bdl	bdl
MS235 2	11/13/13	0.19	0.00	bdl	bdl
MS249	12/17/13	0.07	0.00	0.00	0.00
MS253	1/30/14	0.11	bdl	0.0007	bdl
MS254	1/30/14	0.08	bdl	0.0012	0.0002
MS255	1/30/14	0.19	bdl	0.0018	0.0001
MS256	1/30/14	0.45	bdl	0.0005	bdl
MS257	1/30/14	0.07	0.00039	bdl	bdl
MS269	3/24/14	0.34	bdl	0.0005	bdl
MS270	3/24/14	0.43	bdl	0.0021	<0.00001
MS271	3/24/14	0.11	bdl	0.0026	bdl
MS272	3/24/14	0.15	bdl	0.0003	bdl
MS273	3/24/14	0.10	bdl	0.0001	0.00007
MS274	3/24/14	0.07	bdl	0.0004	0.00009
MS275	3/24/14	0.11	bdl	0.0003	0.00010
MS276	3/24/14	0.16	bdl	0.0012	0.00009
MS277	3/24/14	0.10	bdl	0.0021	0.00003
MS297	3/24/14	0.07	bdl	0.0002	0.00003
MS298	4/10/14	0.02	0.003	0.0001	0.00002
MS299	4/10/14	0.06	0.002	0.0001	0.00002
MS300	4/10/14	0.31	0.002	0.0007	<0.00001
MS301	4/10/14	0.13	0.001	0.0001	<0.00001
MS302	4/10/14	0.54	0.001	0.0004	0.00001
MS303	4/10/14	0.09	0.001	0.0022	bdl
MS304	4/10/14	0.06	0.001	0.0007	<0.00001
MS318	5/20/14	1.15	<0.001	0.0005	0.00002
MS319	5/20/14	0.18	<0.001	0.0013	0.00025
MS320	5/20/14	0.42	<0.001	0.0008	0.00002
MS321	5/20/14	0.55	<0.001	0.0031	0.00009
MS322	5/20/14	0.10	<0.001	0.0076	bdl
MS323	5/20/14	0.10	<0.001	0.0006	0.00003
MS324	5/20/14	0.14	<0.001	0.0001	<0.00001
MS333	7/17/14	0.13	<0.001	0.0002	0.00014
MS334	7/17/14	0.42	0.002	0.0008	0.00015
MS335	7/17/14	0.09	0.001	0.0008	0.00009
MS336	7/17/14	0.18	0.001	0.0009	0.00013
MS337	7/17/14	0.07	0.001	0.0064	0.00008
MS338	7/17/14	0.12	0.003	0.0342	0.00016
MS344	7/28/14	0.20	0.0003	0.0013	0.00008
MS345	7/28/14	0.05	bdl	0.0001	bdl
MS346	7/28/14	0.20	bdl	0.0006	bdl
MS350	7/30/14	0.11	0.0007	0.0009	0.00025

MS351	8/12/14	0.25	0.0006	0.0001	<0.00001
MS352	8/12/14	0.21	0.0005	0.0021	bdl
MS353	8/12/14	0.31	0.0004	0.0007	0.00001
MS354	8/12/14	0.05	0.0004	0.0009	0.00003
MS355	8/12/14	0.23	0.0003	0.0006	bdl
MS356	8/12/14	0.25	0.0002	0.0001	bdl
MS357	8/12/14	0.14	0.0002	0.0002	bdl
MS358	8/12/14	0.18	0.0001	0.0002	0.00002
MS360	8/26/14	0.000	0.0026	0.0001	bdl
MS361	8/26/14	0.360	0.0034	0.0024	bdl
MS375	9/2/14	1.16	bdl	0.0001	bdl
MS376	9/2/14	1.00	bdl	0.0004	bdl
MS377	9/2/14	0.10	bdl	bdl	bdl
MS378	9/2/14	0.08	bdl	0.0039	bdl
MS379	9/2/14	0.10	bdl	0.0003	bdl
MS380	9/2/14	0.13	bdl	0.0001	bdl
MS381	9/2/14	0.45	bdl	bdl	bdl
MS382	9/2/14	0.24	bdl	0.0018	bdl
MS383	9/2/14	0.25	bdl	0.0004	bdl
MS384	9/2/14	0.14	bdl	0.0002	bdl
MS385	9/2/14	0.31	bdl	bdl	bdl
MS386	9/2/14	0.09	bdl	bdl	bdl
MS388	9/15/14	0.23	bdl	bdl	bdl
MS389	9/15/14	0.36	bdl	bdl	bdl
MS390	9/15/14	0.07	bdl	0.0035	bdl
MS391	9/30/14	0.21	0.0006	0.0018	bdl
MS392	9/30/14	0.15	0.0005	0.0035	bdl
MS393	9/30/14	0.19	0.0005	0.0026	bdl
MS394	9/30/14	0.21	0.0004	0.0086	bdl
MS395	9/30/14	0.00	0.0003	0.0002	bdl
MS396	9/30/14	0.36	0.0002	0.0005	bdl
MS397	9/30/14	0.77	0.0002	0.0026	bdl
MS398	9/30/14	1.20	0.0002	0.0004	bdl
MS399	9/30/14	0.26	0.0002	0.0006	0.0008
MS400	9/30/14	0.19	0.0002	0.0011	0.0001
MS401	9/30/14	0.39	0.0001	0.0009	bdl
MS402	9/30/14	0.09	0.0001	0.0088	bdl
MS403	9/30/14	0.10	0.0001	0.0015	bdl
MS404	10/21/14	0.05	bdl	0.0012	0.0005
MS405	10/21/14	0.07	bdl	0.0004	bdl
MS406	10/21/14	0.22	bdl	0.0001	bdl
MS407	10/21/14	0.16	0.0001	0.0002	0.0001
MS408	10/21/14	0.08	bdl	0.0003	bdl
MS409	10/21/14	0.29	bdl	0.0006	bdl

MS410	10/29/14	0.14	0.0028	0.0002	0.0001
MS411	10/29/14	0.08	0.0016	0.0002	bdl
MS412	10/29/14	0.12	0.0012	0.0001	bdl
MS413	10/29/14	0.48	0.0009	0.0002	bdl
MS414	10/29/14	0.58	0.0007	0.0031	bdl
MS415	10/29/14	0.06	0.0005	0.0007	bdl
MS416	10/29/14	0.13	0.0005	0.0001	bdl
MS417	10/29/14	0.17	0.0004	0.0003	bdl
MS418	10/29/14	0.20	0.0003	0.0001	bdl
MS419	10/29/14	0.21	0.0002	0.0003	bdl
MS420	11/9/14	0.14	0.0002	0.0001	bdl
MS421	11/12/14	0.25	0.0002	0.0007	0.0001
MS422	11/12/14	0.24	0.0002	0.0005	bdl
MS423	12/3/14	0.04	0.0002	0.0001	bdl
MS424	12/19/14	0.43	0.0001	0.0077	bdl
MS425	12/19/14	0.08	0.0001	0.0079	bdl
MS426	12/19/14	0.08	0.0001	0.0067	bdl
MS427	12/19/14	0.00	0.0001	0.0053	bdl
MS428	12/19/14	0.05	0.0001	0.0044	bdl
MS429	12/19/14	0.61	0.0001	0.0087	0.0001
MS430	12/19/14	0.31	bdl	0.0037	bdl
MS431	12/19/14	0.04	0.00	0.00	bdl

Appendix H: Ion Chromatography (IC) Water Chemistry Data

Sample	IC-Analysis-Date	Fluoride-(mg/L)	Chloride-(mg/L)	Nitrite-(mg/L	Bromide-(mg/L)	Nitrate-(mg/L)	Phosphate-(mg/L)	Sulfate-(mg/L)
MS007	-	-	45.77	-	-	3.43	0.87	43.81
MS009	-	-	2.14	-	-	1.27	-	11.31
MS010	-	-	16.78	-	-	0.52	1.52	12.04
MS014	-	-	4.15	-	-	1.14	10.76	-
MS015	-	-	222.69	-	1.39	1.60	-	15.89
MS016	-	-	6.89	-	-	2.78	-	7.09
MS017	-	-	44.92	-	0.32	0.24	-	6.57
MS018	-	-	46.22	-	0.32	1.21	-	134.70
MS019	-	-	3.19	-	0.07	0.95	0.68	9.62
MS020	-	-	46.02	-	0.47	1.29	0.31	134.82
MS021	-	-	56.31	-	-	1.10	-	80.51
MS022	-	-	6.00	-	-	1.87	1.21	17.78
MS023	-	-	44.62	-	0.08	1.28	-	20.06
MS024	-	-	38.34	-	0.09	1.20	-	16.28
MS026	-	-	11.35	-	-	1.47	-	35.41
MS027	-	-	12.88	-	0.34	1.64	-	37.12
MS032	-	0.03	14.02	-	0.14	3.14	bdl	38.63
MS033	-	0.08	15.26	-	0.19	0.15	bdl	10.07
MS034	-	0.03	14.88	-	0.08	0.14	bdl	30.94
MS050	9/7/12	5.80	143.64	bdl	bdl	0.96	0.20	34.43
MS051	9/7/12	5.31	1.81	bdl	bdl	0.49	bdl	10.01
MS052	9/7/12	5.35	63.50	bdl	bdl	1.09	bdl	43.50
MS053	9/7/12	3.04	45.79	bdl	0.30	0.62	0.23	102.10
MS054	9/7/12	5.02	1.94	bdl	0.03	0.25	bdl	11.34
MS055	9/7/12	0.10	37.51	bdl	0.21	0.30	bdl	15.66

MS056	9/7/12	5.21	7.68	bdl	bdl	14.69	bdl	30.58
MS057	9/7/12	1.53	7.91	bdl	0.03	0.26	bdl	14.20
MS058	9/7/12	0.13	44.65	-	bdl	1.07	bdl	20.18
MS064	10/19/12	4.27	34.77	bdl	bdl	0.64	bdl	55.29
MS065	10/19/12	4.52	84.99	bdl	bdl	1.15	bdl	21.89
MS066	10/19/12	0.92	12.23	bdl	0.05	0.20	bdl	41.06
MS067	10/19/12	2.79	5.76	bdl	bdl	0.26	bdl	66.49
MS068	10/19/12	1.15	144.76	bdl	bdl	1.04	bdl	20.70
MS071	10/23/12	4.49	6.05	bdl	bdl	0.08	bdl	43.08
MS072	10/23/12	3.03	6.56	bdl	bdl	0.38	bdl	14.70
MS073	10/23/12	2.26	1.64	bdl	bdl	0.08	bdl	11.88
MS074	10/23/12	5.28	6.87	bdl	bdl	bdl	bdl	31.76
MS085	11/14/12	1.00	1.69	bdl	bdl	0.43	2.26	10.92
MS086	11/15/12	2.95	155.07	bdl	bdl	0.69	1.29	24.89
MS087	11/14/12	0.30	17.18	bdl	0.43	0.64	1.19	21.49
MS088	11/14/12	1.24	18.96	bdl	0.15	1.02	0.62	44.34
MS089	11/14/12	3.02	9.85	bdl	bdl	1.26	0.41	23.49
MS090	11/14/12	0.68	65.71	bdl	0.09	1.21	0.60	49.44
MS091	11/14/12	0.96	37.19	bdl	bdl	0.74	1.28	8.52
MS092	11/14/12	4.44	5.60	bdl	0.07	0.43	1.28	22.37
MS093	11/14/12	4.38	7.93	bdl	bdl	1.14	1.30	27.20
MS098	12/18/12	0.15	1.44	bdl	bdl	0.05	0.15	10.93
MS099	12/18/12	2.68	36.03	bdl	bdl	0.54	bdl	105.94
MS100	12/18/12	4.87	20.61	bdl	bdl	bdl	bdl	79.65
MS101	12/18/12	1.88	118.79	bdl	0.88	bdl	bdl	18.33
MS102	12/18/12	2.77	43.10	bdl	0.28	bdl	bdl	105.32
MS103	12/18/12	4.82	16.19	bdl	bdl	14.84	bdl	17.57
MS104	12/18/12	3.70	3.84	bdl	bdl	0.80	bdl	10.37
MS105	12/18/12	3.39	5.25	bdl	bdl	bdl	bdl	16.05

MS106	12/18/12	2.66	16.96	bdl	bdl	bdl	bdl	23.81
MS107	12/18/12	0.65	6.48	bdl	bdl	26.81	bdl	18.61
MS108	12/18/12	4.33	0.80	bdl	bdl	0.36	bdl	12.85
MS113	1/16/13	1.84	20.13	bdl	0.12	1.87	bdl	9.06
MS114	1/16/13	6.07	1.67	bdl	bdl	0.30	bdl	10.42
MS115	1/16/13	0.38	156.41	bdl	bdl	bdl	bdl	31.14
MS116	1/16/13	0.50	128.19	bdl	bdl	0.90	bdl	18.05
MS117	1/16/13	4.87	17.53	bdl	bdl	0.84	bdl	4.50
MS118	1/16/13	5.65	3.40	bdl	bdl	0.20	bdl	34.88
MS119	1/16/13	0.67	34.72	bdl	bdl	25.90	bdl	35.36
MS120	1/16/13	5.54	64.71	bdl	bdl	1.05	bdl	46.79
MS121	1/16/13	0.30	2.79	bdl	bdl	0.21	bdl	14.05
MS124	1/18/13	5.87	271.90	bdl	bdl	1.13	bdl	25.85
MS125	1/18/13	0.05	19.44	bdl	0.19	0.16	bdl	0.58
MS126	1/18/13	6.72	9.40	bdl	bdl	0.32	bdl	71.31
MS127	1/18/13	0.16	59.58	bdl	bdl	0.42	bdl	46.03
MS128	1/18/13	5.97	9.46	bdl	bdl	0.33	bdl	11.26
MS143	1/31/13	1.52	1.08	bdl	0.57	0.17	bdl	9.52
MS145	1/31/13	3.03	40.98	bdl	1.07	bdl	bdl	15.25
MS157	3/5/13	0.77	1.29	bdl	0.05	bdl	bdl	9.84
MS158	3/5/13	6.54	24.41	bdl	bdl	1.80	0.43	36.52
MS159-	3/5/13	1.49	33.29	bdl	0.17	0.67	bdl	28.78
MS160	3/5/13	5.49	35.29	bdl	0.27	0.40	bdl	58.82
MS161	3/5/13	5.78	108.81	bdl	0.91	0.43	bdl	18.03
MS164	3/22/13	1.29	9.00	bdl	bdl	0.28	bdl	5.21
MS165-1	3/22/13	6.52	1.44	bdl	bdl	0.85	bdl	10.36
MS165-2	3/22/13	1.59	1.55	bdl	bdl	0.56	bdl	9.63
MS169	5/14/13	4.88	25.71	bdl	0.55	bdl	bdl	0.18
MS171	5/14/13	4.36	12.80	bdl	0.41	bdl	bdl	1.89

MS172	5/14/13	6.16	16.04	bdl	bdl	2.88	bdl	32.39
MS173	5/14/13	4.85	6.97	bdl	bdl	3.73	bdl	22.78
MS174	5/14/13	2.22	44.58	bdl	0.61	bdl	bdl	0.62
MS175	5/14/13	5.79	5.90	bdl	0.44	bdl	bdl	15.33
MS182	6/3/13	4.12	169.77	bdl	1.74	0.22	bdl	34.89
MS183	6/3/13	1.64	233.74	bdl	3.20	bdl	bdl	24.14
MS184	6/4/13	4.73	42.92	bdl	0.87	bdl	0.32	87.25
MS186	6/4/13	4.68	168.57	bdl	1.59	0.43	bdl	27.57
MS187	6/4/13	2.75	67.70	bdl	0.53	0.65	bdl	60.80
MS188	7/23/13	0.14	4.01	bdl	0.80	0.28	bdl	5.08
MS190	-	0.05	5.14	bdl	0.67	0.22	bdl	15.49
MS192	-	0.11	30.49	bdl	1.46	1.01	bdl	2.46
MS193	-	0.08	45.74	bdl	1.44	0.18	bdl	0.75
MS194	-	0.15	7.45	bdl	0.97	0.05	bdl	3.74
MS195	-	0.18	16.37	bdl	0.97	bdl	bdl	0.38
MS198	8/12/13	0.12	6.08	bdl	bdl	0.41	bdl	27.84
MS199	8/12/13	0.06	3.78	bdl	bdl	2.10	bdl	44.84
MS200	8/12/13	0.11	62.03	bdl	bdl	0.67	bdl	61.03
MS201	8/12/13	0.04	117.37	bdl	0.33	bdl	bdl	32.14
MS202	8/12/13	0.19	187.61	bdl	0.98	1.09	bdl	38.00
MS203	8/12/13	0.07	11.74	bdl	bdl	1.88	bdl	15.30
MS204	8/12/13	0.03	36.79	bdl	bdl	0.63	bdl	35.36
MS205	8/12/13	0.05	69.10	bdl	bdl	2.24	bdl	23.78
MS206	8/12/13	0.52	47.13	bdl	bdl	1.50	bdl	106.71
MS207	8/12/13	0.01	0.66	bdl	bdl	0.05	bdl	22.35
MS209	8/30/13	bdl	36.07	bdl	bdl	2.89	bdl	12.70
MS210	8/30/13	0.18	2.05	bdl	bdl	0.78	0.62	14.10
MS211	8/30/13	bdl	29.57	bdl	bdl	2.93	bdl	20.45
MS212	8/30/13	bdl	154.02	bdl	bdl	1.14	bdl	19.72

MS213	8/30/13	0.39	23.30	bdl	bdl	1.07	bdl	2.63
MS214	8/30/13	bdl	94.28	bdl	bdl	1.05	bdl	0.72
MS215	8/30/13	0.36	78.87	bdl	0.35	1.50	bdl	24.31
MS221	9/17/13	bdl	48.61	bdl	1.04	1.80	bdl	19.62
MS222	9/17/13	bdl	4.38	bdl	1.40	1.77	bdl	19.25
MS223	9/17/13	bdl	11.25	bdl	1.39	10.68	bdl	38.58
MS224	9/17/13	bdl	11.21	bdl	0.59	0.23	bdl	11.46
MS225	9/17/13	bdl	9.19	bdl	0.53	0.39	bdl	12.20
MS226	9/26/13	0.06	7.06	bdl	0.79	0.24	bdl	7.29
MS227	9/26/13	bdl	1.74	bdl	0.96	1.22	bdl	0.38
MS228	9/26/13	bdl	87.12	bdl	1.07	55.89	bdl	21.32
MS229	10/3/13	0.97	195.62	bdl	0.72	0.18	bdl	20.14
MS230	10/28/13	bdl	167.68	bdl	0.90	bdl	bdl	28.10
MS231	10/28/13	bdl	147.24	bdl	0.38	0.42	bdl	31.21
MS232	10/28/13	bdl	12.84	bdl	bdl	0.56	bdl	19.25
MS233	10/28/13	bdl	4.17	bdl	bdl	0.40	bdl	48.99
MS234	10/28/13	bdl	5.59	bdl	bdl	0.31	bdl	29.82
MS235	10/28/13	bdl	34.39	bdl	bdl	0.38	bdl	33.94
MS249	11/19/13	bdl	192.90	bdl	1.90	0.36	bdl	155.90
MS253	1/10/14	bdl	179.10	bdl	0.95	bdl	bdl	111.40
MS254	1/10/14	bdl	329.90	bdl	2.10	2.80	bdl	178.30
MS255	1/17/14	bdl	1.30	bdl	bdl	0.30	bdl	10.70
MS256	1/17/14	bdl	142.60	bdl	bdl	1.50	bdl	29.20
MS257	1/17/14	bdl	10.50	bdl	bdl	0.30	bdl	13.10
MS269	2/19/14	bdl	91.18	bdl	1.13	0.83	bdl	19.44
MS270	2/19/14	bdl	62.87	bdl	0.97	0.77	bdl	30.96
MS271	2/19/14	bdl	8.57	bdl	0.74	0.87	bdl	13.85
MS272	2/19/14	bdl	4.50	bdl	0.83	1.18	bdl	10.08
MS273	3/14/14	bdl	11.45	bdl	0.50	6.66	bdl	19.70

MS274	3/14/14	bdl	2.01	bdl	0.77	18.08	bdl	10.19
MS275	3/14/14	bdl	2.93	bdl	0.92	17.18	bdl	15.14
MS276	3/14/14	bdl	0.48	bdl	1.01	0.59	bdl	12.37
MS277	3/14/14	bdl	87.12	bdl	0.67	17.13	bdl	11.86
MS297	3/22/14	bdl	4.50	bdl	1.41	4.17	bdl	30.13
MS298	4/15/14	bdl	42.47	bdl	0.35	0.38	bdl	3.55
MS299	4/15/14	bdl	43.62	bdl	0.77	0.18	bdl	63.16
MS300	4/15/14	bdl	59.78	bdl	0.64	0.72	bdl	22.06
MS301	4/14/14	bdl	6.53	bdl	0.93	0.30	bdl	13.94
MS302	4/14/14	bdl	210.99	bdl	1.01	0.14	bdl	29.51
MS303	4/14/14	bdl	12.39	bdl	0.52	3.33	bdl	15.93
MS304	4/14/14	bdl	1.74	bdl	0.37	1.27	bdl	25.19
MS318	5/20/14	bdl	35.05	bdl	0.18	0.77	bdl	3.38
MS319	5/20/14	bdl	1.06	bdl	bdl	1.30	bdl	15.59
MS320	5/20/14	bdl	138.75	bdl	0.72	1.02	bdl	41.43
MS321	5/20/14	bdl	113.08	bdl	0.81	0.66	bdl	17.79
MS322	5/20/14	bdl	13.55	bdl	bdl	0.28	bdl	16.54
MS323	5/20/14	bdl	6.16	bdl	bdl	0.49	bdl	19.37
MS324	5/20/14	bdl	7.40	bdl	0.09	1.13	bdl	16.29
MS333	7/17/14	bdl	1.27	bdl	1.00	0.31	bdl	12.84
MS334	7/17/14	bdl	196.57	bdl	3.44	0.18	bdl	30.46
MS335	7/17/14	bdl	7.07	bdl	0.59	0.18	bdl	40.52
MS336	7/17/14	bdl	15.70	bdl	0.86	0.21	bdl	31.17
MS337	7/17/14	bdl	3.98	bdl	0.85	0.19	bdl	50.06
MS338	7/17/14	bdl	7.34	bdl	1.43	0.40	bdl	14.94
MS344	7/24/14	bdl	57.97	bdl	bdl	0.86	bdl	29.39
MS345	7/24/14	bdl	42.42	bdl	0.39	0.20	0.32	79.65
MS346	7/24/14	bdl	31.02	bdl	bdl	0.08	bdl	17.45
MS350	7/31/14	0.13	59.16	bdl	bdl	6.90	bdl	53.62

MS351	8/13/14	bdl	3.86	bdl	bdl	0.25	bdl	6.71
MS352	8/13/14	bdl	1.66	bdl	bdl	0.30	bdl	10.46
MS353	8/13/14	0.08	1.71	bdl	bdl	0.26	bdl	5.86
MS354	8/13/14	0.40	0.53	bdl	bdl	0.35	0.30	1.57
MS355	8/13/14	bdl	1.57	bdl	bdl	0.30	bdl	5.13
MS356	8/13/14	bdl	7.80	bdl	bdl	0.26	bdl	5.92
MS357	8/13/14	bdl	7.83	bdl	bdl	0.42	0.23	14.71
MS358	8/13/14	0.03	18.48	bdl	bdl	22.04	bdl	19.08
MS360	8/26/14	bdl	23.06	bdl	bdl	4.91	bdl	88.84
MS361	8/26/14	bdl	53.01	bdl	bdl	4.23	bdl	9.63
MS375	9/3/14	0.10	35.87	bdl	0.06	3.31	bdl	12.83
MS376	9/3/14	0.10	5.50	bdl	0.04	2.92	bdl	3.41
MS377	9/3/14	0.10	3.43	bdl	bdl	3.23	bdl	18.06
MS378	9/3/14	0.10	90.70	bdl	bdl	11.21	bdl	40.74
MS379	9/3/14	bdl	33.03	bdl	bdl	10.81	bdl	28.54
MS380	9/3/14	bdl	58.12	bdl	bdl	3.04	bdl	39.17
MS381	9/3/14	bdl	72.67	bdl	bdl	5.34	bdl	9.14
MS382	9/3/14	bdl	32.00	bdl	bdl	3.85	bdl	20.34
MS383	9/3/14	bdl	65.84	bdl	0.06	3.08	bdl	24.99
MS384	9/3/14	0.10	34.60	bdl	0.06	3.23	bdl	28.53
MS385	9/3/14	bdl	5.05	bdl	bdl	16.72	bdl	19.65
MS386	9/3/14	bdl	59.73	bdl	bdl	3.54	bdl	35.28
MS388	9/9/14	bdl	26.33	bdl	0.04	2.89	bdl	16.85
MS389	9/9/14	0.1	2.59	bdl	bdl	8.63	bdl	14.21
MS390	9/9/14	bdl	88.59	bdl	bdl	6.53	bdl	51.91
MS391	9/17/14	0.10	27.88	bdl	bdl	0.20	bdl	11.46
MS392	9/17/14	bdl	37.54	bdl	bdl	0.16	bdl	14.10
MS393	9/17/14	0.14	0.82	bdl	bdl	0.99	bdl	8.55
MS394	9/26/14	bdl	171.69	bdl	bdl	7.18	bdl	28.43

MS395	9/26/14	bdl	73.64	bdl	bdl	0.56	bdl	11.49
MS396	9/26/14	bdl	33.49	bdl	bdl	1.09	bdl	6.11
MS397	9/26/14	0.11	38.06	bdl	0.20	0.77	bdl	8.08
MS398	9/26/14	0.33	3.79	bdl	bdl	0.83	bdl	4.21
MS399	9/26/14	bdl	129.79	bdl	bdl	9.21	bdl	25.63
MS400	9/26/14	bdl	5.65	bdl	bdl	0.82	bdl	44.07
MS401	9/26/14	bdl	121.51	bdl	1.10	1.14	bdl	25.38
MS402	9/26/14	0.07	12.25	bdl	bdl	0.13	bdl	14.65
MS403	9/26/14	0.12	5.81	bdl	bdl	0.34	bdl	17.02
MS404	10/16/14	bdl	10.97	bdl	0.54	0.53	bdl	84.26
MS405	10/16/14	bdl	2.84	bdl	0.23	0.25	bdl	162.18
MS406	10/16/14	bdl	7.19	bdl	0.15	0.13	bdl	13.31
MS407	10/16/14	0.12	1.40	bdl	0.05	0.13	bdl	11.15
MS408	10/16/14	0.08	3.44	bdl	0.10	0.21	bdl	25.16
MS409	10/16/14	0.08	20.71	bdl	0.35	0.20	bdl	2.79
MS410	10/29/14	bdl	1.21	bdl	bdl	0.86	bdl	10.03
MS411	10/29/14	bdl	18.96	bdl	bdl	2.60	bdl	65.14
MS412	10/29/14	bdl	5.67	bdl	bdl	1.68	bdl	12.71
MS413	10/29/14	bdl	158.59	bdl	0.65	1.02	bdl	21.37
MS414	10/29/14	bdl	163.92	bdl	1.29	1.11	bdl	20.85
MS415	10/29/14	bdl	41.71	bdl	bdl	1.27	bdl	50.77
MS416	10/29/14	0.04	31.65	bdl	0.11	1.12	bdl	65.64
MS417	10/29/14	bdl	47.72	bdl	0.25	1.00	bdl	34.00
MS418	10/29/14	bdl	94.80	bdl	0.53	0.29	bdl	44.52
MS419	10/29/14	bdl	28.91	bdl	bdl	0.14	bdl	13.11
MS420	11/9/14	bdl	1.38	bdl	bdl	1.12	bdl	10.24
MS421	11/12/14	bdl	37.19	bdl	0.02	3.94	bdl	15.90
MS422	11/12/14	bdl	18.55	bdl	bdl	1.69	bdl	2.57
MS423	12/9/14	0.39	4.56	bdl	bdl	0.53	bdl	0.40

MS424	12/16/14	bdl	142.06	bdl	1.59	0.64	bdl	22.34
MS425	12/16/14	bdl	26.56	bdl	bdl	1.42	bdl	36.80
MS426	12/16/14	bdl	26.19	bdl	bdl	1.53	bdl	36.17
MS427	12/16/14	0.12	26.29	bdl	0.12	0.22	bdl	1.70
MS428	12/16/14	bdl	0.49	bdl	bdl	0.08	bdl	14.86
MS429	12/16/14	0.15	225.42	bdl	0.25	0.42	bdl	2.26
MS430	12/16/14	bdl	15.61	bdl	0.08	0.11	bdl	3.89
MS431	12/16/14	0.7148	5.88	bdl	0.13	0.36	bdl	0.23

Appendix I: Resident data showing distances from nearest unconventional oil and gas well.
Highlighted areas- residents who tested for light hydrocarbons

Resident	Sample Number(s)	Well Depth (ft.)	Pre or Post-drilling sample	Distance from well (m)	Distance from well (ft.)
1	MS007, 026, 027, 032, 033, 034	330	Post	789	2591
2	MS010, 019, 022	480	Post	1000	3282
3	MS009, 014, 051, 073, 085, 098, 114, 143, 157, 165 1-2, 255, 319, 333, 407, 410, 411, 420, 425, 426	105	Post	633	2076
4	MS015, 017, 050, 115, 182, 202, 414	200	Post	905	2969
5	MS052, 120, 160, 187, 205, 300, 344	Unknown	Post	910	2987
6	MS053, 184, 206, 299, 345, 416	700 and 1000	Post	900	2954
7	MS054	Unknown	Post	502	1649
8	MS023, 024, 55, 58, 204, 235, 235ac, 346, 419	195	Post	845	2773
9	MS056	120	Post	405	1329
10	MS057, 072, 301, 324, 338, 357, 412	185	Post	279	916
11	MS064, 125	200	Post	677	2222
12	MS065, 068, 086, 101, 116, 145, 161, 186, 201, 231, 256, 269, 302, 320, 334, 401, 413, 424	178	Post	618	2027
13	MS066	275-375	Post	597	1958
14	MS067, MS335	125	Post	539	1769

15	MS071, 118, 199, 233, 337, 408	140	Post	496	1629
16	MS074, 092, 121, 198, 234	125	Post	547	1794
17	MS087, 272	130	Post	759	2490
18	MS088	165	Post	778	2554
19	MS089	Unknown	Post	910	2986
20	MS090	Unknown	Post	1129	3706
21	MS091	Unknown	Post	742	2436
22	MS093	350	Post	640	2101
23	MS099	390	Post	837	2746
24	MS100	90	Post	620	2035
25	MS018, 020, 102, 270, 321	90	Post	630	2067
26	MS103	80	Post	995	3265
27	MS104	80	Post	578	1897
28	MS105	Unknown	Post	849	2787
29	MS106, 336	190	Post	463	1520
30	MS107	150	Post	582	1911
31	MS108	365	Post	551	1808
32	MS113	185	Post	1129	3703
33	MS117	300	Post	544	1786
34	MS119	350	Post	727	2387
35	MS124	Unknown	Post	986	3237
36	MS126	380-400	Post	591	1938
37	MS127, MS200, MS415	125	Post	558	1832
38	MS128, MS203	200	Post	808	2650
39	MS021, 158	175	Post	823	2701
40	MS159	290	Post	861	2826
41	MS164	Unknown	Post	947	3109
42	MS169	125	Pre	2443	8015
43	MS171, 172, 173, 409, 422, 427	75	Post	444	1457
44	MS174	160	Post	394	1292
45	MS175, 406	100	Post	361	1186
46	MS183	Unknown	Post	1033	3391

47	MS188	150	Post	855	2805
48	MS190	145	Post	860	2823
49	MS192	300	Post	491	1612
50	MS193	Unknown	Post	302	990
51	MS194	> 100	Post	654	2147
52	MS195	Unknown	Post	652	2138
53	MS207, 428	Unknown	Post	313	1027
54	MS016	110	Post	938	3077
55	MS209	70-100	Pre	347	1139
56	MS210	120	Post	726	2384
57	MS211	160	Post	882	2896
58	MS212	30	Post	1506	4941
59	MS213	150	Post	330	1084
60	MS214	Unknown	Post	327	1074
61	MS215	> 100	Pre	940	3087
62	MS221	75	Post	3418	11215
63	MS222	225	Pre	2239	7348
64	MS223	200	Pre	3207	10523
65	MS224	Unknown	Post	495	1623
66	MS225	Unknown	Post	508	1667
67	MS226	121	Post	3127	10260
68	MS227, 228	< 100	Post	1157	3796
69	MS229	600	Post	575	1888
70	MS230	113	Post	1015	3332
71	MS232, 232ac, 257, 271, 303, 322, 402	135	Post	607	1993
72	MS249, 253	80	Post	1554	5100
73	MS254	80	Post	1606	5268
74	MS273	65	Post	876	2874
75	MS274	160	Post	3625	11895
76	MS275	387	Post	3803	12479
77	MS276	101	Post	4230	13878
78	MS277	275	Post	3671	12043
79	MS297	300	Post	3745	12287
80	MS304	320	Post	904	2966
81	MS298, 318	Unknown	Post	1041	3417
82	MS323	Unknown	Post	845	2774
83	MS350	300	Post	924	3033
84	MS351, 352, 353, 354, 355, 356	200	Post	943	3094

85	MS358	shallow, 20 gallons in basin	Post	1069	3509
86	MS360	80	Post	917	3008
87	MS361	300	Post	1089	3573
88	MS375	Unknown	Post	2799	9183
89	MS376	Unknown	Post	2833	9296
90	MS377	70	Post	2710	8891
91	MS378	200	Post	1591	5220
92	MS379	212	Post	1771	5810
93	MS380	300	Post	1799	5903
94	MS381	200	Post	1992	6535
95	MS382	175	Post	1707	5602
96	MS383	125	Post	2743	9001
97	MS384	Unknown	Post	3190	10466
98	MS385	Unknown	Post	1057	3467
99	MS386	Unknown	Post	1782	5847
100	MS388	200	Post	1154	3787
101	MS389	90	Post	804	2638
102	MS390	Unknown	Post	2082	6833
103	MS391	Unknown	Post	2094	6871
104	MS392	100	Post	2166	7106
105	MS393	265	Post	1459	4786
106	MS394	80	Post	1641	5383
107	MS395	Unknown	Post	3413	11199
108	MS396	Unknown	Post	3410	11187
109	MS397	110	Post	2774	9101
110	MS398	Unknown	Post	1587	5206
111	MS399	Unknown	Pre	-	>15,000-
112	MS400	160	Post	3704	12152
113	MS403	175	Post	778	2554
114	MS404	Unknown	Post	4545	14913
115	MS405	60	Post	4525	14845
116	MS417	Unknown	Post	1093	3586
117	MS418	120	Post	1133	3718
118	MS421	Unknown	Pre	-	>15,000
119	MS423, 431	60-80	Post	4156	13636
120	MS429	Unknown	Post	456	1496
121	MS430	120	Post	963	3162

Appendix J: Subset sample of 91 residents and the light hydrocarbon data (in µg/L) ND represents samples with Non-Detected hydrocarbons.

Sample	Methane	Ethane	Ethene	Propane	Propylene	Butane
MS113	42.32	0.58	ND	ND	ND	ND
MS114	1.09	0.02	ND	ND	ND	ND
MS116	0.42	0.01	ND	ND	ND	ND
MS143	ND	ND	ND	ND	ND	ND
MS145	ND	ND	ND	ND	ND	ND
MS164	14.77	0.01	0.01	ND	0.03	ND
MS1651	0.55	ND	ND	ND	ND	ND
MS169	14752.57	8.49	ND	0.03	0.07	0.04
MS171	ND	ND	ND	ND	ND	ND
MS184	1071.54	0.87	ND	0.03	0.05	0.03
MS186	4.21	ND	ND	ND	ND	ND
MS188	2.00	ND	ND	ND	0.02	ND
MS190	5.70	ND	ND	ND	0.04	ND
MS193	297.79	5.88	ND	0.05	0.03	ND
MS194	1625.61	9.70	ND	ND	0.11	ND
MS195	1274.13	71.22	ND	0.02	0.19	ND
MS200	0.52	ND	ND	ND	ND	ND
MS201	1.83	ND	ND	ND	ND	ND
MS206	571.16	0.28	ND	0.02	0.05	ND
MS209	0.31	ND	ND	ND	ND	ND
MS210	9.49	ND	ND	ND	0.04	ND
MS211	ND	ND	ND	ND	ND	ND
MS212	14.50	ND	ND	ND	0.03	ND
MS213	0.69	ND	ND	ND	0.04	ND
MS214	595.57	0.40	ND	ND	0.06	ND
MS215	ND	ND	ND	ND	ND	ND
MS221	4.00	ND	ND	ND	ND	ND
MS222	32.48	ND	ND	ND	0.02	ND
MS223	ND	ND	ND	ND	ND	ND
MS224	76.74	0.02	ND	ND	ND	ND
MS225	0.40	ND	ND	ND	ND	ND
MS226	23.31	ND	ND	ND	0.04	ND
MS227	116.25	0.05	ND	ND	0.03	ND
MS228	ND	ND	ND	ND	ND	ND
MS229	0.60	ND	ND	ND	ND	ND
MS230	0.37	ND	ND	ND	ND	ND
MS231	2.56	ND	ND	ND	ND	ND
MS232	0.56	ND	ND	ND	ND	ND
MS235	9.93	ND	0.03	ND	ND	0.08
MS253	4.96	ND	ND	ND	0.04	ND
MS254	ND	ND	ND	ND	ND	ND

MS255	1.37	ND	0.02	ND	ND	ND
MS256	3.38	ND	ND	ND	ND	ND
MS257	ND	ND	ND	ND	ND	ND
MS269	0.49	ND	ND	ND	ND	ND
MS270	3.60	ND	0.04	ND	ND	ND
MS271	ND	ND	ND	ND	ND	ND
MS272	ND	ND	ND	ND	ND	ND
MS273	ND	ND	ND	ND	ND	ND
MS274	1.14	ND	ND	ND	ND	ND
MS275	ND	ND	ND	ND	ND	ND
MS276	2.51	ND	ND	ND	ND	ND
MS277	ND	ND	ND	ND	ND	ND
MS297	ND	ND	ND	ND	ND	ND
MS298	57.30	0.03	ND	ND	ND	ND
MS299	1557.27	1.43	ND	0.05	0.07	ND
MS300	ND	ND	ND	ND	ND	ND
MS301	0.33	ND	ND	ND	ND	ND
MS302	0.41	ND	ND	ND	ND	ND
MS303	0.35	ND	ND	ND	ND	ND
MS304	ND	ND	ND	ND	ND	ND
MS318	3.20	ND	ND	ND	ND	ND
MS319	ND	ND	ND	ND	ND	ND
MS320	ND	ND	ND	ND	ND	ND
MS321	0.95	ND	ND	ND	ND	ND
MS322	0.37	ND	ND	ND	ND	ND
MS323	ND	ND	ND	ND	ND	ND
MS324	0.32	ND	ND	ND	ND	ND
MS333	0.61	ND	ND	ND	ND	ND
MS334	0.91	ND	ND	ND	ND	ND
MS335	15.11	ND	0.01	ND	ND	ND
MS336	3.62	0.27	ND	0.10	ND	ND
MS337	0.91	ND	ND	ND	ND	ND
MS338	0.36	ND	ND	ND	ND	ND
MS344	0.58	ND	ND	ND	ND	ND
MS345	749.34	0.69	ND	0.03	0.05	ND
MS346	9.57	0.02	0.02	0.02	ND	ND
MS350	ND	ND	ND	ND	ND	ND
MS351	6.54	ND	ND	ND	ND	ND
MS352	3.25	ND	0.02	ND	ND	ND
MS353	1.78	ND	ND	ND	ND	ND
MS354	0.96	ND	ND	ND	ND	ND
MS355	6.90	0.02	0.01	0.02	ND	ND
MS356	3.24	ND	ND	ND	ND	ND
MS357	0.43	ND	ND	ND	ND	ND
MS358	ND	ND	ND	ND	ND	ND

MS360	ND	ND	ND	ND	ND	ND
MS361	ND	ND	ND	ND	ND	ND
MS375	ND	ND	ND	ND	ND	ND
MS376	30.61	ND	ND	ND	ND	ND
MS377	8.37	ND	ND	ND	ND	ND
MS378	ND	ND	ND	ND	ND	ND
MS379	ND	ND	ND	ND	ND	ND
MS380	1.28	ND	ND	ND	ND	ND
MS381	1.52	ND	ND	ND	ND	ND
MS382	1.33	ND	ND	ND	0.02	ND
MS383	123.08	0.09	0.02	0.04	0.03	ND
MS384	10.51	ND	ND	ND	ND	ND
MS385	ND	ND	ND	ND	ND	ND
MS386	8.18	ND	ND	ND	ND	ND
MS388	ND	ND	ND	ND	ND	ND
MS389	3.23	ND	ND	0.14	ND	ND
MS390	1.17	0.02	ND	ND	ND	ND
MS391	11.58	ND	ND	ND	ND	ND
MS392	0.94	ND	0.01	ND	ND	ND
MS393	0.40	ND	ND	ND	ND	ND
MS394	0.37	ND	ND	ND	ND	ND
MS395	1.57	ND	ND	ND	ND	ND
MS396	0.69	ND	ND	ND	ND	ND
MS397	92.88	0.06	ND	ND	0.03	ND
MS398	886.03	65.12	ND	4.07	0.06	0.20
MS399	ND	ND	ND	ND	ND	ND
MS400	0.68	ND	ND	ND	ND	ND
MS401	4.16	ND	ND	ND	ND	ND
MS402	0.86	0.05	ND	ND	ND	ND
MS403	ND	ND	ND	ND	ND	ND
MS404	3.20	0.04	0.02	0.04	0.02	ND
MS405	6.25	0.06	0.03	0.05	0.04	0.03
MS406	9.29	ND	ND	ND	0.02	ND
MS407	0.48	ND	ND	ND	ND	ND
MS408	ND	ND	ND	ND	ND	ND
MS409	888.47	0.96	ND	ND	ND	ND
MS410	1.13	ND	ND	ND	ND	ND
MS411	0.84	ND	ND	ND	ND	ND
MS412	0.26	ND	ND	ND	ND	ND
MS413	0.54	ND	ND	ND	ND	ND
MS414	8.47	ND	ND	ND	ND	ND
MS415	1.95	ND	ND	ND	ND	ND
MS416	151.33	0.12	ND	0.02	0.02	ND
MS417	13.78	ND	ND	ND	ND	ND
MS418	41.24	ND	ND	ND	0.03	ND

MS419	5.26	ND	0.02	ND	ND	ND
MS420	0.74	ND	ND	ND	ND	ND
MS421	ND	ND	ND	ND	ND	ND
MS422	1105.71	0.95	ND	ND	0.02	ND
MS423	7742.42	41.00	ND	7.05	0.03	0.59
MS424	0.72	ND	ND	ND	ND	ND
MS425	ND	ND	ND	ND	ND	ND
MS426	0.28	ND	ND	0.02	ND	ND
MS427	888.47	0.71	ND	ND	ND	ND
MS428	ND	0.14	ND	8.53	0.56	ND
MS429	131.65	0.74	0.05	0.06	ND	ND
MS430	93.97	ND	0.03	ND	ND	ND
MS431	15038.15	84.49	ND	14.12	0.04	1.27

Appendix K: Historic Butler County Groundwater Data
(Poth & Socolow, 1973)

Well Number (Bt)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Sodium (Na)	Chloride (Cl)	Sulfate (SO4)	Nitrate (NO3)
13	0	0.17	47	7.5	1.4	7.5	0.2
18	0.1		35.2		198	1	
20	4	0.6	48		11	60	0.1
25	1.2	0.77	77	4.2	1.2	65	
27			36.3		14	15	
28a	0.2				16	4.8	
28b			12.6		22	3.9	
29b	0.1				26	4.8	
29a			15		23	4.2	
29	0.02		11		10	10	0.3
29	0.14	0.03	17	78	9.2	4.3	
35	0.04	0.05	60	3.6	4	35	6
43	0.8	0.17	64	4.2	1	18	0.5
44	0.1	0.02	15	256	238		0.2
52	0.14	0.17	61	3.5	6.2	38	1
65	4.2		9		49	1.5	
65	0.06		9.5	78	53		0.4
67	4.9	0.14	11	2.5	8.4	33	0.3
68	0.24		42	80	145	53	27
83	2.3	0.15	114	5.5	3.2	207	1.3
84	1.6				2		
85	1.3				3		
86	2.9		63.2			18	
98	11	1.1	40	5	29	52	0.4
163	0.37		87	3.5	2.2	40	
166	0.13		6.5	4.4	2	18	
168	0.2		19	66	50	2.3	
172	7.1		59	45	28	178	
218	0.12		23	216	246	7.4	
226	0.97		49	44	61	17	
232	0.28		24	44	1.3	8.1	
236	0.2		22	319	368	4.1	
237	0.08		16	106	56	4.2	
252	0.2		60	11	3	25	0.5
265	2.2		6.4	5.5	2.2	7.6	
266	1.2		65	8	8	13	

302	52		11300		78900	42	
309	51		8708		60000	3	
209	49		975		9880	3	
311	1.4	0.33	5	3.5	1.9	28	0.2
349	12.44		128		131	705	
362	30		42.4		104	116	
363	18		91.2		160	260	
364	13		51.2		152	72	
365	0.9		48.8		130	20	
366	25		60.7		199.1	195.4	2
367			43.3	155.6	362	94.6	
368	18		60		168	52	