Water: Into the Wells

A discussion of the water input required to hydraulically fracture a Marcellus Shale well – the quantity, additives, and risks.

Introduction

Water has become one of the most contentious issues surrounding proposed Marcellus Shale drilling in New York State. Concerns have been raised about the amounts and sources of water used, the chemicals added to make the fracturing solution, the fate of the fluid that stays in the ground after the shale has been fractured, and the storage and disposal of the fluid that returns to the surface after fracturing. This paper will describe what happens to water until it goes into a well. The next paper in the series, Marcellus Issue 8, Water – Out of the Wells, discusses issues connected to water after it leaves the well.

What is the Marcellus Shale?

About 390 million years ago, during the geological period called the Devonian, the area west of what are now the northern Appalachian Mountains, including New York and Pennsylvania, was covered by a series of warm, shallow seas. The bedrock underneath New York’s Finger Lakes region is made of the silt, mud, and ancient organisms that settled to the bottom of these seas. These sediments were buried deeply as the Appalachian Mountains rose, and through heat and pressure turned to rock over millions of years. The organic matter buried with the mud turned to natural gas under this heat.

Did you know?

- A total of 198 million withdrawn from the Susquehanna River Basin in 2009 for gas drilling - 95 million from public water supplies and 103 million from surface waters. This was about 0.002% of Susquehanna River Basin flow.
- Water has been used in most hydraulic fracturing across the country, but other fluids used have included nitrogen, propane gel (liquefied petroleum gas), and liquefied carbon dioxide.
- The form of energy production that consumes the most water is currently hydroelectric power, thanks to evaporation from the Hoover Dam.
and pressure. If pore spaces between the grains in the rocks were sufficiently large and interconnected, this gas migrated to areas of lower pressure, often forming shallow pockets of gas that were trapped under rock layers through which it could not travel. Shale, the kind of rock that makes up the Marcellus, is often considered a capstone formation – a rock layer that traps gas or water underground because fluids cannot travel through it. Early exploitation of natural gas in New York, as early as the 1860s, was accomplished by drilling vertical wells into these pockets, so that the gas could be brought to the surface to be used for energy.

What is high-volume slickwater horizontal hydraulic fracturing (“hydrofracking”)?

Extracting natural gas from the Marcellus Shale requires different extraction methods than the kinds needed to extract gas from pockets underground. The Marcellus Shale is classified as a tight shale, which means that there are few connections between pore spaces through which the gas can travel to collect in large pockets. It is possible to crack such rocks to release the gas trapped within them. The Marcellus Shale is also a relatively thin layer of rock (usually about 100 feet thick or less).1 As a thin, tight shale, conventional natural gas recovery methods are impractical for economic recovery of natural gas. To address these challenges, two processes – horizontal drilling and hydraulic fracturing – are being combined to recover natural gas from the Marcellus Shale and other tight shales. For a more thorough explanation of gas drilling, please see Marcellus Shale Issue 6: Drilling Technology.

High volume, slickwater horizontal hydraulic fracturing (hereafter, hydraulic fracturing) differs from conventional gas drilling in several important ways.

1) Fracturing. Hydraulic fractures are cracks created in rock formations by changes in fluid pressure. This can and does happen naturally (see Marcellus Issue 5: Jointing and Fracturing in the Marcellus Shale), but it can also be induced by forcing fluid into rock formations at high pressures.

2) Horizontal drilling. For horizontal drilling, the well bore (the hole the well makes under the ground) is drilled vertically, then turns to travel horizontally through the target layer; thus, horizontal drilling. This allows each well to come in contact with, and therefore fracture, a larger amount of the formation. See Figure 1. This is especially useful in thin layers, like the Marcellus Shale. It requires far more water...
Most of the water used in natural gas production in the Marcellus Shale is used for hydraulic fracturing, but one other large water requirement is the water that is used to help drill the well itself. This water is used to lubricate the drill bit and carry rock cuttings back to the surface. Industry estimates that 100,000 gallons of water are used in the drilling process, while the Groundwater Protection Council estimates that it takes about 80,000 gallons of water to drill a well. 100,000 gallons of water would fill about 5 ½ school busses. While this water is only a fraction of the amount used in hydraulic fracturing, it could be a disposal concern. Some drillers use only freshwater to drill, while others use additives. Please see Marcellus Shale Issue 9: Beyond Water for more information about drilling mud additives and disposal.

### Table 1: Water Use for Hydraulic Fracturing Compared to Other Water Bodies and Uses

<table>
<thead>
<tr>
<th>Body/Use of Water</th>
<th>Amount of Water in Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily Irrigation requirements for the average US golf course</td>
<td>312,000</td>
</tr>
<tr>
<td>Olympic-Sized Swimming Pool</td>
<td>660,000</td>
</tr>
<tr>
<td>Marcellus Well (Susquehanna River Basin Commission Average)</td>
<td>4,300,000</td>
</tr>
<tr>
<td>Total freshwater withdrawn daily from surface waters in Ithaca</td>
<td>9,160,000</td>
</tr>
<tr>
<td>One year’s worth of 10-minute showers for each Ithaca resident</td>
<td>219,000,000</td>
</tr>
<tr>
<td>Cayuga Lake Volume</td>
<td>2,500,000,000,000</td>
</tr>
<tr>
<td>Freshwater withdrawn in New York State in 1 year</td>
<td>3,600,000,000,000</td>
</tr>
</tbody>
</table>

*Table 1: Water Use for Hydraulic Fracturing Compared to Other Water Bodies and Uses*

### How much water does it take to hydraulically fracture a well?

Throughout this paper and its companions, *Marcellus Shale Issue 8: Water – Out of the Wells*, and *Marcellus Shale Issue 9: Beyond Water*, Pennsylvania is used as the basis for likely drilling scenarios in New York. The amount of water required to fracture a well is largely a function of the specific characteristics of the target formation, the rock layer from which gas will be extracted (in this case, the Marcellus Shale). Because the physical characteristics of the Marcellus Shale in New York are approximately similar to those of the Marcellus in Pennsylvania, data on the volume of water used for fracturing wells in Pennsylvania are used to estimate the volume that might be required for wells in New York.

Many estimates for the amount of water typically used to hydraulically fracture a single well can be found in the media, literature from groups advocating for or against developing the Marcellus in New York, and technical literature: 2 to 9 million gallons, 3 to 6 million gallons, about 5.5 million gallons, over 80,000 gallons versus under 80,000 gallons, among others. Where do these numbers come from and what do they mean?

The Marcellus Shale is only one of a number of similar gas-bearing shales that are currently under development via horizontal drilling and hydraulic fracturing in the US. Others include the Barnett Shale in Texas and the Haynesville Shale in Louisiana. Still more are being developed around the world. The amount of water required to hydraulically fracture a well depends upon the rock properties of the particular target formation in question, which can also differ from well to well within that formation, as condi-
tions are nor uniform throughout a formation. The amount of water required to stimulate (the industry term for cracking the shale through hydraulic fracturing to release the natural gas) an individual well also depends heavily upon the length of the laterals (the horizontal portions) of that well. It takes between 300,000 and 500,000 gallons of water to fracture each 500 feet of well bore. The widest range of estimates of water use per well, 2 to 9 million gallons, reflects data from various shale basins, as well as differences in drilling practices, like the length of the laterals in a well, that would require more or less water.

One of the most frequently mentioned estimates for the amount of water used in a Marcellus well is 3 to 6 million gallons of water per well. This comes from an analysis by the Susquehanna River Basin Commission (SRBC) of data from 220 Marcellus wells in Pennsylvania. This analysis found an average of 4.3 million gallons used per well, with a maximum of 6.1 million gallons per well. Chesapeake Energy, one of the largest operators in Pennsylvania, and a company that is expected to be a large operator in New York, determined that they use an average of 5.5 million gallons of water to fracture each of their wells. We use SRBC’s 4.3 million gallon average for calculations in this paper and in Marcellus Shale Issue 8: Water – Out of the Wells.

The amount of water is measured in the millions of gallons, rather than the tens or hundreds of thousands that have been used to hydraulically fracture vertical wells in the natural gas development that has been seen up until this point in New York. Hydraulically fracturing a horizontal well takes much more water than hydraulically fracturing a vertical well because the portion of the well bore to be fractured is longer. The wells currently covered under the 1992 Generic Environmental Impact Statement (GEIS) for natural gas development were considered high-volume if they use more than 80,000 gallons of water for fracturing. Horizontal Marcellus wells all use more than 80,000 gallons of water, and are thus considered high-volume wells under the drilling regulations in New York. In the most recent version of the draft supplemental Generic Environmental Impact Statement (dSGEIS) released by the New York Department of Environmental Conservation (NY DEC), the minimum amount of water used in a well that would be considered high-volume was raised to 300,000 gallons. Anything under 80,000 gallons would still be considered low volume, and any well using between 80,000 and 300,000 gallons might be considered high or low volume.

### Consumptive Water Use vs. Non-Consumptive Water Use

The Susquehanna River Basin Commission defines a consumptive use of water as “the loss of water from a ground-water or surface water source through a manmade conveyance system (including such water that is purveyed through a public water supply system) due to transpiration by vegetation, incorporation into products during their manufacture, evaporation, diversion from the [water source], or any other process by which the water withdrawn is not returned to the waters of the basin undiminished in quantity.” Water withdrawal for public water supply, agriculture, industrial uses like cooling power plants, and Marcellus Shale drilling are considered consumptive uses of water. A non-consumptive water use is one for which the water is returned to the water source immediately. Certain kinds of hydroelectric power generation are considered non-consumptive, as are recreational uses of water such as boating and swimming. Water use for Marcellus Shale drilling in this paper is compared to consumptive uses of water in New York State and other systems.

Most of the water used to hydraulically fracture a well is not returned to the surface; only about 10% to 30% of it comes back up the well at all. The rest remains in the cracks created by the hydraulic fracturing. The water that does return contains chemicals from the fracturing fluid as well as brine (salty water), volatile organic compounds (VOCs), and naturally occurring radioactive material (NORM) from the Marcellus formation itself. For more information on the content and fate of flowback and produced water from Marcellus wells, see Marcellus Shale Issue 8: Water – Out of the Wells.

Because most of this water is not returned to the original water source, water used in Marcellus wells is considered a consumptive use of water. Other consumptive water uses includes evaporation, human or animal ingestion, or use in products or crops. The NY DEC considers any injection of water underground to be a consumptive use.
How does Marcellus drilling compare to other water uses in New York State?

To put Marcellus water use in perspective, New York State as a whole withdraws 10 billion gallons of fresh water daily from surface and groundwater combined. That's 3.6 trillion gallons per year. The majority is used for thermoelectric power generation, but 2.6 billion gallons per day are withdrawn for public water supplies and domestic use. The rest is divided among livestock and agricultural uses, irrigation, mining, and industrial uses.\(^2\)

The industry estimates used by NY DEC suggest that 2,462 wells could be drilled during a peak development year.\(^2\) This peak development estimate reflects the number of wells projected to be drilled per year during the most intensive years of a decades-long process. Neither peak development nor the beginnings of development reflect an average development year. Marcellus Shale development in Pennsylvania is still early in its projected development time frame.\(^9\) The first four years of drilling in Pennsylvania, 2007-2010, saw 18, 165, 703, then 1,373 wells. We have used the peak development number to estimate water use for drilling, because it is a useful estimate for the most demanding scenarios. Using SRBC's 4.3 million gallon figure for the average well, it would take approximately 10.6 billion gallons of water per year, assuming no wastewater recycling (please see Marcellus Shale Issue 8: Water – Into the Wells), to fracture new wells. The NY DEC estimates the total water use for a peak development year to be 9 billion gallons.\(^8\) At 9 billion gallons of water used per year, water withdrawn for Marcellus Shale drilling would account for 0.25% of all New York freshwater withdrawals in a given year and 0.95% of all water withdrawn for drinking and domestic use. 10.6 billion gallons per year would be 0.29% of total freshwater withdrawals and 1.1% of water withdrawn for drinking and domestic use.

It is important to note, however, that although the total amount of water that would be required to develop the Marcellus Shale in New York is small in comparison to the total amount of water withdrawn in
New York, not all water withdrawals have equal impact on watersheds and the overall environment. For example, withdrawing 4.3 million gallons of water from the mouth of the Susquehanna River would not have the same impact as removing 4.3 million gallons from the mouth of a small tributary.

One way of envisioning this is to consider the amount of time it takes for the 4.3 million gallons to flow past a specific point on a river. The mean flow at the United States Geological Survey (USGS) monitoring area in the Chenango River at Sherburne, NY, a headwater tributary of the Susquehanna River, is 105 cubic feet, or 785.4 gallons, per second (cfs). At this rate, it would take about just under 2.5 hours, capturing all the water that flowed past, to collect enough water to fracture a Marcellus well. At the mouth of the Susquehanna River in Conowingo, MD, the mean flow is 40,863 cfs, or 305,656 gallons per second. At this rate it would take just over 14 seconds to collect enough water to fracture a well.

Withdrawing equal amounts of water from a small stream and a larger river would have a much greater impact on the available water in a small stream.

The rates above are average river flow rates, but rivers have periods of high and low flow. Seasonal changes in precipitation and snow melt cause the amount of water flowing through rivers to vary from month to month. In the northeastern U.S., including New York and Pennsylvania, the months of August, September, and October see the lowest flow rate in rivers.11 Even when there are no drought conditions, seasonal variation in precipitation makes these months drier. Just as withdrawing water from a larger river would have greater impact than withdrawing the same amount of water from a larger one, withdrawing water during periods of low flow would have a larger impact than withdrawing the same amount of water in a period of higher flow.

The NY DEC’s solution to regulating water withdrawals in the face of varying flow conditions is the use of a passby flow. This is also a method used by the Susquehanna River Basin Commission and the Delaware River Basin Commission in their streams and rivers. Passby flow is defined as the “prescribed quantity of [water] flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal [for hydraulic fracturing] is occurring.” These passby flows are determined by the entities that govern withdrawal for each stream or river (see below) from which water will be withdrawn. If weather conditions or amount of water withdrawal cause a stream to fall below its passby flow, withdrawals must cease.

Where would the water come from?

Ninety four percent of current freshwater withdrawal in New York is from surface water, replenished by precipitation and snow melt. The other 6% comes from groundwater, which is replenished (or recharged) as precipitation percolates through the ground and into the aquifers.

In the Susquehanna River Basin in Pennsylvania, 20% of water used for natural gas drilling has come from purchases from public water suppliers, such as municipal water suppliers, as of August 2011, and most of the remaining water comes from direct surface water withdrawals from streams and rivers.6 The water in public water supplies also ultimately comes from surface water in the Susquehanna River Basin, and the Susquehanna River Basin Commission coordinates with the 30 public water suppliers currently approved to sell water to natural gas companies who have sufficient water to sell and are otherwise in compliance with permits.11 These percentages may differ in New York.

Who governs water withdrawal in New York?

All of the surface water in New York State occurs in one of seventeen major river basins.14 All of the land that drains into a large river or one of its tributaries is part of that river’s river basin. A watershed includes all of the land drained by a smaller stream; river basins are composed of watersheds.15 Nine of the 17 river basins are wholly or partially underlain by the Marcellus Shale. Five are underlain by the Marcellus fairway, which is the area where gas companies believe gas extraction will be most profitable. Development will likely be concentrated in this fairway, but areas surrounding it will most likely see drilling as well. The five river basins that contain...
withdrawals of both surface and groundwater within the entire Susquehanna River Basin. In New York, this includes both the Susquehanna and Chemung Rivers and their tributaries. Existing regulations had required all consumptive withdrawals of over 20,000 gallons per day to be permitted through them; since 2008, however, newer regulations have required gas companies to request a permit to withdraw any amount of water from the Susquehanna River Basin, including withdrawals from municipal supplies within the basin. The SRBC is responsible for the quantity, though not the quality, of the water, which is monitored by the individual states. As of June 2011, the SRBC had approved five surface sites for natural gas withdrawals in New York State. Four more are pending. On their peak days, the permitted withdrawals of water at each of the five sites are 107,000 gallons, 36,000 gallons, 25,000 gallons, 999,000 gallons, and 101,000 gallons, respectively. The volume of water required for natural gas development in the Marcellus Shale in New York will obviously increase the amount of water withdrawn from river basins to meet the needs of high-volume hydraulic fracturing. The SRBC has developed an interactive map to track the water withdrawal and

well pad (the area at the surface that immediately surrounds the well. It contains the machinery and equipment for drilling and fracturing and is where most of the work of drilling and fracturing takes place) sites within the river basin. It can be seen here: http://gis.srbc.net/WRPMap/

The DRBC is responsible for

both water quantity and quality within the Delaware River Basin. They are in the process of revising their regulations for drilling operations in the river basin. Revisions to current regulations will require all natural gas water withdrawals to be approved by the DRBC and include rules for siting well pads, access roads, and other activities associated with drilling that must be followed in addition to any state regulations. They have included special provisions for their Special Protection Waters (areas of special ecological or scenic value), which extend from Hancock, NY to Trenton, NJ.

Withdrawals from the Genesee River Basin and from the Seneca-Oneida-Oswego River Basin, which both empty into Lake Ontario, are regulated under the Great Lakes-St. Lawrence River Basin Water Resources Compact. The Finger Lakes are part of this Compact. A 2011 law requires DEC to approve water withdrawals of over 100,000 gallons in areas, like the Great Lakes-St. Lawrence Basin, that do not fall under a multi-state river basin commission. Because the Marcellus Shale overlies several different river basins, regulations for water withdrawal will vary throughout the drilling region. This creates the potential for water withdrawal impacts to vary throughout the region, as well. Different policies or enforcement standards among the governing entities could cause one or more of these regions to be more severely impacted by water withdrawals than another.
What chemicals are used during hydraulic fracturing?

Early hydraulic fracturing fluids included gelled crude oil, kerosene, and refined oil. Water is the main fluid used in Marcellus wells in Pennsylvania and West Virginia. A variety of chemicals are mixed with the water, each for a different purpose. Some of these additives are benign, but many are toxic to human health if mishandled or ingested. According to industry estimates, less than 1% of the volume of hydraulic fracturing fluid is made up of these potentially dangerous chemicals; the rest is made up of water (90%) and sand and other silica or ceramic pieces of various sizes, known as proppant (about 9%). Proppant is injected into the well to hold open fractures after the fluid has receded so that gas can flow to the well bore and up to the surface. NY DEC estimates of the amount of potentially dangerous chemical additives are higher -- up to 2% of the mixture. Although this is small relative to the amount of fresh water used, in a well using 4.3 million gallons of fracture fluid, there would be between 43,000 and 86,000 gallons of potentially harmful chemicals injected into a well.

Before the shale can be fractured, the well must be drilled, cased, and cemented, and the cement must be perforated at depth (shorthand for the portion of the well at the depth of the target formation, in the case of the Marcellus, this is in the lateral) to allow fluids through the wellbore to carry proppant into the shale. (For more details, see Marcellus Shale Issue 6: Drilling Technology.) The well is then stimulated. Because

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**Table 2: Chemicals Used in Hydraulic Fracturing**

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Purpose</th>
<th>Common Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acids</td>
<td>Clears the wellbore of excess cement, makes the formation rock easier to break</td>
<td>Hydrochloric Acid (HCl), 3% to 28% concentrations</td>
</tr>
<tr>
<td>Gels</td>
<td>Increases fracturing fluid viscosity, allowing it to hold more proppant to deliver to the fractures</td>
<td>Guar gum</td>
</tr>
<tr>
<td>Cross-linkers</td>
<td>Maintains fracture fluid viscosity at high heat and pressure found at depth</td>
<td>Sodium perborate and acetic anhydride</td>
</tr>
<tr>
<td>Breakers</td>
<td>Break the links created by the gels and the crosslinkers so the proppant stays in the fractures and more fluid comes back out of the well</td>
<td>Peroxydisulfates</td>
</tr>
<tr>
<td>Friction reducers</td>
<td>Reduces the internal friction of the fluid to reduce the amount of pressure that needs to be exerted at the surface to fracture the wells</td>
<td>Heavy naptha</td>
</tr>
<tr>
<td>Surfactants</td>
<td>Reduce the surface tension of the fluid and increases the amount of water that comes back out of the well</td>
<td>Methanol</td>
</tr>
<tr>
<td>Corrosion inhibitors</td>
<td>Reduces the damage to steel casing and other equipment that would be caused by the acid</td>
<td>N, n, dimethylformamide</td>
</tr>
<tr>
<td>Boosters</td>
<td>Increases the effectiveness of the corrosion inhibitors at high temperature and pressure</td>
<td>-</td>
</tr>
<tr>
<td>Biocides</td>
<td>Prevents growth of bacteria and other microorganisms in the wellbore and fractures</td>
<td>Glutaraldehyde, bleach, DAZOMET, and 2,2-dibromo3-nitriol-propionamide</td>
</tr>
<tr>
<td>Clay stabilizers (Salts)</td>
<td>Prevents clay in the formation from swelling when the fracture fluid is added</td>
<td>Potassium chloride (KCl)</td>
</tr>
<tr>
<td>pH adjusters</td>
<td>Keeps the pH of the fluid within the correct range for all of these chemicals to react as needed</td>
<td>-</td>
</tr>
</tbody>
</table>
the laterals can reach several thousand feet in length, it is not possible to maintain the pressure needed to fracture the entire lateral at once. Therefore stimulation happens in several stages along the length of each horizontal well drilled.

Generally, acid is first pumped down the well to clear the well bore of excess cement (see Marcellus Shale Issue 6: Drilling Technology) so that the fracturing fluid can more easily reach the shale. Acid may also be used in etching the formation rock, making it easier to break apart the shale.

The acid is followed by the fracture fluid. This is where most of the water is used. The purpose of the fracture fluid is to open fractures in the shale and deliver proppant. To be effective, the fluid must be viscous enough to hold and deliver proppant to the fractures rather than letting it settle to the bottom of the wellbore, but friction must be reduced so that the fluid can maintain enough speed and pressure while reducing the still considerable amount of force needed at the surface. Gels are used to increase the viscosity. At the temperature and pressures present at depth, these gels can break down, so other additives, called **cross-linkers**, are added. Cross-linkers maintain viscosity even as the heat increases at depth. For the hydraulic fracturing to be successful, the proppant should stay in the fractures. The gel has to break down to release the proppant into the fractures. If the gel does not break down, chemicals called **breakers** are pumped down the well at the end of the fracture treatment to break down the gels and decrease the viscosity of the fluid. This both allows the proppants to stay in the well rather than be carried back up with the flowback fluid, and increases the amount of fluid that will flow back out of the well after the fracture treatment.

Other chemicals, called **friction reducers**, which give slickwater fracturing its name, reduce the friction of the fracture fluid relative to the well bore and within the fluid itself. This allows the fluid to travel at higher speeds with lower surface pressures, which is important in fracturing deep, tight shales. Still other chemicals, called **surfactants**, reduce surface tension and, like breakers, increase the amount of fracture fluid recovered from the well.

If acid is used, it must be followed by a **corrosion inhibitor** in the fracture fluid so that the steel in the casing (a metal tube surrounded by cement that lines the well bore), tools, tubes, tanks, etc. are not damaged. The amount of corrosion inhibitor depends upon the type of casing used, and the temperatures at depth in the well. If temperatures are sufficiently high, another chemical called a **booster**, is added to allow the corrosion inhibitor to work effectively.

The gels added to drilling fluid are largely organic compounds, – that is, carbon-containing molecules (not to be confused with pesticide-free farming), – and as such provide an environment in which bacteria can thrive. Bacterial growth can clog fractures and produce metabolic byproducts that can corrode equipment. Chemicals that kill bacteria, called **biocides**, are therefore added to the fracture fluid to inhibit the growth of microorganisms.

**Salts** are generally added to the fracture solution, to prevent clay in the target formation from swelling, migrating, and blocking fractures. The salt content of the fracture fluid must be similar to the groundwater already present in the rock to prevent the clay from swelling. Salts are also referred to as **clay stabilizers** in this context. A **pH adjuster** can also be used to regulate the acidity of the fluid at the correct level for the surfactants, crosslinkers, and friction reducers to interact properly.

The fracturing fluid travels down the well bore to the section of the lateral being fractured. The lateral section has been perforated at regular intervals to allow the fluid to move between the well and the rock and the gas to flow back into the well bore. Here the water is forced under pressure through the perforations in the cement into the formation. Changes in pressure widen and lengthen existing fractures and create new fractures in the formation to be filled with fluid and proppant. Proppant allows the fractures to stay open even after pumping ceases and the pressure and the amount of in the well has declined. For much more on the process of drilling and stimulating a well, see Marcellus Shale Issue 6: Drilling Technology

Table 2 contains some of the commonly used chemicals during well stimulation, but different chemicals in different concentrations are used in each well. Hundreds of different chemicals have been used as components of hydraulic fracture fluid, though not all of them are used at every well; a typical number...
might be up to about a dozen in any given fracturing event. Some chemicals are useful in some kinds of wells and not in others; for instance, the friction reducers used in slickwater fracturing are not necessarily used in coal bed methane wells.

Before a natural gas pipeline can be hooked up to a producing well to transfer gas to market or storage, a portion of the fracturing fluid – industry estimates in the Marcellus shale in Pennsylvania range from 10-30% - will flow back out of the well. This is called flowback fluid. Some water that was present in the Marcellus formation itself will also come back up the well. This is called formation water. For more information on the composition of and disposal options for the water that comes back out of the well, see Marcellus Shale Issue 8: Water – Out of the Wells.

Though this is not necessarily the case in other states, New York has proposed mandatory disclosure of the chemicals used in wells for Marcellus drilling. The chemicals will be disclosed to the DEC, but not necessarily to the general public.

1 MSDS were found by searching for chemicals by Chemical Abstract Service Number (CAS#) in various chemical databases and on Google.

**How dangerous are the chemicals used in fracturing?**

While some of the chemicals used in hydraulic fracturing – like guar gum, citrate, and some alcohols – pose no threat to human health, many of the fracture chemicals do, even if only in high concentrations. We compiled available Material Safety Data Sheets (MSDS) for the individual chemical constituents listed in the draft SGEIS and the chemicals that were listed as being used in New York in the Endocrine Disruption Exchange database, a well-respected public health website. MSDSs are semi-standard forms that contain health and safety, reaction, and chemical properties of a wide variety of substances. Between the Endocrine Disruption Exchange and the dSGEIS, 334 chemicals were listed. Of those, MSDS could be located for 187.

Most of these MSDSs provide hazard information for the chemicals in much higher concentrations than those likely to be encountered during gas drilling operations. Many of them have to be inhaled or come in contact with mucous membranes or eyes before their effects would be felt. The health hazards they represent are therefore likely to be lower than suggested here, especially any acute effects. That being said, some of the chemicals can be hazardous at very low concentrations.

Clearly, many of the chemicals likely to be used in hydraulic fracturing of the Marcellus in New York are potentially hazardous to human health. However, although there are anecdotal reports, no scientific studies currently exist that examine the
health effects of living in proximity to natural gas drilling by hydraulic fracturing, from exposure to either fluids or fumes.

What are the alternatives to current fracturing formulas?

Some drilling companies are investigating alternatives to some of the common hydraulic fracturing additives. These alternatives can be as simple as swapping one chemical additive in the fracture fluid for a less toxic substitute, or as complicated as developing an entirely different fluid system. For example, Haliburton, a company that was initially strongly opposed to disclosure of chemical additives, has a new chemical formula for hydraulic fracturing called CleanStim, which was undergoing field testing in 2010. CleanStim boasts a formula “made entirely of materials sourced from the food industry”. A Canadian company called GasFrac has developed a way to use liquefied propane as the fracture fluid. They have been fracturing wells using this technique since 2008. This formula still uses some of the same kinds of cross-linkers and breakers as water-based fluid, and while it virtually eliminates the need for water in drilling, it comes with its own potential hazards – propane is of course highly flammable. For more on the specifics of propane fractures, please see Marcellus Issue 6 – Drilling Technology.

What are the risks for contamination of ground and surface waters?

Surface spills and leaks of water containing fracture chemicals are considered by many to be one of the main potential risks to surface and groundwater associated with Marcellus Shale drilling. Surface spills or leaks can happen at any of a number of steps in the process of developing a well. Such incidents may not only contaminate ground or surface waters; they may also damage local vegetation. A study performed in the Fernow Experimental Forest in West Virginia, for example, found that when untreated hydraulic fracture fluid was spread over 0.20 hectare (less than .001 mi²), almost all ground vegetation died within two days, trees started dropping foliage within 10 days, and 56% of the trees in that area were dead after two years. Leaks of hydraulic fracturing fluid might also damage other parts of ecosystems. For example, freshwater mussel populations, many of which are already seriously reduced as a result of human activity, may be particularly vulnerable. These filter feeders are particularly susceptible to toxins in the water because of the way they feed. Besides acute toxicity, changes in pH or salinity from hydraulic fracturing fluid or waste water can affect other plants, animals, and microorganisms that inhabit streams and other surface waters.

NY DEC has sought to evaluate the impact that transportation of materials to and from wells could have on roads. They estimate 1,148 loaded heavy truck trips and 831 loaded light truck trips per well. Doubled for a round trip, truck trips total 3,958 per well in the early stages of well pad development. This is expected to decrease during peak development, when water pipelines are set up to transport some of the water to the pads that would otherwise be carried by truck. Estimates for this phase of development are 625 loaded heavy truck trips per well and 795 loaded light truck trips for a total of 2,840 trips per well. These are likely overestimates, as well pads are expected to have more than one well per pad. (The current average in Pennsylvania is 2.11 wells per pad, and this number appears to be increasing.) Increased truck traffic increases the risk of accidents, which could also result in spills or leaks. The most harmful potential spills and leaks would be from trucks carrying fracture chemicals to the wells, or carrying waste water away from the well. Not all truck trips carry these hazardous materials. Some carry things like equipment or construction materials. See Figure 3 for the breakdown of how many truck trips carry what kinds of things. According to data collected by the environmental group Toxics Targeting in 2009, there were two reported commercial vehicle accidents associated with the natural gas industry leading to spills in New York since 1986. There have been truck accidents.
with vehicles carrying Marcellus drilling materials and waste in Pennsylvania, though an exact number is not available. When vehicles fail to obey traffic regulations, chances of accidents increase. In just three days of heavy enforcement in the summer of 2010, Pennsylvania state police issued 669 citations and 818 written warnings to trucks carrying Marcellus wastewater. There will almost certainly be Marcellus-related commercial vehicle accidents leading to surface spills if drilling proceeds in New York. In addition to spills and leaks of fluids caused by truck accidents, increased truck traffic, especially over undeveloped roads, can contribute to erosion which would cause damage to local streams and so to surface waters generally.32

Well pads themselves can also be sites of spills and leaks of drilling and fracturing materials. An MIT study on hydraulic fracturing found that, among 43 highly-publicized accidents, 33% were onsite spills.28 These can be caused by improper storage or handling of materials, or unforeseen environmental causes. This number is unlikely to be truly illustrative of the total percentage of accidents that are caused by spills, however, because it only includes incidents that were reported on by the media. Improper storage and handling of materials can contribute to spills at the well pad and at any step in the process. A Pennsylvania Land Trust analysis of Pennsylvania Department of Environmental Protection citations of Marcellus drillers found a total of 1614 violations of drilling regulations in Pennsylvania Marcellus wells between 2008 and 2010, 1056 of which were judged likely to impact the environment. These include violations that could contribute to a higher likelihood of spills, including 155 “discharge of industrial waste” violations, which means that drilling waste was released onto the ground or into streams.33 New York is almost certain to see a certain amount of surface spills and leaks on well pads associated with drilling.

In addition to human error, certain environmental conditions can contribute to spills and leaks on well sites. Storms and flooding can wreak havoc on fluid storage systems and cause spills. The DEC will require comprehensive site-specific Stormwater Pollution Prevention Plans (SWPPP) for each well site. These would provide plans to prevent stormwater runoff from adversely impacting the environment at all stages in the construction and drilling process.

For more information on storage hazards and options for fracturing fluids on well pads, please see Marcellus Shale Issue 8: Water – Out of the Wells.

In addition to surface spills, problems with the drilling itself can contaminate ground and surface waters. These are caused by human error, unexpected geological conditions, or a combination of the two. Here are some examples of these problems:
Vertical well drilling can hit unexpected pockets of higher pressure.

A natural gas well is drilled to reach a rock formation that acts as a natural gas reservoir rock, in this case the Marcellus Shale, but the Marcellus Shale is not the only rock layer with gas in the rocks that underlie New York. While the depth of some gas reservoirs can be predicted during well drilling, some reservoir rocks may have allowed natural gas to migrate into voids in surrounding rocks. Indeed, this migration into traps – porous rocks overlain by less permeable rocks – provides the conditions for most conventional vertical wells. If a concentration of gas is not anticipated, however, it can cause a blowout (sudden uncontrolled release of gas and fluids from the well) and contaminants can move from the source to nearby surface waters, or through the soil into near-surface groundwater.

As a well is drilled, various drilling technologies monitor the pressures in the well. Air, freshwater, or drilling muds (see Marcellus Shale Issue 9: Beyond Water) are used to lubricate the drill bit as it moves through the layers of rock and carry cuttings (bits of rock displaced by the drilling process) back to the surface. Air or freshwater are commonly used initially to drill through the shallowest rock, passing through groundwater zones. A casing is put in place from the surface to below the groundwater zone. Then drilling, sometimes with drilling muds, which contain some of the same kinds of chemicals used in hydraulic fracturing, begins below the groundwater zone. In principle, the hydrostatic pressure of the drilling muds (a combination of the density and temperature of the muds, the height in the well, and gravitational forces) counters the increasing pressures in the well, keeping the well open until the next section can be cased. If a shallow, unexpected pocket of gas is hit while drilling the well,
A. The total number of truck trips is 1148. About 14% of the trips carry chemicals or disposal water and pose a greater threat to the environment if there is a leak or spill. The other 86% have non-chemical cargo. B. The total number of truck trips is 831. About 39% of these truck trips could carry hydraulic fracturing chemicals, which pose a greater risk to the environment if spilled. The other 60% have non-chemical cargo. C. The total number of truck trips is 625. About 13% of the trips carry chemicals or disposal water and pose a greater threat to the environment if there is a leak or spill. The other 87% have non-chemical cargo. D. The total number of truck trips is 795. The percent of chemical carrying and non-chemical carrying trips is not available.¹

¹ The NY DEC gave the total truck trips in table 6.60 in the SGEIS, but duplicated the cargo breakdown from B.
however, pressure in the well will quickly and dramatically increase. If the downhole pressure provided by the drilling muds is not sufficient to contain the pressure, the gas released from the pocket can mix with the drilling muds, flow back to the surface, and require venting or burning of that gas. The higher the pressure in the shallow gas pocket, the more gas will be released suddenly.

This poses a danger at the surface, because gas is explosive and can be ignited by the machines running above ground. It can also contaminate nearby groundwater sources with methane if casing has not yet been installed to separate the fluids in the well bore from the surrounding rock.\textsuperscript{34,35} Shallow gas pockets are not the only things that can potentially cause blowouts, but they are the most likely to contaminate groundwater sources if they occur.

Valves called blowout preventers that help regulate erratic pressure changes that can be found while drilling, are found at all gas wells to help prevent and contain blowouts, but sometimes they fail.

Blowouts have occurred in Pennsylvania Marcellus Wells. In April 2011, a well operated by Chesapeake Energy in Bradford County had a blowout that released thousands of gallons of fracture fluid into the surrounding area and required the evacuation of families in the area. In June 2010, a well in Clearfield County had a blowout that resulted in the release of natural gas, flowback fracture fluid, and brine.\textsuperscript{36} The amount of damage caused by a well blowout depends upon the pressure of the gas pocket, how fast the well can be contained, and the speed with which appropriate mitigation measures can be implemented. \textit{Drilling equipment and casings can fail.}

In the Marcellus Shale, hydraulic fracturing is carried out along the horizontal leg of the well, thousands of feet below the water table, but well bores must still go through groundwater sources to reach the Marcellus formation. Metal casings and cement are put in place during the drilling process to seal off the well bore from the surrounding rocks. This is done for several reasons: to prevent methane from the Marcellus from escaping the well bore into other, shallower rock units or aquifers; to prevent groundwater from entering the well bore and being extracted with the gas (and then processed back out at the surface); to prevent hydraulic fracturing fluid from entering formations other than the Marcellus; and to prevent the collapse of the well bore. For more information on how wells are cased, please see \textit{Marcellus Issue 6: Drilling Technology.}

Improper casing of wells or casing failures have contributed to contamination of groundwater in Pennsylvania, Colorado, and Wyoming. Among these states, contamination in the Marcellus Shale in Pennsylvania is most illustrative of types of potential problems in New York. One of the more publicized recent incidents of groundwater contamination occurred in Dimmock, Pennsylvania. There, the contamination has been attributed to improperly cemented Marcellus wells that allowed methane to migrate up the wells and into groundwater.\textsuperscript{36} A Duke University study found the gas that contaminated the Dimmock groundwater to be consistent with methane that traveled up the well bore from formations that are shallower than the Marcellus.\textsuperscript{37} Because they also found no contamination by fracture fluids or saline water from the Marcellus formation in the wells they tested, the Duke researchers’ findings are consistent with casing failure causing the methane contamination rather than fluid migration from the Marcellus formation due to hydraulic fracturing.

If casings fail, not only can gas and fluids enter the groundwater in the immediate vicinity of the well, but the fluids can enter shallow fractures that connect to other fractures and allow the gas to travel thousands of feet. In addition, gas drilling has a long history in New York State; many wells have been drilled to various depths and formations. Not all of these wells have been properly plugged. For more on how old and abandoned wells can influence gas migration, please see \textit{Marcellus Shale Issue 6: Drilling Technology.}

\textbf{Summary}

Developing the Marcellus Shale natural gas resource in New York State will increase the degree of risk to our water resources. While the amount of water that would be required to extract natural gas from the Marcellus Shale is small compared to the amount of water withdrawn for other purposes, regulation and permitting for withdrawals should be carefully managed to prevent any one water source from damage from overuse. A number of chemical additives are used to hydraulically fracture a well – additives that pose
threats to human health and the environment if they come into contact with water or land resources. Contamination of surface water is a risk during transportation, storage, and use of these chemicals in the drilling process. Drilling also poses a risk of ground and surface water contamination if wells have been constructed improperly. The regulations proposed by the NY DEC to cover drilling in tight shales are designed to mitigate damage and minimize risk to the environment, though no regulations can guarantee that there will be no impact to water resources from Marcellus Shale drilling. For more information on water and the Marcellus Shale, specifically what happens to the water after it returns from the well after hydraulic fracturing, please see Marcellus Shale Issue 8: Water – Out of the Wells.

References


Glossary

**tight shale** – a shale that has few connections between pore spaces through which the gas can travel to collect in large pockets

**well bore** - the hole the well makes under the ground

**slickwater** – refers to the use of friction reducers hydraulic fracturing fluid to decrease the amount of pressure needed at the surface to fracture wells; target formation – the rock layer from which the natural gas will be extracted

**lateral** – the horizontal portions of the well bore. These travel through the Marcellus shale, and are the part of the well where the hydraulic fracturing takes place

**river basin** - all of the land that drains into a large river or one of its tributaries

**watershed** – all of the land drained by a smaller stream, river basins are composed of watersheds

**fairway** – the section predicted to be most profitable within a formation that is under natural gas development

**proppant** - sand and other silica or ceramic pieces of various sizes injected into the well to hold open the fractures after the pressure from the fluid has diminished

**at depth** - shorthand for the portion of the well at the depth of the target formation, in the case of the Marcellus, this is in the lateral

**stimulation** – the process of cracking the rock in the target formation to release the natural gas, hydraulic fracturing

**traps** – porous rocks overlain by less permeable rocks

**passby flow** – the “prescribed quantity of [water] flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal [for hydraulic fracturing] is occurring”

**casing** – a metal tube surrounded by cement that lines the well bore

**cuttings** – bits of rock displaced by the drilling process


36. New York State Department of Environmental Conservation, September 2011, Revised draft supplemental generic environmental impact statement on the oil, gas and solution mining regulatory program, [http://www.dec.ny.gov/energy/58440.html](http://www.dec.ny.gov/energy/58440.html).


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