Marcellus Shale Gas: Development Potential and Water Management Issues and Laws

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Summary

Until relatively recently, natural gas-rich shale formations throughout the United States were not considered to have significant resource value because no technologies existed to economically recover the gas. Development and deployment of advanced drilling and reservoir stimulation methods have dramatically increased the gas production from these "unconventional gas shales." The Marcellus Shale formation potentially represents one of the largest unconventional natural gas resources in the United States, underlying much of West Virginia and Pennsylvania, southern New York, eastern Ohio, western Maryland, and western Virginia. Directional drilling and "hydraulic fracturing" are essential to exploiting these low permeability shale gas resources. Although oil and gas developers have applied these technologies in conventional oil and natural gas fields for some time, recent improvements in both technologies have allowed them to be applied effectively to unconventional gas shales on an industrial scale.

While creating significant economic benefits, development of the Marcellus Shale faces infrastructure challenges, such as the need for gathering pipelines. Marcellus development also has generated controversy due to its potential scale and its potential impacts on land and water resources, communities, public infrastructure, and environmental quality.

Several water quality issues have arisen, including concerns about the potential for hydraulic fracturing operations to contaminate groundwater and drinking water supplies. The 111th Congress urged the U.S. Environmental Protection Agency (EPA) to study this issue, and the agency expects to publish initial research results in 2012 and a final report in 2014. Notably, EPA does not have the authority to regulate hydraulic fracturing (except where diesel fuel is used).

Additionally, managing the large volumes of wastewater produced during natural gas production (including flowback from hydraulic fracturing and water produced from the shale formation) has emerged as a major water quality issue related to Marcellus development. In some areas across the Marcellus Shale region, the geology may limit the use of underground injection wells (the most common produced-water disposal practice in oil and gas fields), and wastewater disposal is posing treatment, quality, and regulatory challenges. Both industry best practices and state regulations continue to evolve.

Other concerns associated with shale gas development include the contamination of water from surface spills, migration of methane gas and contaminants into residential water wells from faulty well construction, siltation of streams from drilling and pad construction activities, and potential impacts that large water withdrawals might have on water resources, streams, and aquatic life.

The development of the Marcellus Shale on private or state land is subject primarily to state laws and regulations, including requirements for well construction and operation. Provisions of two federal water quality laws—the Safe Drinking Water Act (SDWA) and the Clean Water Act (CWA)—can apply to activities related to wastewater disposal through underground injection and discharge to surface waters. Additionally, several of the states include watersheds that are subject to water resource regulations resulting from the adoption of interstate compacts (primarily the Delaware River Basin Compact and the Susquehanna River Basin Compact).

This report reviews the Marcellus Shale resource, development processes, and related surface water and groundwater issues. It also discusses related federal and state regulatory authorities and related developments, and pending federal legislation.

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Introduction

Until relatively recently, natural gas-rich shale formations throughout the United States were not considered to have significant resource value because no technologies existed to economically recover the gas. Development and deployment of advanced drilling and reservoir stimulation methods have dramatically increased the gas production from these "unconventional gas shales." The Marcellus Shale formation of the Appalachian basin, in the northeastern United States, potentially represents one of the largest unconventional natural gas resources in the United States.

Natural gas prices have fallen significantly in the last five years, but particularly since mid-2008 due in large part to the development of shale gas. Prices briefly exceeded $13 per million Btu (MBtu) in 2008, but fell below $4 per MBtu by the summer of 2009.[1] The Energy Information Administration (EIA) expects that the Henry Hub spot price for natural gas will average $3.53 per MBtu in 2012, a drop of $0.47 per MBtu from the 2011 average.[2] However, increased drilling activity in Pennsylvania and West Virginia and industry presence in New York and Maryland reflect strong interest in the Marcellus Shale. As a result, natural gas reserves in the United States may show a significant increase.[3] Low natural gas prices have raised expectations that demand for natural gas will increase. Moreover, unlike the natural gas found in some regions, the gas produced from the eastern portion of the Marcellus formation is of high enough quality that it requires minimal treatment for injection into transmission pipelines. Multiple gas transmission pipelines already serve the northeast United States. The Millennium Pipeline project in southern New York could accommodate increased shale gas production from New York and parts of Pennsylvania to serve the natural gas needs of the region. West Virginia may face obstacles to developing additional pipeline capacity and other infrastructure, as its terrain is more rugged. Gas producers would also have to construct an extensive network of gathering pipelines to bring the gas out of the fields to market. One study by the Interstate Natural Gas Association of America estimated that almost 60,000 miles of gathering pipelines would be needed in the Marcellus area.[4]

Directional drilling and "hydraulic fracturing" are essential to exploiting shale gas resources. Although oil and gas developers have applied these technologies in conventional oil and natural gas fields for some time, recent improvements in both technologies have allowed them to be applied effectively to unconventional gas shales on an industrial scale. As a result, gas development has expanded in traditional gas producing areas, and has moved into areas that may have rugged topography, dense vegetation, higher population densities, and where residents may be less familiar with the oil and gas exploration and production industry.

Shale gas development in the Marcellus region has been particularly controversial. The potential economic benefits from both the drilling activities and the lease and royalty payments compete with the public's concern for environmentally safe drilling practices and protection of

[1] See U.S. Department of Energy (DOE), Energy Information Administration (EIA), *Natural Gas page*, http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html.

[2] EIA, *Short-Term Energy Outlook*, December 6, 2011, http://www.eia.doe.gov/emeu/steo/pub/contents.html#Natural_Gas_Markets.

[3] "Reserves are those quantities of petroleum, which, by analysis of geoscience and engineering data, can be estimated with reasonable certainty to be commercially recoverable ..." in: Society of Petroleum Engineers, *Petroleum Resources Management System*, 2007, p. 3, http://www.spe.org/spe-app/spe/industry/reserves/prms.htm.

[4] "INGAA: Study Predicts $20 Billion in Pipeline Projects Headed for Marcellus," *Pittsburgh Business Times*, May 24, 2011.

groundwater and surface water resources. Water supply is an important issue because hydraulic fracturing requires large amounts of fresh water, but contamination of water resources is also a major concern to many across the region.

As with oil and gas production generally, development of the Marcellus Shale is primarily subject to state law and regulation, and requirements for well construction and operation differ among the states. Additionally, provisions of two federal laws—the Safe Drinking Water Act (SDWA) and the Clean Water Act (CWA)—can apply to some activities, specifically those related to wastewater disposal through underground injection or discharge to surface waters. The SDWA exempts from regulation the underground injection of fluids (except diesel fuel) for hydraulic fracturing.[5] Two bills introduced in the 112th Congress (as in the last Congress) would remove the exemption and explicitly authorize regulation of hydraulic fracturing under the SDWA.[6]

As exploration and production activities have increased, so has concern that development of the Marcellus Shale could harm human health and the environment. One concern is that hydraulic fracturing or faulty well construction might damage groundwater and drinking water wells by introducing chemicals, natural gas,[7] and other contaminants into aquifers. A second issue is the potential contamination of water wells from surface activities related to gas production. Accidental spills, leaky surface impoundments, equipment failure, or careless surface disposal of drilling fluids[8] at the natural gas production site could increase the risk of contaminating a nearby water well or run off to surface water.

Managing the wastewater produced from the fracturing process has emerged as a major water resource issue in the Marcellus region. Critics maintain that improper treatment and disposal of the large quantities of water used for, and resulting from, the hydraulic fracturing process may harm local and regional water supplies and that disposing the "flowback" and brine extracted from the shale after fracturing may affect the water quality of lakes, rivers, and streams and potentially damage public wastewater treatment plants and water supplies.

Gas producers have pointed out that virtually all oil and natural gas production, including all the historical conventional production in the United States, requires wells that penetrate the local groundwater aquifers. Several shale gas contamination incidents have been attributed to poor well construction or surface activities that would be associated with any oil or gas drilling and production operation, and not just with the unique techniques associated with the hydraulic fracturing process. However, these observations emphasize the importance of good well design

[5] The Energy Policy Act (EPAct) of 2005 (P.L. 109-58, §322), amended the SDWA to exempt from the definition of underground injection the injection of fluids or propping agents (other than diesel fuel) for hydraulic fracturing purposes. For a discussion of the background of this provision and the EPA underground injection control program and its role in regulating hydraulic fracturing, see CRS Report R41760, *Hydraulic Fracturing and Safe Drinking Water Act Issues*, by (name redacted) and (name redacted).

[6] H.R. 1084 and S. 587, the Fracturing Responsibility and Awareness of Chemicals Act (FRAC Act), would amend the SDWA to repeal the exemption for hydraulic fracturing operations that was established in EPAct 2005, and would amend the term "underground injection" to include explicitly the injection of fluids used in hydraulic fracturing operations related to oil and gas production, thus authorizing EPA to regulate this process under the SDWA.

[7] Methane is the dominant component of natural gas, but it may also contain lesser amounts of ethane, propane, butane, and other hydrocarbons.

[8] Drilling fluids are composed primarily of water and minerals in a mud used to remove drill cuttings during the drilling process. Drilling fluids are different from the hydraulic fracturing fluids, which are introduced after the well is drilled.

and construction for any wells that penetrate local aquifers, regardless of their purpose. (See "Well Construction and Casing," below.)

Incidents of well-water contamination have been reported as Marcellus Shale development has expanded. In one case, Pennsylvania regulators confirmed that methane had migrated from drilling sites to private drinking water wells, and issued notices of violations to a drilling company for, among other things, "failure to prevent gas from entering fresh groundwater."[9] In this case, state regulators attributed the contamination to faulty well construction.[10]

In some cases of well-water contamination attributed to gas development in various gas producing areas, the source of contamination remains undetermined. Identifying the cause of contamination can be difficult for various reasons, including the complexity of hydrogeologic processes and investigations, and a lack of baseline testing of nearby water wells prior to drilling and fracturing, as well as the confidential business information status historically given to fracturing compounds across the states. Major oil and gas producing states have asserted that the hydraulic fracturing process has not been linked directly to groundwater contamination.[11] However, contamination incidents attributed to poor well construction have raised concerns regarding the adequacy and/or enforcement of state well construction regulations for managing oil and gas development that increasingly depends on fracturing. This report discusses the Marcellus Shale resource, technical methods used to develop it, and associated groundwater and surface water issues.[12] The report also discusses relevant federal and state regulatory authorities, recent developments at the federal and state levels, and pending federal legislation.[13]

The Marcellus Shale as a U.S. Natural Gas Province

Unconventional Gas Shale Resources in the United States

Unconventional gas shales are fine-grained, organic-rich, sedimentary rocks. The shales are both the source of and the reservoir for natural gas, unlike conventional petroleum reservoirs. In the shales, gas freely occupies pore spaces, and organic matter adsorbs gas on its surface.[14] The

[9] Pennsylvania Department of Environmental Protection (PA DEP), Consent Order and Agreement, November 4, 2009; http://www.dep.state.pa.us/dep/deputate/minres/oilgas/Final%20COA%20121510.pdf. PA DEP determined that 18 drinking water supplies serving 19 homes in the Dimock, PA, area were affected by drilling activities.

[10] John Hanger, Secretary, Pennsylvania Department of Environmental Protection, Letter to Cabot Oil, October 19, 2010, http://wbcitizensvoice.com/pdfs/HangerLetter.pdf.

[11] See, for example, the Ground Water Protection Council at http://www.gwpc.org. The GWPC is an association of state groundwater and underground injection control agencies responsible for protecting and conserving groundwater.

[12] Other environmental concerns associated with the development of the Marcellus Shale include potential air quality impacts, increased truck traffic, and land use changes (including those related to the development of access roads, gathering pipelines, and drill pads). Although such issues can be significant for state regulators, gas developers, local communities, and landowners, they are not addressed in this report.

[13] This report replaces CRS Report R40894, *Unconventional Gas Shales: Development, Technology, and Policy Issues,* coordinated by (name redacted).

[14] The Society of Petroleum Engineers describes "unconventional resources" as petroleum accumulations that are pervasive throughout a large area and that are not significantly affected by hydrodynamic influences. (They are also called "continuous-type deposits.") In contrast, conventional petroleum and natural gas occur in porous sandstone and carbonate reservoirs. Under hydrodynamic pressure exerted by water, the petroleum migrated upward from its organic source until an impermeable cap-rock (such as shale) trapped it in the reservoir rock. The "gas-cap" that accumulated (continued...)

shales' extremely small pore sizes make them relatively impermeable to gas flow, unless natural or artificial fractures occur.

Major gas shale basins exist throughout the lower 48 United States. There are at least 21 shale basins in more than 20 states.[15] Based on a recent assessment of natural gas resources, the United States has a resource base of 1,836 trillion cubic-feet (tcf).[16] Shale gas made up an estimated one-third of this resource base, roughly 616 tcf. The U.S. Geological Survey (USGS) estimated in 2011 that the Marcellus Shale holds 84 tcf of undiscovered, technically recoverable natural gas and 3.4 billion barrels of natural gas liquids. Annual U.S. dry natural gas production has improved significantly in the last half decade. The 22.4 tcf produced in 2010 matched the peak production of the early 1970s, due in large part to unconventional resources, particularly gas shales. In 2009, the United States reclaimed the top spot as the world's largest natural gas producer, the first time since 2001. EIA, in its 2011 *Annual Energy Outlook* reference case, forecast shale gas production to grow from about 25% of total U.S. natural gas production in 2011 to 46% in 2035.

Geology of the Marcellus Shale Formation

The Marcellus Shale is a sedimentary rock formation deposited over 350 million years ago during the middle-Devonian period on the geologic timescale. Geologic strata deposited in the Appalachian basin during this period are more likely to produce gas than oil. Regional oil production is associated with Pennsylvanian age strata (of the later Carboniferous period). The black, organic-rich, Marcellus Shale lies beneath much of West Virginia, western and northeastern Pennsylvania, southern New York, eastern Ohio, and parts of Virginia and Maryland. It is an estimated 95,000 square miles in areal extent and ranges from 4,000 feet to 8,500 feet in depth, running deeper the farther north it goes along the cross section.[17] The shale's thickness varies from 50 feet to 250 feet. Some reports indicate that the shale may be as much as 900 feet thick in places, however.[18] (See **Figure 1**.)

(...continued)

over the petroleum has been the source of most produced natural gas. After drilling a well into a conventional petroleum reservoir, the pressure of the gas-cap and oil-dissolved gas may be adequate, initially, to lift the oil to the surface (i.e., gas drive). Water trapping the petroleum from below also exerts an upward hydraulic pressure (water drive). Petroleum reservoirs produced by the pressure of their natural gas and water drives are thus termed "conventional drive." After a reservoir's production declines, lifting further petroleum to the surface requires pumping—giving rise to the term "artificial lift."

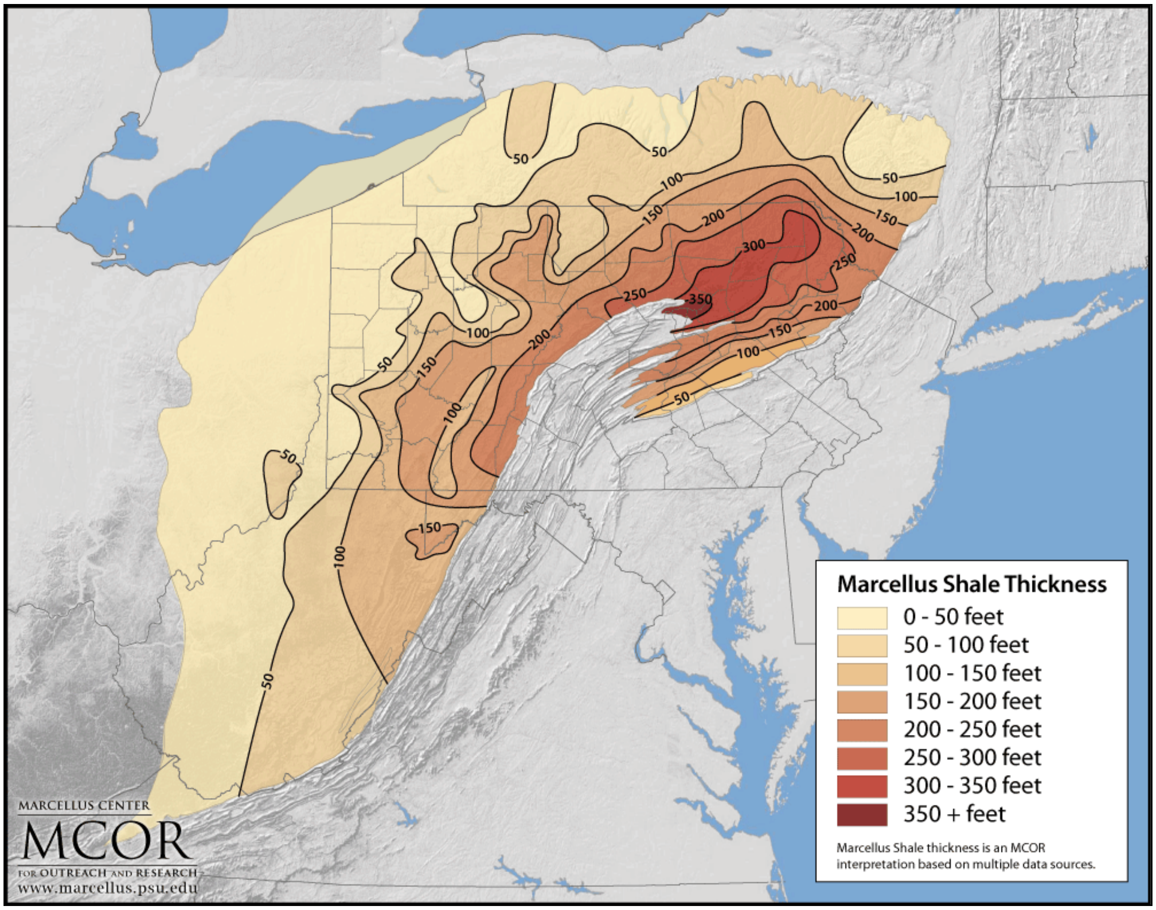
[15] Navigant Consulting, *North American Natural Gas Supply Assessment*, for Clean Skies Foundation, July 4, 2008.

[16] Colorado School of Mines, *Potential Gas Committee Reports Unprecedented Increase in Magnitude of U.S. Natural Gas Resource Base*, June 18, 2009, http://www.mines.edu/Potential-Gas-Committee-reports-unprecedented-increase-in-magnitude-of-U.S.-natural-gas-resource-base.

[17] DOE, Office of Fossil Energy and the National Energy Technology Laboratory, *Modern Shale Gas Development in the United States: A Primer*, DE-FG26-04NT15455, April 2009, http://fossil.energy.gov/programs/oilgas/publications/naturalgas_general/Shale_Gas_Primer_2009.pdf.

[18] U.S. Geological Survey, Assessment of Undiscovered Natural Gas Resources in Devonian Black Shales, Appalachian Basin, Eastern U.S.A, Open-File Report 200-1268, 2005.

Figure 1. Marcellus Shale Location and Thickness Across the Region

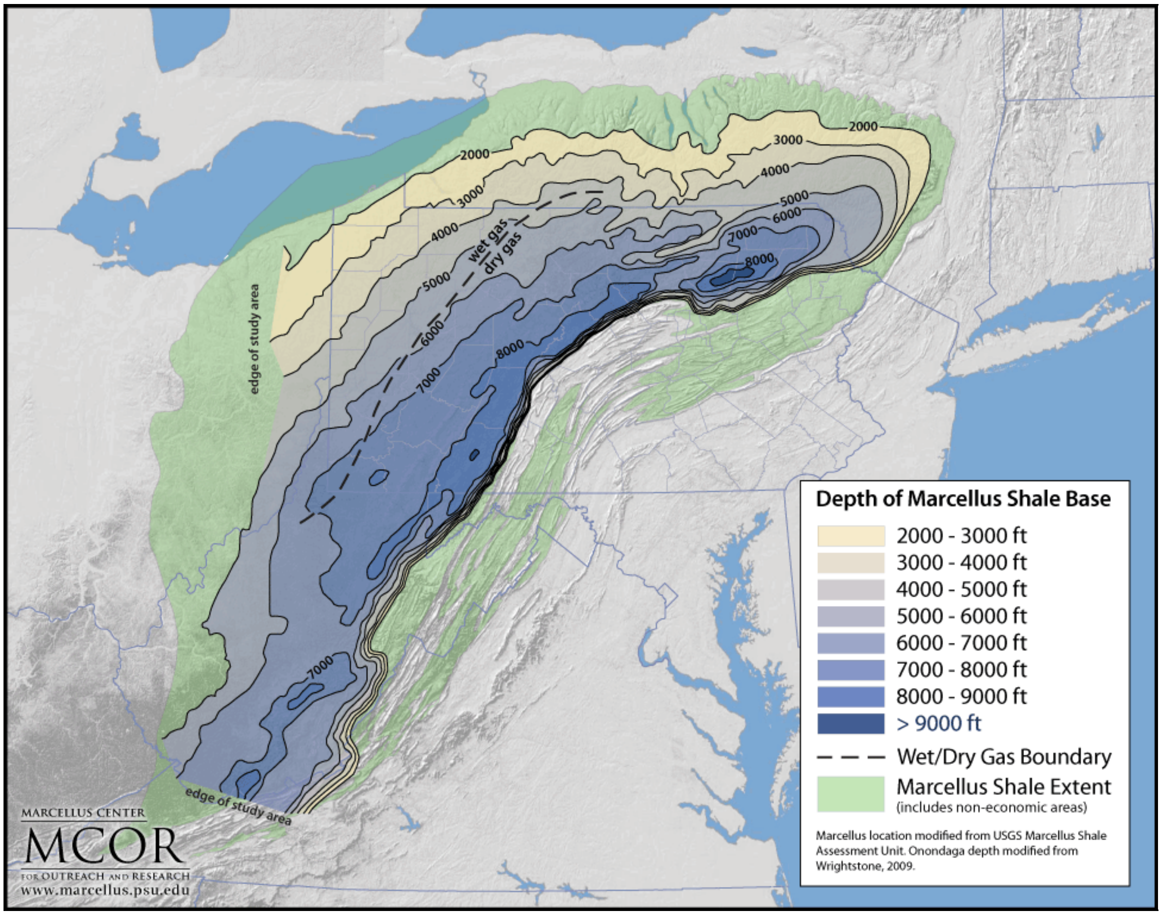


Source: Marcellus Center for Outreach and Research (MCOR), Penn State University, http://www.marcellus.psu.edu.

Typically, thicker shales with greater organic material yield more gas, and thus are more economically desirable to produce. Shale in northeast Pennsylvania and southeast New York has these characteristics and produces dry pipeline quality natural gas.[19] Shale in western New York and western Pennsylvania produces a wetter gas that contains natural gas liquids that must be removed from the gas before it can be piped and used. Natural gas liquids (NGL), such as ethane, butane and propane, add to gas shale profitability and increase the incentive to produce the shale when natural gas prices are low. (See **Figure 2**.)

[19] The natural gas received and transported by the major intrastate and interstate mainline transmission systems must meet the quality standards specified by pipeline companies in the "General Terms and Conditions (GTC)" section of their tariffs. These quality standards vary from pipeline to pipeline and are usually a function of a pipeline system's design, its downstream interconnecting pipelines, and its customer base. In general, these standards specify that the natural gas be within a specific Btu content range (1,035 Btu per cubic foot, +/- 50 Btu); be delivered at a specified hydrocarbon dew point temperature level (below which any vaporized gas liquid in the mix will tend to condense at pipeline pressure); contain no more than trace amounts of certain components such as hydrogen sulfide, carbon dioxide, nitrogen, water vapor, and oxygen; and be free of particulate solids and liquid water that could damage the pipeline or its ancillary operating equipment. EIA, *Natural Gas Processing: The Crucial Link Between Natural Gas Production and Its Transportation to Market*, http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2006/ngprocess/ngprocess.pdf.

Figure 2. Marcellus Shale Depth and Transition Between Wet and Dry Gas



Source: Marcellus Center for Outreach and Research (MCOR), Penn State University, http://www.marcellus.psu.edu.

Note: Natural gas liquids (NGL) that may be present in wet gas include butane, ethane, and propane.

The Utica Shale is an organic-rich black shale source rock that underlies the Marcellus Shale. It contains both conventional oil and gas resources and unconventional gas resources. The majority of the oil and natural gas discovered in this petroleum system is located on the east-dipping, western flank of the Appalachian basin in central and eastern Ohio, northwestern Pennsylvania, and western New York. Generally, the oil and (or) gas fields produce from a variety of lower Paleozoic reservoirs at depths of less than 6,000 feet. The total Utica–Lower Paleozoic petroleum system is estimated to represent an estimated 1.8 billion to 2.4 billion barrels of oil equivalent (BBOE).[20]

USGS has identified three principal hydrogeological (groundwater) environments overlying the Marcellus Shale: (1) glacial sand and gravel aquifers in New York, northern Pennsylvania, and northeastern Ohio, (2) valley-and-ridge carbonate rock and other aquifers in Pennsylvania and eastern West Virginia, and (3) Mississippian sandstone aquifers in northern Pennsylvania and northeastern Ohio. These aquifer systems are important supplies of fresh water for communities

[20] USGS, *Assessment of Appalachian Basin Oil and Gas Resources: Utica-Lower Paleozoic Total Petroleum System*, Open-File Report 2008–1287, 2008.

and landowners, especially in rural areas, although most residents of these states generally obtain their drinking water from surface water sources. Typically, these aquifers are much closer to the ground surface than the Marcellus Shale, which can be thousands of feet deep; the groundwater wells in these states may reach only several hundred feet in depth.

The layers of rocks separating most fresh water aquifers from the Marcellus Shale are typically siltstones and shales layered with minor sandstones and limestone. Siltstones and shales generally act as barriers to fluid flow. These intervening layers of rocks can be several thousand feet thick in the eastern and northern portions of the area where the Marcellus Shale is deepest. On the western and southern portions of the area, the Marcellus Shale is shallower, and separated from the potentially usable groundwater above by a thinner package of siltstones and shales. An overarching concern for developing the Marcellus Shale is the potential for affecting the overlying aquifers.

Natural Gas Resource Potential of the Marcellus Shale

The Marcellus Shale's resource potential has been the subject of various interpretations. A 2005 USGS estimate placed the shale's mean undiscovered *conventional* natural gas resource potential at nearly 2 tcf, and possibly as high as 12 tcf, considering the total extent of Devonian/Ohio basin shales (which include the Marcellus formation), with the qualification that not all of the gas may be economically recoverable. At the time of the 2005 estimate, hydraulic fracturing was not yet being used to recover gas from shale, and that USGS estimate include no unconventional resources.

A 2008 estimate by two geoscience professors raised the resource potential to 516 tcf, based on limited production data from companies using horizontal drilling and hydraulic fracturing to recover the shale gas.[21] In July 2011, EIA released a contractor report reviewing various shale gas plays throughout the United States.[22] The report estimated that ultimate recovery from the current area under lease (10,622 square miles) could reach 177.9 tcf, and the undeveloped areas (84,271 square miles) could reach 232.4 tcf (for a combined total of 410.3 tcf). EIA also estimated that a Marcellus well may ultimately produce 2.3 billion cubic feet (bcf) of natural gas, on average. Assuming $4 per 1,000 cubic feet of gas at the well head (comparable to current prices), producers might realize $9 million per well.

In August 2011, USGS revised its assessment to include more detailed geologic studies of the Marcellus Shale using recent shale gas production data to estimate both conventional and unconventional volumes of undiscovered, technically recoverable shale gas. The new USGS assessment increased the mean undiscovered estimate to slightly more than 84 tcf.[23] Although considerably higher than its 2008 estimate, it is substantially lower than EIA's 2011 estimate (and thus the recent controversy about conflicting government estimates of shale gas in the Marcellus Shale).

[21] Terry Engelder, "Marcellus," Basin Oil & Gas, August 2009, pp. 18-22, http://www.fwbog.com/.

[22] EIA, *Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays*, July 2011.

[23] USGS, *Assessment of Undiscovered Oil and Gas Resources of the Devonian Marcellus Shale of the Appalachian Basin Province, 2011*; Fact Sheet 2011-3092; August 2011.

Both EIA and USGS have significantly revised their technically recoverable resource (TRR) estimates for the Marcellus Shale based on newly available information. Using data though 2010, USGS increased its TRR estimate to 84 tcf from its 2002 estimate of 2 tcf. (USGS assigned a 90% confidence level that the TRR ranges from 43 to 144 tcf.) EIA decreased its estimate for the Marcellus Shale from 410 tcf to 141 tcf. EIA used more recent drilling and production data available through 2011 and excluded production experience from the pre-shale era (before 2008).[24]

The various estimates of the Marcellus resource potential appear to hinge on assumptions made regarding the success in applying advanced drilling and well stimulation technology. However, reconciling these estimates exceeds this report's scope.

Regional Natural Gas Supply and Demand

In 2009, the northeast region consumed roughly 4 tcf of natural gas.[25] New York led the region in consumption, with over 1.14 tcf. The United States as a whole consumed nearly 23 tcf.[26] The northeast region produced roughly 580 bcf of natural gas from more than 121,000 operating gas wells. Pennsylvania and West Virginia combined made up nearly 89% of the production, with New York and Virginia making up the balance.[27] In summary, the region consumes about seven times as much natural gas as it currently produces. The 410.3 tcf of gas, estimated by EIA as technically recoverable from the Marcellus Shale, would be sufficient to supply the region through the century at the current rate of consumption. The USGS estimate of 84 tcf would supply the region's entire natural gas demand for more than 21 years at current rates of consumption.

Pipelines are needed to collect and distribute natural gas, and the major pipeline infrastructure in the northeast/mid-Atlantic region is in place to take advantage of Marcellus production. Twenty interstate natural gas transmission pipelines serve the northeast region of the United States. (See **Figure 3**.) This pipeline system delivers natural gas to several intrastate natural gas pipelines and at least 50 local distribution companies in the region. In addition to the natural gas produced in the region, several long-distance natural gas transmission pipelines supply the region from the Southeast into Virginia and West Virginia, and from the Midwest into West Virginia and Pennsylvania. Canadian imports come into the region principally through New York, Maine, and New Hampshire. Liquefied natural gas (LNG) supplies also enter the region through import terminals in Massachusetts, Maryland, and New Brunswick, Canada.

Although the gas-transmission pipeline network needed to supply the northeast United States is in place, gas producers would need to construct an extensive network of gathering pipelines and supporting infrastructure to move the gas from the well fields to the transmission pipelines. A lack of this infrastructure may constrain development in some parts of the Marcellus region.

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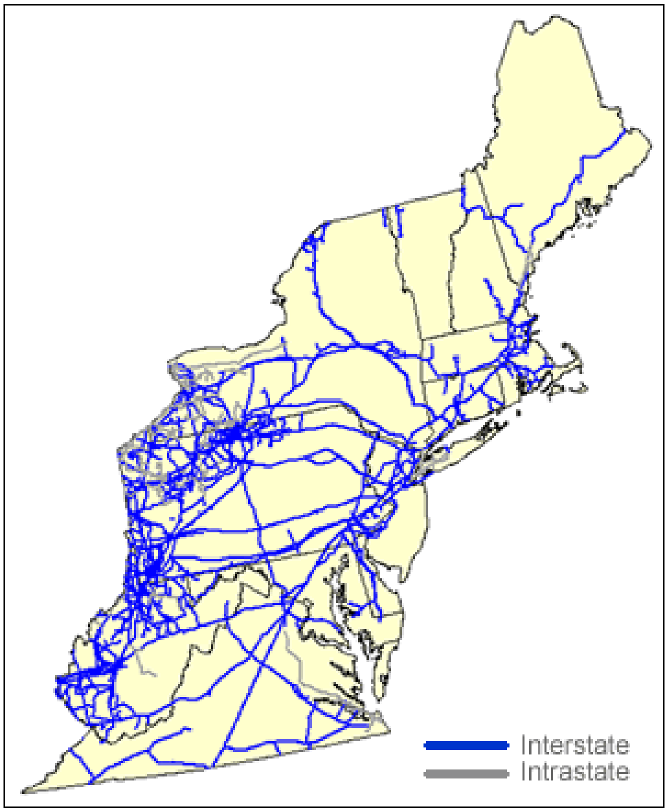
[24] EIA, *AEO2012 [Annual Energy Outlook] Early Release Overview*, January 2012, http://www.eia.gov/forecasts/aeo/er/.

[25] EIA, *Natural Gas Consumption by End Use*, http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.

[26] Reported by EIA as 22.84 tcf for 2009, and 24.13 tcf for 2010, http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.

[27] Ohio lies outside the northeast region but is a significant gas producing state with Devonian and also Marcellus Shale gas resources. In 2009, Ohio had some 35,000 operating gas wells; the state produced 0.98 tcf and consumed 0.74 tcf of natural gas.

Figure 3. Northeast Region Natural Gas Pipeline Network



Source: EIA, Office of Oil & Gas, Natural Gas Division, Gas Transportation Information System, http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/northeast.html.

Note: Includes Connecticut, Delaware, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Virginia, and West Virginia.

Shale Gas Well Drilling and Stimulation

Well drilling technology has progressed markedly over the last 50 years. An important recent advance in drilling is the ability to direct the drill bit horizontally beyond the region immediately beneath the drill rig.[28] It is this directional drilling, in combination with hydraulic fracturing, that has made it feasible to develop the Marcellus Shale and other unconventional gas and oil formations.

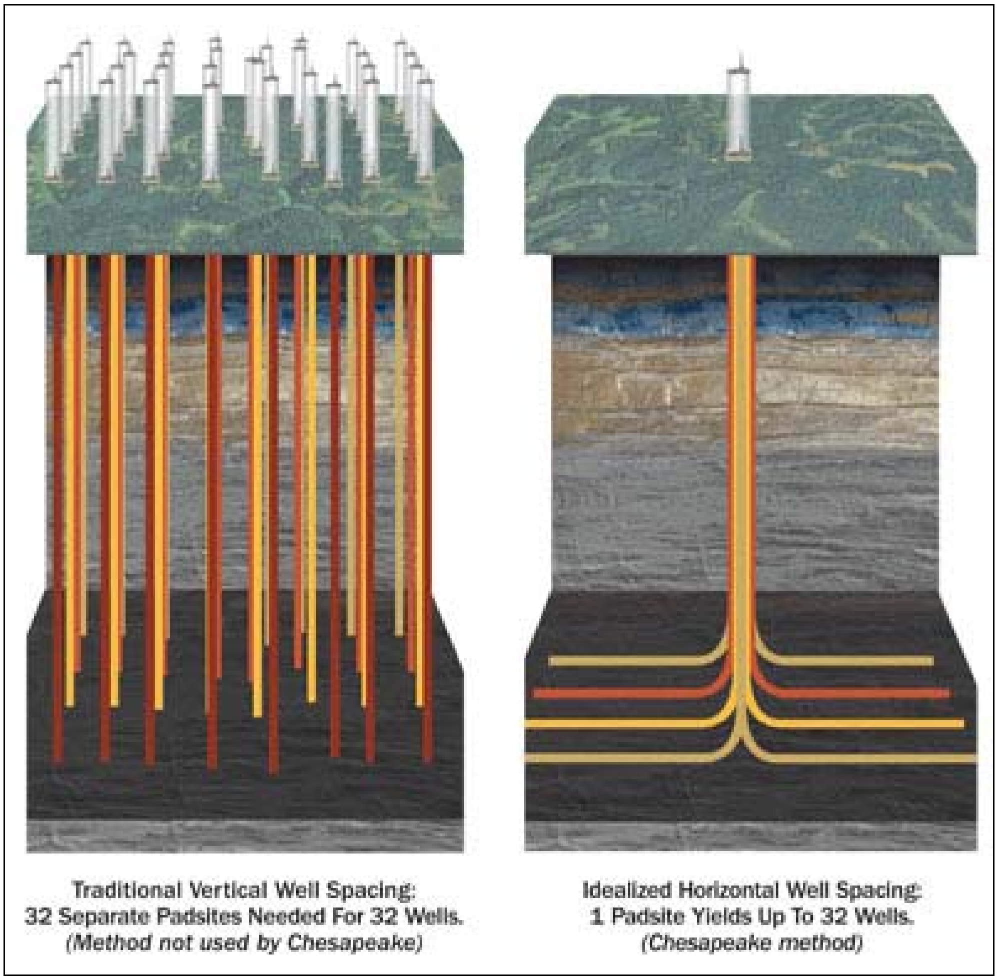
Directional drilling offers a significant advantage over vertical well drilling in developing gas shales. In the case of thin or inclined shale formations, a long horizontal well increases the length of the well bore in the gas-bearing formation and therefore increases the surface area for gas to

[28] Early directional drilling involved placing a steel wedge down-hole (whipstock) that deflected the drill toward the desired target, but lacked control and consumed time. Advances such as steerable down-hole drill motors that operated on the hydraulic pressure of the circulating drilling mud offered improved directional control. Newer rotary steerable systems introduced in the 1990s drill directionally with continuous rotation from the drilling rig at surface. Continuous rotation eliminates the need to slide a steerable down-hole motor. Rotation also leads to higher rates of penetration and fewer incidents of the drill-string sticking. Schlumberger, *Better Turns for Rotary Steerable Drilling: Overview*, http://www.slb.com/content/services/resources/oilfieldreview/ori002/01.asp?.

flow into the well. Directional drilling technology also enables drilling a number of wells from a single well pad, thus cutting costs and reducing environmental disturbance. (See **Figure 4**.) However, this drilling technique alone is often insufficient to significantly improve gas production without some means of artificially stimulating flow. In tight formations like shale, inducing fractures can increase flow by orders of magnitude. However, before stimulation can take place, the well must be cased, cemented, and completed (the well casing perforated).

Figure 4. Traditional Wells vs. Multi-Well Pad

(multi-well pad (right) used in Marcellus Shale)



Source: Chesapeake Energy, http://www.askchesapeake.com/Eagle-Ford-Shale/Drilling/Pages/information.aspx.

In the late 1940s, drilling companies began inducing hydraulic pressure in wells to fracture the producing formation. This fracturing process stimulated further production by effectively increasing the area from which a single well could produce gas. Combining hydraulic fracturing with directional drilling has opened up production of tighter (less permeable) petroleum and natural gas reservoirs, and in particular, unconventional gas shales like the Marcellus.

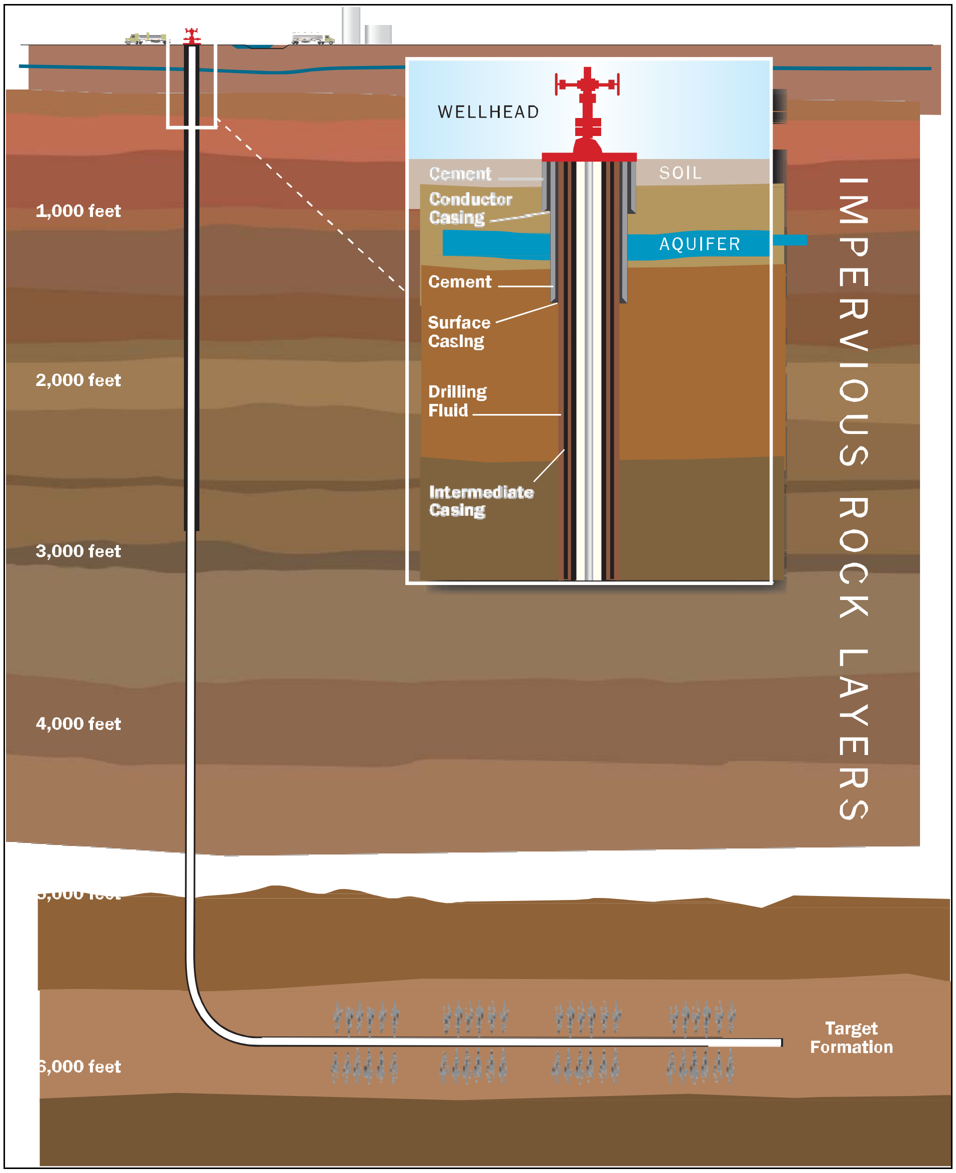
Well Construction and Casing

Wells, whether commercial gas and oil or municipal water-supply, use a series of telescoping steel well casings to prevent well-bore collapse and water infiltration while drilling. The casing also conducts the produced reservoir fluids (gas or oil) to the surface. A properly designed and cemented casing also prevents reservoir fluids from infiltrating the overlying aquifers.

During the first phase of drilling, termed "spudding-in," shallow casing is installed underneath the drilling platform to reinforce the ground surface. Drilling continues to the bottom of the water table (or the potable aquifer), at which point the drill string is removed to lower a second casing string, which is cemented-in and plugged at the bottom. Drillers use special oil-well cement that expands when it sets to fill the void between the steel casing and the rock wellbore.

When properly constructed, surface casing and the casing extending to the bottom of the water table should prevent water from flooding the well while also protecting the groundwater from contamination by drilling fluids and reservoir fluids. (The initial drilling stages may use compressed air in place of drilling fluids to avoid contaminating the potable aquifer.) Drilling and casing then continue to the "pay zone"—the formation that produces gas or oil. The number and length of the casings will depend on the depth and the properties of the geologic strata. (See **Figure 5**.)

Figure 5. Typical Well Casing and Horizontal Well Schematic



Source: American Petroleum Institute, http://www.api.org/policy/exploration/hydraulicfracturing/upload/HYDRAULIC_FRACT_ILLUSTRATION_121609.pdf.

Note: Graphic is not necessarily a shale well and is not to scale.

After completing the well to the target depth and cementing-in the final casing, the drilling operator may hire an oil-well service company to run a "cement evaluation log." An electric probe, lowered into the well, measures the cement thickness to detect anomalies that may correlate with voids in the cement. A cement evaluation log provides the critical confirmation that the cement will function as designed—preventing well fluids from bypassing outside the casing and infiltrating overlying formations. Absent any cement voids, the well is ready for completion. A perforating tool that uses explosive shape charges punctures the casing sidewall at the pay zone. The well may then start producing under its natural reservoir pressure or, as in the case of gas shales, may need stimulation (i.e., hydraulic fracturing). Good well construction is key to protecting ground water during gas production, and complaints that well stimulation treatments (discussed below) affect drinking-water wells may have links to poor well construction practices.

Hydraulic Fracturing

Despite the Marcellus Shale formation's abundant content of natural gas, the gas does not flow freely from the shale because of its low permeability. Economic production depends on some means of artificially stimulating the shale to liberate gas. Hydraulic fracture stimulation treatments have been adapted to unconventional shale formations, such as the Barnett Shale (TX) and Haynesville Shale (AR, LA, and TX), and more recently the Marcellus Shale.

Hydraulic fracturing involves injecting large volumes of water containing sand or other proppant into production wells.[29] Specialized chemicals are also included in the fracture fluid as surfactants or for other purposes, and the fluid is injected under enough pressure to fracture low-permeability geologic formations containing oil and/or natural gas.[30] The sand or other proppant holds the new fractures open to allow the oil or gas to flow freely out of the formation and into a production well.

Typical "frac" treatments or frac jobs (as they are commonly known) are massive operations. The oilfield service company contracted for the work may take a week to stage the job and a convoy of trucks to deliver the equipment and large volumes of water and materials required.

One company involved in developing gas shale offered the following description of a frac job:[31]

> Shale gas wells are not hard to drill, but they are difficult to complete. In almost every case, the rock [pay zone] around the wellbore must be hydraulically fractured before the well can produce significant amounts of gas. Fracturing involves isolating sections of the well in the producing zone, then pumping fluids and proppant (grains of sand or other material used to hold the cracks open) down the wellbore through perforations in the casing and out into the shale.
>
> The pumped fluid, under pressures up to 8,000 psi, is enough to crack shale as much as 3,000 ft in each direction from the wellbore. In the deeper high-pressure shales, operators pump slickwater (a low-viscosity waterbased fluid) and proppant. Nitrogen-foamed fracturing fluids are commonly pumped on shallower shales and shales with low reservoir pressures.

Ideally, hydraulic fractures propagate outward from the section of the well casing where it has been perforated (completed prior to the frac job). In vertical wells, the fracture height approximates the length of the perforated casing section, which is confined to the thickness of the formation to maximize production. In horizontally drilled wells, the height and depth of the fracture depend on the thickness of shale formation (in the case of the Marcellus) and the physical

[29] According to the Schlumberger *Oilfield Glossary*, propping agents, or proppants, are "particles mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment. In addition to naturally occurring sand grains, man-made or specially engineered proppants, such as resin-coated sand or high-strength ceramic materials like sintered bauxite, may also be used." The glossary is available at http://www.glossary.oilfield.slb.com/default.cfm.

[30] This process is distinct from enhanced oil and gas recovery and other secondary and tertiary hydrocarbon recovery techniques, which involve separate wells. Injections for hydraulic fracturing are done through the production wells.

[31] Schlumberger, Inc., *Shale Gas: When Your Gas Reservoir is Unconventional, So is Our Solution*. See http://www.slb.com/media/services/solutions/reservoir/shale_gas.pdf.

properties of the overlying rock formations to confine the fracture. Frac treatments attempted at too shallow a depth may result in horizontally oriented fractures (which is undesirable), and some state regulations identify minimum fracture depths. As noted, the depth of the Marcellus where production is occurring generally places it far below any potential groundwater aquifers, and the possibility of creating a fracture that reaches the near surface is remote. However, geology is never 100% predictable or certain. (See discussion under "Potential Risks to Groundwater," below.)

Fracturing Fluids

Fracturing fluid functions in two ways: opening the fracture and transporting the "propping" agent (or proppant) the length of the fracture.[32] As the term propping implies, the agent functions to prop or hold the fracture open to create conductive paths for the natural gas to reach the wellbore so it can be produced. Silica sands and ceramic beads are the most commonly used proppants.

Water-based fluids consist of 99% water, with the remainder made up of additives.[33] Acid-based fluids also use hydrochloric acid to dissolve the mineral matrix of carbonate formations (limestone and dolomite) and thus improve porosity; the reaction produces calcium chloride salt and carbon dioxide gas. Gelling agents, based on water-soluble polymers such as vegetable-derived guar gum, adjust frac fluid viscosity. The most widely used additives for breaking down fluid viscosity after fracturing are oxidizers such as ammonium (NH^{+4}), potassium, and sodium salt of peroxydisulfate ($S_2O_8^{-2}$); enzyme breakers may be based on hemicellulase (actually a mixture of enzymes which can hydrolyze the indigestible components of plant fibers). Silica flour serves as good fluid-loss additive. Biocides added to polymer-containing fluids prevent degradation of the polymers by bacteria (as the polysaccharides (sugar polymer) used to thicken water are an excellent food source for bacteria). Methanol (an alcohol) and sodium thiosulfate ($Na_2S_2O_3$—an antidote to cyanide poisoning) are commonly used stabilizers added to prevent polysaccharide gels degrading above temperatures of 200°F. Notably, the service companies adjust the proportion of these and many other frac fluid additives to the unique conditions of each well. In addition to the water-based frac fluids, oil-based fluids are used in hydrocarbon bearing formations susceptible to water damage, but they are expensive and difficult to use. They have been used primarily in coal-bed methane frac jobs. At the federal level, the Occupational Safety and Health Administration (OSHA) requires that material safety data sheets (MSDS) accompany each chemical used on the drill site, but the proportion of each chemical additive may be kept proprietary.[34] A number of states recently have adopted new or expanded disclosure rules for chemicals used to stimulate wells.[35]

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[32] Michael J. Economides and Kenneth G. Nolte, ed., "Chapter 7 - Fracturing Fluid Chemistry and Proppants," in *Reservoir Stimulation*, 3rd ed. (John Wiley & Sons, LTD, 2000).

[33] The fluid's properties must exhibit the proper viscosity and low friction pressure when pumped, break down and clean up rapidly when treatment is over, and provide good fluid-loss control (not dissipate). The fluid chemistry may be water-based, oil-based, or acid-based, depending on the properties of the formation. Water-based fluids (sometimes referred to as slickwater) are the most widely used (especially in shale formations) because of their low cost, high performance, and ease of handling.

[34] 29 C.F.R. §§1910 Subpart Z, Toxic and hazardous substances.

[35] For a discussion of disclosure developments among the states, see CRS Report R41760, *Hydraulic Fracturing and Safe Drinking Water Act Issues*, by (name redacted) and (name redacted).

Hydraulic Fracture Process

It is in the operating company's interest to control the fractures and keep them within the formation to maximize production. Fracture treatments are planned, monitored, and adjusted operations that proceed in stages. Before beginning a treatment, the service company performs a series of tests on the well to determine if it is competent to hold up to the hydraulic pressures generated by the fracture pumps.

In the initial stage, a hydrochloric acid (HCl) solution pumped down the well cleans up residue left from cementing the well casing. The portion of the well that lies within the shale is separated into zones, and each zone is isolated from the rest of the well (with a cement barrier or mechanical device) and fractured separately by the application of very high pressures to the shale via the fracking fluid containing proppants and chemical additives. Each successive "frac" stage pumps fluid (slickwater) and proppant down the well into each isolated zone to open and propagate the fracture further into the formation. The treatment may last upwards of an hour or more, with the final stage designed to flush the well. Marcellus wells are likely to receive multiple treatments to produce multiple fractures within each zone along the horizontal wells.

A fracture treatment for a single zone may consume more than 500,000 gallons of water.[36] Wells subject to multiple treatments consume 3 million to 5 million gallons or more. For comparison, an Olympic-size swimming pool holds over 660,000 gallons of water, and the average daily per capita consumption of fresh water (roughly 1,430 gallons per day) works out to 522,000 gallons over one year.[37]

The high injection pressure not only opens and propagates the fracture but also drives fluid into the shale's pore spaces. A high volume of fluid remains in the fracture and impedes gas flow to the well if not pumped out. The subsequent "flowback" treatment attempts to recover as much of the remaining fluid as possible without removing the proppants. The "flowback" water pumped out of the well along with brine from the shale formation may be high in dissolved salts and frac chemicals, however, making it unsuitable for continued use, and thus requiring disposal through deep well injection or treatment before reuse or disposal to surface water. After the well begins producing gas, it may produce more flowback water. Flowback disposal presents environmental issues, as discussed in the "Surface Water Quality Protection" section below.

Potential Risks to Groundwater

The geologic environment that led to the deposition of the Marcellus Shale, and the overlying layers of siltstone, shale, sandstone, and limestone has kept gas from the Marcellus Shale confined at depth, and prevented it from naturally migrating upward into fresh water aquifers. The process of developing a shale gas well—drilling through an overlying aquifer, stimulating the well via hydraulic fracturing, completing the well, and producing the gas—is an issue of concern for increasing the risk of groundwater contamination. Typically, well drilling and completion practices, as described above, require that the well be sealed by casing throughout the aquifer interval. A properly cased well would allow the gas to be produced up the well to the surface, while preventing drilling fluids, hydraulic fracturing fluids, or natural gas from leaking into the

[36] *Modern Shale Gas Development in the United States: A Primer*, pp. 58-59.

[37] USGS, *Summary of Water Use in the United States, 2000*, http://ga.water.usgs.gov/edu/wateruse2000.html.

permeable aquifer and contaminating groundwater. Similarly, groundwater in the aquifer would be prevented from leaking down the well where it could interfere with the gas production process.

The challenge of sealing off the groundwater and isolating it from possible contamination is not unique to development of the Marcellus Shale; thousands of oil and gas wells in New York, Pennsylvania, West Virginia, and eastern Ohio also require similar well drilling and proper casing procedures to protect groundwater resources. The inset to **Figure 4** shows how a well could be designed to protect against leakage into a drinking water aquifer by a succession of casing types down the well from the surface through the aquifer. To protect against contamination, the well must be properly designed and properly constructed. Problems could arise even for a properly designed well—for example, if the casing is not properly cemented, and gaps or pockets in the cement provide a pathway for fluids to migrate outside the casing. Improperly cemented wells might also allow gas or brine to leak into the well from gas-bearing shale formations thousands of feet above the Marcellus. The gas and brine could migrate up the well outside of the casing into an overlying drinking water aquifer. As with the development of other gas-bearing formations, sound well construction and operating practices are essential to reducing the risk of groundwater contamination in the Marcellus Shale region.

Another concern is the possibility of introducing contaminants into aquifers from the hydraulic fracturing process itself, described above. Hydraulic fracturing is intended to induce new fractures into the Marcellus Shale and/or lengthen existing fractures. Concerns have been raised that this process would create or extend fractures linking the Marcellus Shale to an overlying aquifer and provide a pathway for gas or fracturing fluids to migrate. The chances of this occurring are likely remote, because the vertical distance separating the Marcellus Shale from most aquifers is usually much greater than the length of the fractures induced during hydraulic fracturing. Also, thousands of feet of rock layers typically overlie the Marcellus Shale and serve as barrier to flow. It should be noted, however, that if the shallow portions of the Marcellus Shale are developed, then the thickness of the overlying rocks would be less and the distance from the Marcellus to drinking water aquifers would be shorter, posing more of a risk to groundwater.[38]

Engineers designing and carrying out the hydraulic fracturing procedure have an incentive to keep the fractures contained within the gas producing shale. Extending the fractures into a surrounding formation might allow saline fluids or brines to enter the induced fracture and flow into the gas producing portion of the shale, which could significantly hamper gas production. Even if hydraulically induced fractures extend into overlying formations, the possibility for fluids to leak upward into an aquifer is remote, unless those fractures are also connected to some other pathway, such as leaky wells and casings.

In the Marcellus Shale region, a single well may need multiple hydraulic fracture treatments, which could require injecting 3 million to 5 million gallons or more. After the formation is hydraulically fractured, a portion of these fluids is typically recovered and pumped back out of the well to the surface. In the Marcellus region, typically less than 35% of injected fluids are recovered at the surface.[39] Historically, produced waters from oil and gas wells have been disposed of by injecting them into deep wells or treating them before disposal into surface

[38] State geological surveys and oil and gas agencies estimate that the Marcellus Shale lies between 7,650 feet and 2,125 feet beneath treatable ground water. DOE, *Modern Shale Gas Development: A Primer*, p. 17.

[39] In other shale gas producing regions, according to industry estimates, the volume of flowback water can range from less than 30% to more than 70% of the original fracture fluid volume. DOE, *Modern Shale Gas Development in the United States: A Primer*, p. 66.

waters.[40] Underground injection is not always a practical or economic option in the Marcellus Shale region. (See "Underground Injection of Shale Gas Wastewater.")

If these recovered fluids are improperly disposed of at the surface and allowed to infiltrate from the ground surface downward, they could present a risk for contaminating shallow groundwater. Improper surface disposal could pose a particular risk for shallow aquifer systems in northern Pennsylvania and southern New York that are composed of very permeable unconsolidated sand and gravel deposits. Many of these surficial sand and gravel aquifers form valley-fill deposits, in low-lying areas or stream valleys, and are recharged by precipitation that runs off surrounding, less permeable uplands.[41] As such, they would be particularly susceptible to leaky surface impoundments or careless surface disposal because of the relatively short distance and travel time from the land surface to the top of the water table. New York, for example, has deemed these unconsolidated sand and gravel aquifers "primary" or "principal" aquifers, which are highly productive and presently are used as a significant source of water, or are a potentially abundant water supply.[42]

Leaks resulting from improper disposal of fluids at the surface could be exacerbated by poorly constructed drinking water wells in the vicinity. Generally, drinking water wells are shallower than natural gas wells, may not be cased for the entire depth, and may not be subject to the same level of oversight and scrutiny as natural gas wells. A water well that is not cased from the surface, or is not constructed and cased properly, might allow contaminated water to flow from the ground surface and enter the water well, possibly compromising the quality of drinking water in the well and even contaminating the aquifer itself. In such instances, and particularly where natural gas drilling and stimulation activities are nearby, leaky surface impoundments or careless surface disposal of drilling fluids at the natural gas operation could increase the risk of contaminating the nearby water well.

A further confounding factor in regions where drinking water wells and natural gas wells are in close proximity is the possibility of water well contamination from surface waters unrelated to drilling activities. For example, a leaky septic system, or improper disposal of domestic refuse such as car batteries or used oil, can leak from the surface into the water well. If this is the case, a dispute could ensue as to who may be responsible for contaminating the water well. Resolving the dispute could involve a hydrogeological investigation, possibly combined with chemical analysis or isotopic analysis, to prove or disprove any linkage between natural gas development activities and water well contamination, often at considerable expense and with an uncertain outcome, given the complexity of groundwater flow at most sites.

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[40] The Schlumberger glossary notes that "produced fluid is a generic term used in a number of contexts but most commonly to describe any fluid produced from a wellbore that is not a treatment fluid. The characteristics and phase composition of a produced fluid vary and use of the term often implies an inexact or unknown composition." "Flowback" refers to "the process of allowing fluids to flow from the well following a treatment, either in preparation for a subsequent phase of treatment or in preparation for cleanup and returning the well to production."

[41] Henry Trapp Jr. and M. A. Horn, "U.S. Geological Survey Ground Water Atlas of the United States," HA 730-L (1997).

[42] See New York State, Department of Environmental Conservation, "Primary & Principal Aquifers," http://www.dec.ny.gov/lands/36119.html.

Federal and State Laws and Regulations Affecting Marcellus Shale Gas Development

Development of natural gas resources in the Marcellus Shale is subject to regulation under several state and federal environmental laws. In particular, the large volumes of water needed to drill and hydraulically fracture the shale, and the disposal of this water and other wastewater associated with gas extraction, may pose significant water quality and quantity challenges that trigger regulatory attention. USGS noted in a 2009 publication that "concerns about the availability of water supplies needed for gas production, and questions about wastewater disposal have been raised by water-resource agencies and citizens through the Marcellus Shale gas development region."[43] Essentially all permitting, inspection, and enforcement activities related to gas development are conducted by state agencies. In the cases where federal laws may apply, these regulatory requirements also are typically administered by the states. The following sections review key provisions of two relevant federal laws—the Safe Drinking Water Act (SDWA) and the Clean Water Act (CWA)—and related state requirements.

Surface Water Quality Protection

As previously described, hydraulic fracturing involves injecting water, proppants, and chemicals into the shale layer at extremely high pressures, which creates fractures that allow natural gas to flow from the shale. It is a water-intensive practice. Typical Marcellus Shale projects may use 3 million to 5 million gallons of water, although pumped fluid volumes of 7 million to 8 million gallons are not unusual; 0.5 million pounds of sand or other proppant; and smaller amounts of chemicals for each well. Furthermore, production sites may have multiple wells. Regarding the Marcellus Shale region, USGS observed "many regional and local water management agencies are concerned about where such large volumes of water will be obtained, and what the possible consequences might be for local water supplies."[44]

Some of the injected fluids remain trapped underground, but a portion of the injected water—in the Marcellus Shale region, roughly 9% to 35%—returns to the surface as "flowback" after the frac treatment. It typically contains proppant (sand) and chemical residues as well as metals and trace amounts of naturally occurring radioactive elements that may be present in the water produced from the geologic formations.[45] USGS notes that because the quantity of fluid used is so large, the additives in a 3 million-gallon frac job would yield about 15,000 gallons of chemicals in the waste.[46] Frac fluid flowback returns to the surface in the first few weeks, although flowback can continue for several months after gas production has begun but slows over time.

[43] Daniel J. Soeder and William M. Kappel, *Water Resources and Natural Gas Production from the Marcellus Shale*, U.S. Department of the Interior, Fact Sheet 2009-3032, May 2009, http://pubs.usgs.gov/fs/2009/3032/pdf/FS2009-3032.pdf. Hereafter, USGS Fact Sheet.

[44] USGS Fact Sheet, p. 4.

[45] These particles, termed naturally occurring radioactive materials (NORMS), can be brought to the surface on drilling equipment and in fluids. Subsurface formations may contain low levels of such materials as uranium and thorium and their daughter products, radium 226 and radium 228. On gamma-ray logs, shales can be differentiated from other rocks such as clean sandstones and limestones because shales have higher concentrations of potassium-40-bearing minerals. See Commonwealth of Pennsylvania, Department of Conservation and Natural Resources, *Pennsylvania Geology*, vol. 38, no. 1 (Spring 2008), p. 5. http://www.dcnr.state.pa.us/topogeo/pub/pageolmag/pdfs/v38n1.pdf.

[46] USGS Fact Sheet, p. 4.

Normally, flowback fluid is stored on-site until it can be disposed of or reused. That is, the well service company may temporarily retain the flowback in tanks or open-air, lined retention ponds before reusing it, if possible. Flowback waters from natural gas well drilling activities can generally be recycled until they reach certain very high concentrations of total dissolved solids (TDS), at which point the wastewater must be disposed. In the Marcellus Shale region, wastewater management is particularly of interest in the states where natural gas drilling and production that uses hydraulic fracturing already occurs—Pennsylvania, West Virginia, and eastern Ohio—or is expected to begin soon—New York.

Many natural gas operations in the Marcellus Shale region have begun employing on-site treatment processes to facilitate reuse of the flowback fluids, especially in light of technical and regulatory constraints to offsite options, discussed below. Several companies have introduced mobile and fixed treatment units using processes such as evaporation, distillation, oxidation, and membrane filtration for recycling and reuse. On-site treatment technologies may be capable of returning 70%-80% of the initial water to potable water standards, thus making the water immediately available for reuse. The remaining 20%-30% is very brackish and considered brine water. A portion may be further recoverable as process water, but not to achieve potable water standards. The economics of any such options are critical, and site factors such as available power and final water quality are often the determinant in treatment selection. Ultimately, flowback water and production brine that are not reused require proper disposal, either through underground injection or treatment and surface discharge.

As described below ("Underground Injection of Shale Gas Wastewater"), produced water from natural gas extraction may be disposed of through underground injection. Although this disposal method is commonly used in other shale plays, in some areas across the Marcellus Shale region (such as northeastern Pennsylvania), the local geology can limit the disposal of wastewater through underground injection wells. Where underground injection is not feasible, the well service company may discharge the flowback and other produced water to surface waters if the discharge does not violate a stream or lake's water quality standards. Standards established by states under Section 303 of the Clean Water Act (CWA) protect designated beneficial uses of surface waters, such as recreation or public water supply.[47] But direct discharge of untreated flowback and formation brine water is rarely possible in the Marcellus Shale region, because of the chemical additives, naturally occurring contaminants, and salinity found in the wastewater.

Because contaminants present in the flowback broadly prevent discharge to surface water without further treatment, it is likely that the service company will transfer the wastewater off-site to an industrial treatment facility or a municipal sewage treatment plant for processing the wastewater. In this case, the operator of the publicly owned treatment works (POTW) or private centralized waste treatment (CWT) facility would assume responsibility for treating the waste before discharging it into nearby receiving water in compliance with effluent limits contained in the facility's discharge permit.[48]

The chemical frac additives returned in flowback and the produced brine could cause operational problems for POTWs. First, chemical contaminants in industrial process wastewaters can kill the biota essential to a POTW's operation. Second, if TDS or other contaminants pass through the

[47] 33 U.S.C. §1313.

[48] Under CWA Section 301, it is illegal to discharge pollutants into the nation's waters except in compliance with substantive and procedural provisions of the law, which include obtaining a discharge permit. 33 U.S.C. §1311.

POTW without adequate treatment, the discharge could violate water quality standards. TDS is an indicator of salinity, which can be toxic to aquatic organisms. If wastewater is discharged from a POTW or CWT without adequately removing contaminants, the discharges also may contribute to impaired drinking water quality for downstream users. In that regard, there is particular concern for bromides and other salts that comprise TDS, as these chemicals can combine with chlorine in drinking water treatment processes to potentially form carcinogenic disinfection byproducts (DBPs).

The potential scale of natural gas drilling and extraction in the Marcellus Shale region has enormous wastewater management implications, as described by Pennsylvania regulators.[49]

> The Marcellus Shale play has resulted in thousands, and will result in tens of thousands, of new sources of natural gas drilling wastewaters. Although the industry has shown some recent success with reduction in volumes of wastewater needing treatment through the recycling and reuse of flowback and production waters, it is clear that the future wastewater return flows and treatment needs will be substantial.... This play, estimated to contain as much as 500 trillion cubic feet of recoverable natural gas, could result in the development of up to 50,000 new, producing gas wells over the next 20 years.... These wells are anticipated to produce very highly concentrated TDS wastes (over 300,000 mg/L) continuously over the course of 20 to 30 years. For example, if these wells produce an average of ten barrels per week of produced water over their useful lives, a single average well could produce about 27 tons of salt per year (at 300,000 mg/L). Multiply this amount by tens of thousands of Marcellus gas wells, and the potential pollutional effects from these loadings are tremendous. Finally, not enough is known at this point about whether Marcellus wells may need to be "re-fracked" one or more times in the future, thus providing additional uncertainty regarding treatment and disposal needs for the wastewater.

Conventional POTW technology is largely ineffective at treating flowback and brine from gas extraction operations in the Marcellus Shale region. POTWs may remove heavy metals, but the processes employed generally do not actually treat for the very high-TDS concentrations, sulfates, chlorides, or radionuclides in natural gas drilling wastewater. In particular, the very high concentrations of TDS will necessitate treatment by evaporation/distillation technology, which is not typically standard at municipal sewage treatment plants.

Under the Clean Water Act (CWA), regulatory authorities must ensure that permits issued to a POTW or CWT adequately account for and limit discharges of contaminants that could harm aquatic life in streams and rivers. If wastewater is transported to a CWT for treatment, subsequent discharges are subject to EPA-established limitations and standards that are reflected in the facility's permit.[50] If wastewater is transported to a POTW, the facility's permit must include conditions requiring characterization of effluent introduced to the plant, to ensure that incompatible wastes are not allowed. Throughout the Marcellus Shale region, states are authorized to implement these provisions of the CWA and to oversee facilities' compliance with CWA permits.[51]

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[49] Pennsylvania Department of Environmental Quality, "Wastewater Treatment Requirements, 25 PA Code Ch. 95," August 21, 2010, http://www.pabulletin.com/secure/data/vol40/40-34/1572.html. Footnotes omitted.

[50] These EPA limitations and standards are published in the *Code of Federal Regulations* at 40 C.F.R. Part 437.

[51] For information on applicable CWA requirements, see U.S. Environmental Protection Agency, "Natural Gas Drilling in the Marcellus Shale, NPDES Program Frequently Asked Questions," March 16, 2011, http://www.epa.gov/npdes/pubs/hydrofracturing_faq.pdf.

EPA also has a continuing oversight role regarding state CWA programs. In Pennsylvania, the federal agency has accelerated efforts, working with state regulators, to require POTWs and CWTs that receive fracking wastewater to conduct sampling for radionuclides and to issue CWA information requests to POTWs and CWTs for compliance determinations and evaluation of the adequacy of CWA discharge permits. Also, Pennsylvania regulators are working with treatment facilities and community water systems to monitor for radionuclides, TDS, bromide, chloride, and other substances of concern.[52]

In the fall of 2008, water samples from the mid-Monongahela River valley of Pennsylvania showed high levels of TDS. Although the TDS was determined to pose little threat to health or safety, it can have a profound environmental impact, particularly by killing microorganisms and insect larvae essential to healthy ecosystems, such as trout streams. It can also degrade soil if used for irrigation. Preliminary analysis suggested that the principal source likely was large truck deliveries of wastewater from gas well drilling sites in the Marcellus Shale to POTWs discharging, directly or indirectly, into the Monongahela River. At that time, state officials ordered nine sewage treatment plants to reduce their volumes of gas well drilling water, which contains high concentrations of TDS. Subsequent analysis concluded that discharge from abandoned mines was more responsible for the high TDS than drilling wastewater discharges from municipal wastewater treatment plants.[53] However, as indicated by the above quotation, state officials remain concerned about the projected need for treatment of wastewater (both initial flowback water from hydraulic fracturing and longer-term production brines) from gas well development—estimated to be as much as 20 million gallons per day in 2011—and the capacity of the state's surface waters to assimilate associated wastewaters.

In 2010, the Pennsylvania Department of Environmental Protection issued new standards for facilities that accept oil and gas wastewater for treatment. The standards apply to new or increased discharges from treatment facilities, and set strict discharge limits for TDS, chlorides, barium, and strontium. The new standards are intended to protect aquatic life by promoting reuse of water. The goal is to prohibit new and expanding sources of high-TDS wastewater discharge from the natural gas industry.[54] However, 27 Pennsylvania POTWs, which had historically accepted drilling wastewater, are not bound by the 2010 standards unless they increase the amount of drilling wastewater that they accept. During 2010 and early 2011, 11 of these municipal plants voluntarily stopped taking shale gas extraction waste. Both Pennsylvania and federal regulators took steps in 2011 to end the practice of natural gas companies sending fracking wastewater to POTWs because of concerns that the facilities are inadequately equipped to handle waste from fracking operations. In April, state environmental regulators asked drilling operators to stop sending Marcellus Shale wastewater to the 16 remaining POTWs, citing evidence linking the wastewater to elevated levels of bromides in western Pennsylvania rivers.[55] Subsequently, EPA sent information request letters to six natural gas drillers directing them to disclose how and where they dispose of or recycle wastewater generated by their Marcellus Shale natural gas exploration, extraction, and production activities. In response, all six companies

[52] For information on these EPA and Pennsylvania activities, see http://www.epa.gov/region03/marcellus_shale/.

[53] "Minimal Impact on Total Dissolved Solids Found in Monongahela River Last Fall," Natural Gas, Tapping Pennsylvania's Potential, May 20, 2009, http://marcelluscoalition.org/category/newsroom.

[54] Pennsylvania Department of Environmental Quality, "Wastewater Treatment Requirements, 25 PA Code Ch. 95," August 21, 2010, http://www.pabulletin.com/secure/data/vol40/40-34/1572.html.

[55] Commonwealth of Pennsylvania, Department of Environmental Protection, "DEP Calls on Natural Gas Drillers to Stop Giving Treatment Facilities Wastewater," press release, April 19, 2011.

indicated their intention to employ reuse, disposal through underground injection, and/or treatment rather than conventional treatment by any of Pennsylvania's POTWs. The companies indicated intention to recycle 90% or more of produced water (including flowback) in Pennsylvania, where injection wells are limited.[56] Marcellus Shale operators have stopped sending wastewater to the state's POTWs.[57]

West Virginia, too, recognizes that wastewater disposal is "perhaps the greatest challenge regarding these operations."[58] State officials say that underground injection (see discussion below) may be the best option for wastewater disposal, but the state has only two permitted commercial injection wells available. The state has one industrial wastewater treatment facility in Wheeling, and state officials are cautious about the capability of the municipal POTWs to handle the flow and quality of waste that they might receive.[59] In 2009 the West Virginia Department of Environmental Protection proposed changes to the state's oil and gas drilling rules (which required approval of the state legislature) and to an industry guidance document to assist operators in planning for the water issues associated with drilling and operating these wells. However, local groups criticized the proposed rules and draft non-binding guidance for failing to address disposal of wastewater, disclosure of chemicals used in hydraulic fracturing, and where the additional quantities of water required for drilling will come from.[60] Subsequently, the state's legislature considered a number of bills to implement the proposed rules, and also to make other changes such as increasing permit fees. In December 2011, the state legislature passed, and the governor signed, the Horizontal Well Act, which requires drillers to provide water management plans and to disclose all chemicals used in hydraulic fracturing fluids, among numerous other provisions intended to protect water supplies.

For several years, New York State regulators have been evaluating the potential environmental impacts of high-volume hydraulic fracturing in the state. During this time, New York has imposed a moratorium on processing permits to drill Marcellus Shale wells under the existing Generic Environmental Impact Statement (SGEIS). (Traditional oil and gas wells still may be permitted using the SGEIS). In September 2011, the state's Department of Environmental Conservation released a Revised Draft Supplemental Generic Environmental Impact Statement (RDSGEIS) with recommendations that, when finalized, are intended to allow natural gas development consistent with environmental protection requirements while banning drilling in specified sensitive areas, including the New York City and Ithaca watersheds.[61] Regarding wastewater

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[56] The six companies—Atlas Resources, Cabot Gas & Oil Corp., Chesapeake Energy; Range Resources-Appalachia, SWEIP, and Talisman Energy USA—hold more than half of all permits issued for natural gas drilling in Pennsylvania. EPA's May 12, 2011, letters to the companies and their responses regarding wastewater management are available at http://www.epa.gov/region03/marcellus_shale/.

[57] Traditional oil and gas well operators may continue to take their produced water to authorized facilities.

[58] State of West Virginia, Department of Environmental Protection, Office of Oil and Gas, "Industry Guidance, Gas Well Drilling/Completion, Large Water Volume Fracture Treatments (Draft)," March 13, 2009, p. 3, http://www.wvsoro.org/curent_events/marcellus/Marcellus_Guidance_Draft.pdf.

[59] Ibid. at 3-4. Reportedly, one company with wells in the Marcellus Shale in West Virginia has its hydraulic fracturing wastewater trucked to an out-of-state commercial facility that treats the water and then injects it into depleted oil and gas reservoirs. (P. Kasey, "New Drilling Efforts Raise Questions," *The State Journal*, August 14, 2008.)

[60] West Virginia Surface Owners' Rights Organization, "Proposed Changes to Oil & Gas Rules, Marcellus Guidance Document," http://www.wvsoro.org/curent_events/.

[61] New York State Department of Environmental Conservation, Revised Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program: Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs, Albany, NY, September 30, 2011, http://www.dec.ny.gov/energy/75370.html.

management, the revised draft SGEIS would allow POTWs to accept flowback water if the municipal plant has a state-approved pretreatment program for accepting industrial waste and the plant's discharge permit assures that surface water quality standards for TDS and other contaminants are not violated. Underground injection, discussed below, also may be authorized.

To help POTWs manage produced water, in October 2011, EPA initiated a rulemaking to develop technology-based standards that shale gas wastewaters must meet before going to a POTW. EPA expects to issue a proposed rule for shale gas wastewater standards in 2014.[62]

Other Surface Water Quality Issues

Another potential source of water pollution from oil and gas drilling sites is runoff that occurs after a rainstorm. Storm water runoff can transport sediment to nearby surface water bodies. Provisions of the CWA generally regulate storm water discharges from industrial and municipal facilities by requiring implementation of pollution prevention plans and, in some cases, remediation or treatment of runoff.[63] Industries that manufacture, process, or store raw materials and that collect or convey storm water associated with those activities are subject to the act's requirements. Furthermore, fracking fluid chemicals and wastewater can leak or spill from injection wells, flow lines, trucks, tanks, or holding pits, and thus may contaminate soil, air, and water resources.

The federal Clean Water Act (CWA) specifically exempts the oil and gas industry from these storm water management regulatory provisions. CWA Section 402(l)(2) exempts mining operations or oil and gas exploration, production, processing, or treatment operations or transmission facilities from federal storm water regulations, and Section 502(24) extends the exemption to construction activities, as well.[64] Thus, federal law contains no requirements to minimize uncontaminated sediment pollution from the construction or operation of oil and gas operations. However, the federal exemption does not hinder states from requiring erosion and sedimentation controls at well sites, under authority of non-federal law. Pennsylvania, for example, requires well drill operators to obtain a permit for implementation of erosion and sedimentation controls, including storm water management, if the site disturbance area is more than 5 acres in size. If the site is less than 5 acres, a plan for erosion and sediment control is required. Storm water requirements are part of this permit.[65] New York has similar requirements for erosion and sedimentation controls at well sites, regardless of site area. West Virginia requires erosion and sediment control plans for proposed well sites that would disturb 3 or more acres of land.[66] The Delaware River Basin Commission, which has jurisdiction over water quality in a portion of the area underlain by the Marcellus Shale (see section on "State Water Quality Laws") has similar requirements, regardless of site area.

[62] EPA is developing standards for wastewater discharges produced by natural gas extraction from shale formations and coal beds. The regulations will be established under EPA's effluent guidelines program, which sets national regulations to control the discharge of pollutants from industry to surface waters and to POTWs. Effluent guidelines are specific to an industry and are established under the authority of CWA §304(m). For more information, see http://water.epa.gov/lawsregs/lawsguidance/cwa/304m/.

[63] Clean Water Act §402(p); 33 U.S.C. §1342(p).

[64] 33 U.S.C. §1342(l)(2); 33 U.S.C. §1362(24).

[65] The Pennsylvania permit is called an Earth Disturbance Permit (ESCGP-1).

[66] W. Va. C.S.R. §35-8-3, Department of Environmental Protection Oil and Gas, Rules Governing Horizontal Well Development, http://www.dep.wv.gov/oil-and-gas/Documents/35-8%20%20%20Horizontal%20Well%20Rule.pdf.

Groundwater and Drinking Water Protection

A controversial water quality issue associated with development of the Marcellus Shale regards the potential for hydraulic fracturing operations to contaminate groundwater and drinking water wells (as discussed under "Potential Risks to Groundwater"). Responding to widespread public concern, the 111th Congress urged EPA to study the impact that fracturing may have on potable aquifers and drinking water supplies.[67] However, EPA is not authorized to regulate the underground injection of fluids for hydraulic fracturing purposes, except where diesel fuel is used.[68] The agency expects to publish initial research results in 2012, and a final report in 2014. As part of the research, EPA has identified three Marcellus Shale case studies in Pennsylvania: two retrospective case studies to investigate drinking water contamination incidents, and one prospective study where shale gas development is planned.[69]

A question that has arisen is whether state oil and gas laws and regulations are adequate to protect groundwater and drinking water wells, given the increasingly extensive development of unconventional gas and oil resources that rely on hydraulic fracturing in combination with deep vertical and horizontal drilling. The deep horizontal wells used in unconventional oil and gas development can be subjected to greater pressures than conventional wells and may be at greater risk of failure if not properly constructed and operated.

In 2009, the Ground Water Protection Council (GWPC)[70] reviewed state oil and gas regulations designed to protect water resources for the major producing states.[71] The GWPC concluded that, in general, state oil and gas regulations are adequately designed to protect water resources. State regulations generally include permitting, well drilling and construction, well closure and abandonment, and waste fluid management. Until recently, few states explicitly mentioned hydraulic fracturing in their oil and gas regulations; however, drilling, construction (e.g., casing and cementing), pressure testing, completion, blowout prevention, reporting, and other requirements are intended to protect fresh water aquifers (and hydrocarbon resources) during oil and gas production.

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[67] P.L. 111-88, H.Rept. 111-316.

[68] The Energy Policy Act (EPAct) of 2005 (P.L. 109-58, §322) amended the SDWA to exempt from the definition of underground injection the injection of fluids or propping agents (other than diesel fuel) for hydraulic fracturing purposes. For a history of this provision, and the EPA underground injection control program and its role in regulating hydraulic fracturing, see CRS Report R41760, *Hydraulic Fracturing and Safe Drinking Water Act Issues*, by (name redacted) and (name redacted).

[69] EPA has selected seven sites for case studies to develop information about the potential impacts of hydraulic fracturing on drinking water resources under different circumstances. Two sites are prospective case studies where EPA will monitor aspects of the hydraulic fracturing process at future development sites (i.e., the Haynesville Shale in DeSoto Parish (LA), and the Marcellus Shale in Washington County (PA). Five retrospective studies will investigate reported drinking water contamination attributed to hydraulic fracturing operations at gas production sites (i.e., the Bakken Shale in Kildeer, Dunn County (ND); the Barnett Shale in Wise County (TX); the Marcellus Shale in Bradford and Susquehanna Counties (PA); the Marcellus Shale in Washington County (PA); and the Raton Basin (CO)). For information on the EPA hydraulic fracturing study, see the agency's hydraulic fracturing website, http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/. The final study plan is available at http://www.epa.gov/hfstudy/HF_Study__Plan_110211_FINAL_508.pdf.

[70] The Ground Water Protection Council is a professional association of state groundwater and underground injection control agencies responsible for groundwater protection.

[71] GWPC, DOE, Office of Fossil Energy, National Energy Technology Laboratory, *State Oil and Natural Gas Regulations Designed to Protect Water Resources*, May 2009.

Although major oil and gas producing states have extensive programs to manage oil and gas development activities, the GWPC noted that related state groundwater protection rules and practices can be uneven. Among other actions, the Council recommended the development of best management practices (BMPs) for hydraulic fracturing, which state agencies could use either to develop state-specific BMPs or develop new state regulations. GWPC advised states to review rules to determine whether "they meet an appropriate level of specificity (e.g. use of standard cements, plugging materials, pit liners, siting criteria, and tank construction standards, etc.)" to protect water resources.[72]

In a groundwater contamination case in Pennsylvania, Department of Environmental Protection officials attributed the migration of methane gas into 18 residential water wells in Dimock, PA, to "defective casing and cementing" of shale gas wells.[73] The state since has updated oil and gas rules. The regulators explained the need for the revised regulations.[74]

> Many of the regulations governing well construction and water supply replacement were promulgated in July 1989 and remained largely unchanged until this final-form rulemaking. Since that time, recent advances in drilling technology have attracted interest in producing natural gas from the Marcellus Shale, a rock formation that underlies approximately 2/3 of this Commonwealth. New well drilling and completion practices now employed to extract natural gas from the Marcellus Shale and other similar shale formations in this Commonwealth, as well as several recent incidents of contaminated drinking water caused by traditional and Marcellus Shale wells resulted in the Department's decision to reevaluate the existing well construction requirements.
>
> It was determined that the existing regulations were not specific enough in detailing the Department's expectations of a properly cased and cemented well, especially in light of the new techniques used by Marcellus Shale operators. The Department also determined that the existing regulations did not address the need for an immediate response by operators to a gas migration complaint and did not require routine inspection of existing wells by the operator.
>
> The final-form rulemaking contains revised design, construction, operational, monitoring, plugging, water supply replacement and hydraulic fracturing reporting requirements. The final-form rulemaking also provides material specifications and performance testing to ensure the proper casing, cementing and operation of a well. Additionally, the final-form rulemaking contains new provisions that require routine inspection of wells and outline the actions an operator and the Department will take in the event of a gas migration incident.

Other states in the region also have amended or are revising regulations to address challenges related to unconventional oil and gas development, including hydraulic fracturing. In 2010, Ohio legislators made major revisions to the state oil and gas law, adding requirements for companies to submit hydraulic fracturing records, and to report the type and volume of materials used, pumping pressures, and return volumes.[75] The law also expanded well construction, casing, and

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[72] Ibid, pp. 39-40.

[73] See Pennsylvania Department of Environmental Protection website, http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/OILGAS/Final%20COA%20121510.pdf. For further information on this complex matter, see http://www.cabotog.com/pdfs/Letter_Sec_Hanger.pdf. For a review of non-routine incidents in Pennsylvania involving development of the Marcellus Shale, see http://www.dec.ny.gov/docs/materials_minerals_pdf/rdsgeisch100911.pdf.

[74] In February 2011, the Pennsylvania Environmental Quality Board published notice of final oil and gas well regulations to prevent gas migration incidents, 25 PA. Code Ch. 78, http://www.pabulletin.com/secure/data/vol41/41-6/239.html.

[75] For information on Ohio's environmental regulations on drilling for natural gas in the Marcellus and Utica shales, (continued...)

cementing requirements to protect underground sources of drinking water.[76] And, as discussed, New York State has undergone a comprehensive review of the issues associated with shale-gas development, and is developing a new regulatory regime for horizontal drilling and high-volume hydraulic fracturing.

In December 2011, West Virginia enacted the Horizontal Well Act, which makes numerous changes to existing law.[77] The act imposes new conditions on horizontal well permits to protect groundwater, surface water, and water resource supplies. (See section below, "State Regulation of Water Resources.") The act requires well operators to provide state regulators with well-casing plans, details on the rock formation, and drilling-depth plans. Additionally, the law increases permit fees to support more state inspectors. Among other provisions, the law specifies minimum distances horizontal wells must be from water wells, public water supplies, streams, wetlands, etc.

As noted, managing the large volumes of wastewater produced during natural gas production (including flowback from hydraulic fracturing and brine produced from the rock formation) has emerged as a major water quality issue related to Marcellus Shale development. In some areas across the Marcellus Shale region (such as northeastern Pennsylvania), the local geology can limit the disposal of wastewater through underground injection wells. However, underground injection remains the most common—and traditionally preferred—produced water disposal practice in the oil and gas production industry, and is increasing in this region as gas development expands.

The increased use of underground injection for wastewater disposal, combined with proposals to authorize EPA to regulate hydraulic fracturing as underground injection, has drawn new attention to the federal underground injection control program. This program's statutory and regulatory framework is reviewed briefly below.[78]

Federal Underground Injection Control Program

The disposal of flowback and other water produced from gas wells through deep well injection is regulated through EPA's Underground Injection Control (UIC) program authorized by the federal Safe Drinking Water Act (SDWA).[79] This act established the national program for protecting "underground sources of drinking water" by limiting, through regulation, underground injection that could contaminate usable aquifers. Although the SDWA excludes from regulation the

(...continued)

see http://www.epa.ohio.gov/shale.aspx.

[76] SB 165, Ohio Department of Natural Resources, Division of Mineral Resources Management, Oil and Gas, June 30, 2010. For information on the law and rules, see http://www.ohiodnr.com/oil/SB165updates/tabid/22848/Default.aspx. Additionally, Ohio and Pennsylvania recently had their oil and gas regulatory programs reviewed under State Review of Oil and Natural Gas Environmental Regulations (STRONGER), to evaluate the adequacy of their hydraulic fracturing requirements. STRONGER is a state program review process, conducted by a multi-stakeholder, national nonprofit group. State hydraulic fracturing reviews are available at http://www.strongerinc.org/.

[77] H.B. 401, 80th Leg., 4th Spec. Sess. (W. Va. 2011).

[78] For a discussion of EPA's UIC program and its role in oil and gas production and hydraulic fracturing activities, see CRS Report R41760, *Hydraulic Fracturing and Safe Drinking Water Act Issues*, by (name redacted) and (name redacted).

[79] The Safe Drinking Water Act of 1974 (P.L. 93-523) authorized the UIC program at EPA. UIC provisions, as amended, are contained in SDWA Part C, §§1421 - 1426; 42 U.S.C. §§300h - 300h-5.

underground injection of fluids used in hydraulic fracturing (unless diesel fuel is used), the injection of wastewater produced during oil and gas development is subject to this law.[80]

Section 1421 of SWDA directs the EPA administrator to issue regulations for state UIC programs, and mandates that the EPA rules "contain minimum requirements for programs to prevent underground injection that endangers drinking water sources."[81] To implement the UIC program, EPA has established six classes of underground injection wells based on categories of materials that are injected into the ground for each class. The wells within a class are required to meet a set of performance criteria for protecting underground sources of drinking water (USDW), and the rules broadly prohibit the injection of waste fluids into USDWs. The UIC regulations for each class include the following broad elements: site characterization, area of review, well construction, well operation, site monitoring, well plugging and post-injection site care, public participation, and financial responsibility.[82] Class II injection wells are used to dispose of brines (salt water) and other fluids associated with oil and gas production or storage, to store natural gas, or to inject fluids for enhanced oil and gas recovery.[83]

The SDWA authorizes EPA to delegate primary enforcement authority (primacy) for UIC programs to the states, provided that the state program meets EPA regulations developed under Section 1421 and prohibits underground injection that is not authorized by a state permit or rule.[84] If a state's UIC program plan is not approved, or the state has chosen not to assume program primacy, then EPA must implement the UIC program in that state. However, in lieu of meeting the specific requirements of EPA's regulations for the injection of brine or other fluids brought to the surface in connection with oil or gas production (Class II injection wells), Section 1425 allows states to demonstrate that their Class II UIC programs are effective in preventing endangerment of underground sources of drinking water.[85] This gives states flexibility to implement their own program requirements, rather than meet the specific EPA regulations.

Where a state has primacy, EPA is still required to take enforcement actions for regulatory violations if the state fails to do so.[86] Additionally, the SDWA grants the EPA administrator

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[80] EPAct 2005 (P.L. 109-58, §322) amended the SDWA to exempt from the definition of underground injection the injection of fluids or propping agents (other than diesel fuel) for hydraulic fracturing purposes (42 U.S.C. §300h(d)). EPA retains the authority to regulate the use of diesel fuel for the purpose of hydraulic fracturing, and the agency is developing guidance to help states implement this provision. EPA's website notes that "any service company that performs hydraulic fracturing using diesel fuel must receive prior authorization from the UIC program," and that "injection wells receiving diesel fuel as a hydraulic fracturing additive will be considered Class II wells by the UIC program." See http://water.epa.gov/type/groundwater/uic/class2/hydraulicfracturing/wells_hydroreg.cfm#safehyfr.

[81] 42 U.S.C. §300h(b).

[82] Regulatory requirements for state UIC programs are established in 40 C.F.R. §§144-147.

[83] EPA historically has differentiated Class II wells from production wells. The agency's UIC website states that "production wells bring oil and gas to the surface; the UIC Program did not regulate production wells." EPA, Class II Wells—Oil and Gas Related Injection Wells (Class II), "What are the types of Class II wells?," http://water.epa.gov/type/groundwater/uic/class2/index.cfm.

[84] 42 U.S.C. §300h-1. The minimum requirements for a state UIC program can be found at 40 C.F.R. Part 145. To receive primacy, a state must demonstrate to EPA that its UIC program is at least as stringent as the federal standards; the state requirements may be more stringent than the federal requirements. For Class II wells, states must demonstrate that their programs are effective in preventing endangerment of underground sources of drinking water (USDWs).

[85] 42 U.S.C. §300h-4 (SDWA §1425). To receive approval under §1425 optional demonstration provisions, a state program must include permitting, inspection, monitoring, and record-keeping and reporting requirements.

[86] 42 U.S.C. §300h-2 (SDWA §1423).

emergency powers to issue orders and commence civil actions to protect public water systems or underground sources of drinking water.[87]

In the Marcellus region, Maryland, Ohio, and West Virginia have assumed primacy and have lead implementation and enforcement authority for their UIC programs. As with most oil and gas producing states, Ohio and West Virginia have received primacy for Class II wells under Section 1425, which enables these states to administer their own equivalent program, rather than adopt EPA regulations. Maryland has adopted EPA regulations, but has no Class II injection wells for the disposal of wastewater from oil and gas production.[88] In New York, Pennsylvania, and Virginia, EPA directly implements the entire UIC program. Permits are required both by EPA and the state environmental agency in New York and Pennsylvania, if the disposal method for shale gas wastewater is by deep well injection.

Underground Injection of Shale Gas Wastewater

Most of the fluid injected into Class II wells is brine brought to the surface in producing oil and gas. This brine, a naturally occurring formation fluid, is often very saline and may contain toxic metals and naturally occurring radioactive substances. To prevent contamination of land, surface water, and groundwater, Class II wells provide a means for disposing of brines by re-injecting them back into their source formation or into similar formations at significant depths. As states have adopted rules to limit or prohibit the disposal of saline water to surface water and land, and treatment remains challenging and costly, injection remains the preferred way to dispose of this waste fluid, where the local geology permits.

The amount of water produced by shale gas wells, separate from the flowback of water injected for hydraulic fracturing purposes, is likely to vary across the Marcellus Shale region. Given the limited experience with development of the shale, it is uncertain how much produced water might be generated. Generally speaking, shale gas formations are relatively impermeable and typically produce much less water than traditional oil and gas fields or coalfields. However, because large amounts of water must be used to fracture the shale, the disposal of this water and produced brine presents a challenge. Moreover, the impermeability of the shale indicates that reinjection of wastewater from fracturing into the shale formation may not be feasible in many locations, unless other suitable formations are locally available.

Wastewater injection into the permeable Cambrian sandstones that lay beneath the Marcellus Shale appears feasible. The Cambrian Mt. Simon Sandstone, considered an ideal geologic unit in Ohio for disposal and long-term storage of liquid wastes, is relatively deep, and underlain and overlain by impervious confining layers that prevent migration of injected fluids.[89] In contrast, the geology in Northeastern Pennsylvania is not favorable for injection.

[87] 42 U.S.C. §300i (SDWA §1431) authorizes the administrator to take action when information is received that (1) a contaminant is present in or is likely to enter a public drinking water supply system or underground source of drinking water "which may present an imminent and substantial endangerment to the health of persons," and (2) the appropriate state or local officials have not taken adequate action to protect such persons.

[88] EPA, 2010 UIC Well Inventory, Office of Water, 2010, http://water.epa.gov/type/groundwater/uic/.

[89] Ohio Department of Natural Resources, Division of Geological Survey, *The Geology of Ohio—The Cambrian*, GeoFacts No. 20, May 1998.

Capacity for deep well injection of wastewater varies across the Marcellus region. In Ohio, oil and gas permits generally prohibit the discharge of brine directly into state waters, and roughly 98% of all brine is disposed of by deep well injection.[90] The Ohio Department of Natural Resources has permitted 184 Class II brine disposal wells, and permit requests for additional wells are pending. Since Marcellus Shale gas development began in West Virginia, the number of permitted commercial Class II disposal wells there has increased from two to 13. New York has six active Class II disposal wells; however, before New York stopped processing permits for horizontal drilling and high-volume hydraulic fracturing in 2008, operators from one company had submitted more than 60 permit applications for such wells.[91] In Pennsylvania, six Class II disposal wells are operating, and EPA (which implements the UIC program for the state) has approved two more wells, but these permits are under appeal. However, since the state has limited surface water discharges, interest in deep well injection within the commonwealth is increasing.

Emerging Issue: Deep Well Injection and Seismic Events

In recent months, several small earthquakes have occurred in eastern Ohio in the vicinity of injection wells used to dispose of brine and other wastewater produced from oil and gas wells. No causal link has been established between the wastewater injection and these seismic events, but state officials have had operators shut-in the nearby wells while the events are investigated. Past incidents of induced seismicity have been identified: in 1967, the injection of wastes at the Rocky Mountain Arsenal was halted once fluid injection was linked to a series of earthquakes. In 1990, the U.S. Geological Survey (USGS) reported that,

> of the well-documented cases of earthquakes related to fluid injection, most are associated with water-flooding operations for the purpose of secondary recovery of hydrocarbons… [The] operations often entail large arrays of wells injecting fluids at high pressures into small confined reservoirs that have low permeabilities. In contrast, waste-disposal wells typically inject at lower pressures into large porous aquifers that have high permeabilities. This explains, in large part, why, of the many hazardous and nonhazardous waste-disposal wells in the United States, only two have ever been conclusively shown to be associated with triggering significant adjacent seismicity. (The wells are near Denver, CO, and Ashtabula, OH.)[92]

Currently, EPA and USGS are evaluating several case studies of possible induced seismicity. The forthcoming report will include lessons learned and make recommendations to assist states in regulating injection well operations.

State Water Quality Laws

In addition to federal laws, state laws addressing the quality of surface water and groundwater also apply to Marcellus Shale development. For example, in New York, various aspects of unconventional gas development would require a permit under the state's State Pollutant Discharge Elimination System (SPDES).[93] SPDES is an "approved," rather than delegated, version of the federal National Pollutant Discharge Elimination System (NPDES) permit program under the Clean Water Act, which means that the state program differs from the federal rules in various ways, but that EPA has determined that the state program is at least as protective as federal rules. One significant difference in the state program is that, while the federal NPDES

[90] Ohio Department of Natural Resources, Division of Oil and gas Resources Management, *Underground Injection Control (UIC)*, http://www.ohiodnr.com/mineral/injection/tabid/10374/Default.aspx.

[91] J. Daniel Arthur, et al, *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs*, 2008, available at http://www.all-llc.com.

[92] Craig Nicholson and Robert L. Wesson, *USGS Bulletin 1951*, U.S. Geological Survey, Earthquake Hazard Associated with Deep Well Injection - A Report to the U.S. Environmental Protection Agency, 1990.

[93] N.Y. Envtl. Cons. Law §17-0505.

covers only discharges to surface water, SPDES covers discharges to groundwater also. The SPDES permit requirement could apply to hydraulic fracturing, unless four conditions are met. Most importantly, the state must determine that injection will not degrade groundwater.[94] A wastewater treatment plant would likely dispose of fluids produced from the well, in which case the plant's SPDES permit would apply. SPDES permits would also cover treatment facilities built specially for disposing of flowback water, if there would be discharges into a water body. Applicable state water quality standards would control the permit's discharge limits, in part.[95]

The New York State Environmental Quality Review Act (SEQRA) is also relevant.[96] As with its federal counterpart, the National Environmental Policy Act, a requirement that an environmental impact statement be prepared in certain circumstances lies at the heart of the statute.[97] New York has been evaluating the potential environmental impacts associated with directional drilling and hydraulic fracturing activities for more than 15 years. As noted above, in September 2011, the state's New York Department of Environmental Conservation (DEC) released for public comment the Revised Draft Supplemental Generic Environmental Impact Statement (RDSGEIS) under SEQRA on high-volume hydraulic fracturing natural gas development in the Marcellus Shale region of the state with recommendations to comprehensively revise the state's procedures for regulating operations using High Volume Hydraulic Fracturing (HVHF). Until New York completes a final SGEIS consistent with SEQRA, regulators will not process permit applications for gas wells involving horizontal drilling and high-volume hydraulic fracturing.[98] The DEC received more than 32,000 comments on the revised draft and is now reviewing them.

The RDSGEIS would not apply to specified areas, including within the New York City and Syracuse watersheds, on primary aquifers, on certain state lands, in floodplains, within 2,000 feet of public drinking water supplies, and within 500 feet of private water wells (unless agreed to by the landowner). Nor would the RDSGEIS apply to HVHF operations in shallow portions of shale formations, specifically in locations where the top of the target fracture zone would be shallower than 2,000 feet below the surface, or less than 1,000 feet below the base of a known fresh water supply. In these locations, site-specific environmental assessments and SEQRA determinations of significance would be required for HVHF permit applications. (**Figure 6** indicates specific geographic areas where drilling permits would not be granted under the RDSGEIS and, in effect, prohibited.) The DEC also has proposed regulations that revise existing oil and gas regulations, establish new regulations for HVHF, and update the SPDES regulations.

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[94] N.Y. Code of Rules and Regulations (Conservation) §750-1.5(a)(6).

[95] N.Y. Envtl. Cons. Law §17-0501.

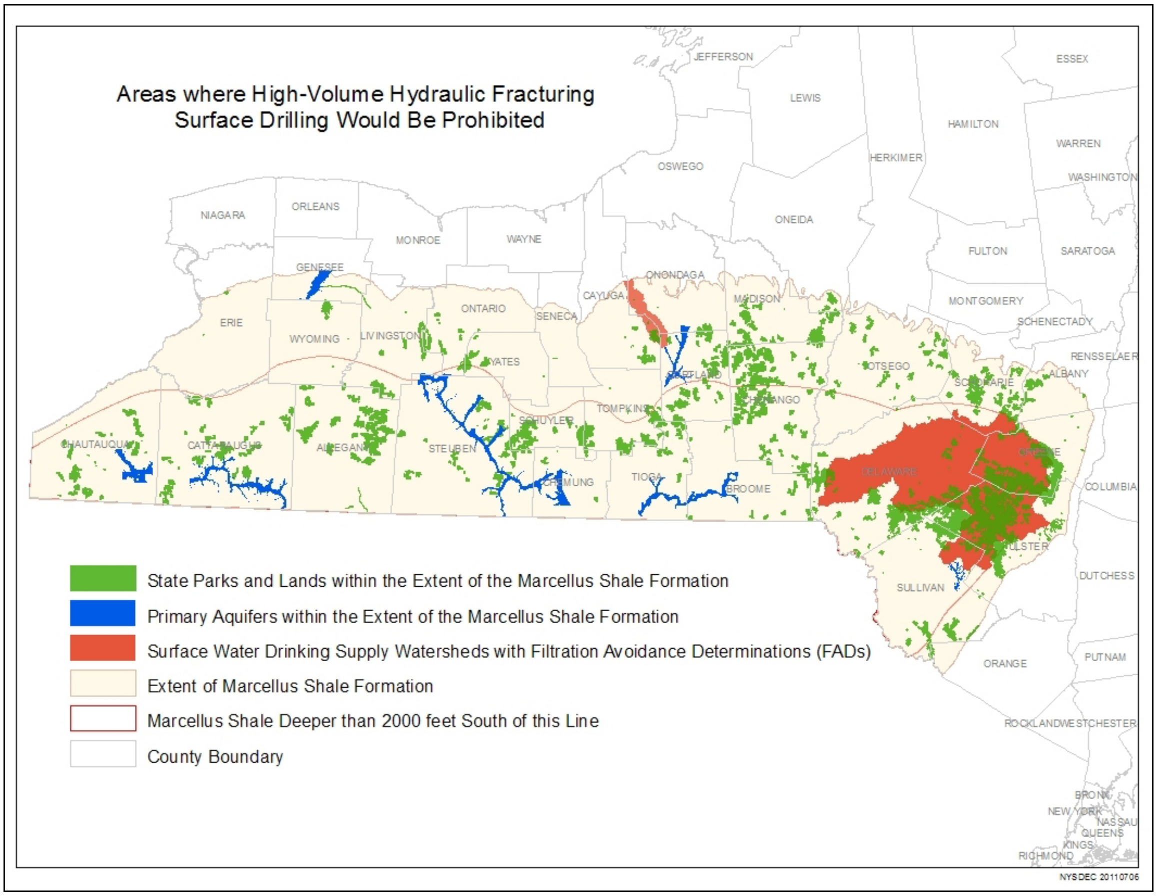
[96] N.Y. Envtl. Cons. Law §§8-0101–8-0117.

[97] *Id*. at §8-0109.

[98] David A. Paterson, Governor, New York, "Executive Order No. 41: Requiring Further Environmental Review," December 10, 2010, http://www.dec.ny.gov/energy/46288.html#41. The September 2011 Revised Draft SGEIS is available at http://www.dec.ny.gov/energy/75370.html.

Figure 6. New York State Areas Where Shale Development Is to Be Prohibited

(NYC and Syracuse watersheds, primary aquifers, and state lands)



Source: New York Department of Environmental Conservation, http://www.dec.ny.gov/energy/75370.html.

Note: The Draft Revised Supplemental Generic EIS also establishes setbacks from public water supplies and private wells and contains other high-volume hydraulic fracturing drilling restrictions.

Maryland, too, currently is not processing permit applications for drilling and hydraulic fracturing in the state's portion of the Marcellus Shale (although several permits are pending). Officials plan to study "best practice" standards for drilling and fracking before permitting a small number of exploratory wells to evaluate the environmental viability of gas production.[99]

In Pennsylvania, oil and gas exploration and development are regulated under a number of state laws, including the Clean Streams Law, the Solid Waste Management Act, and the Water Resources Planning Act. For example, pursuant to the Clean Streams Law,[100] Pennsylvania regulates waste discharges from municipal and industrial sources and regulates the impact of mining on water quality, supply, and quantity. It also is the basis for state permit requirements to

[99] Robert M. Summers, Acting Secretary of the Maryland Department of the Environment, Testimony before the U.S. Congress, Senate Committee on Environment and Public Works, Subcommittee on Water and Wildlife, "Hydraulic Fracturing in the Marcellus Shale and Water Quality," April 12, 2011.

[100] 35 P.S. §691.1 et seq.

manage stormwater runoff from oil and gas operations through erosion and sediment control plans. (See “Other Surface Water Quality Issues.”)

As another example, West Virginia’s NPDES permit program would apply to wastewater treatment plants to which flowback from Marcellus Shale production sites was taken and to treatment facilities built specially for the frac water that discharges into a water body.[101] Applicable state water-quality standards would control the permit’s discharge limits, in part.[102] However, this program applies to surface water only, not groundwater, and the state’s Groundwater Protection Act exempts “groundwater within geologic formations which are site specific to ... the production ... of ... natural gas....”[103] The state’s underground injection control program regulates the injection of flowback and produced water for disposal.[104]

In addition to state water-quality laws, the interstate Delaware River Basin Commission (36% of whose jurisdictional land area in Pennsylvania and New York overlies the Marcellus Shale formation) would also impose water quality requirements.[105] The Commission’s water quality (and other) requirements are legally separate from those of the affected states—that is, obtaining state approval does not excuse an applicant from seeking Commission approval—although in some cases the two requirements may be substantively identical. Another interstate-compact-created commission within the Marcellus Shale region, the Susquehanna River Basin Commission, regulates only water quantity, not water quality.[106] These commissions are discussed further below.

Water Supply Management

Thousands of wells are being drilled in the Marcellus Shale region, and large volumes of water are needed to develop each well. Roughly 1 million gallons typically may be needed for every 1,000 feet fractured in the horizontal portion of a well, for perhaps 3 million to 8 million gallons per well, and wells may need to be hydraulically fractured several times during their productive lifespan.

Availability of adequate supplies of fresh water required for drilling and hydraulic fracturing can be a constraint for gas producers who must arrange to procure water in advance of their drilling and development activity. Extensive development of the Marcellus Shale could place short-term, but potentially significant, demands on local water resources. This is especially true if water needed for gas development is taken from smaller headwater streams or limited groundwater

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[101] W. Va. Code Ann. §22-11-4(a)(16). See regulations at W. Va. Code of State Rules, Tit. 47, ser. 10.

[102] W. Va. Code of State Rules tit. 47, ser. 2.

[103] W. Va. Code Ann. §22-12-5(i).

[104] W. Va. Code Ann. §22-11-8(b)(7). See regulations at W. Va. Code of State Rules tit. 47, ser. 13.

[105] The compact creating the Delaware River Basin Commission was ratified by Congress: P.L. 87-328, 75 Stat. 688. Section 3.8 of the Compact states: “No project having a substantial effect on the water resources of the basin shall hereafter be undertaken by any person, corporation, or government authority unless it shall have been first submitted to and approved by the commission....” Section 2.3.5 B of the Delaware River Basin Comm’n Administrative Manual (Rules of Practice and Procedure) lists 18 types of projects that must be submitted to the Commission, including withdrawal of groundwater and discharge of pollutants into surface or ground waters of the basin. Codified at 18 C.F.R. §401.35(b).

[106] The compact creating the Susquehanna River Basin Commission was ratified by Congress: P.L. 91-575, 84 Stat. 1509 (1970).

supplies. In these cases, large water withdrawals have the potential to impair water quality through diminished stream flows that could affect aquatic life, fishing and recreational activities, or private wells and water supplies. Concerns have arisen specifically regarding the ability to maintain baseline stream flows to avoid cumulative and seasonal impacts. Management of water use for Marcellus Shale operations is largely a matter of geography—in some areas, it is the responsibility of interstate commissions, and in other areas, it is the responsibility of state agencies.

State Regulation of Water Resources

The laws and regulations governing the availability of fresh water lie with each state, and water rights and water supply regulations generally differ among the states. Depending on individual state resources and historic development, states may use one of two water rights doctrines, riparian or prior appropriation, or a hybrid of the two. Under the riparian doctrine, a person who owns land that borders a watercourse has the right to make reasonable use of the water on that land.[107] Traditionally, the only limit to users under the riparian system is the requirement of reasonableness in comparison to other users.[108] Under the prior appropriation doctrine, a person who diverts water from a watercourse (regardless of his location relative thereto) and makes reasonable and beneficial use of the water may acquire a right to use of the water.[109]

States east of the Mississippi River generally follow a riparian doctrine of water rights, while western states typically follow the prior appropriation doctrine.[110] The system of water rights allocation in a particular state with shale gas resources may affect the development process, particularly in times when shortages in water supply affect the area of shale gas development. In areas where the Marcellus Shale is located, which are generally riparian states, water rights may not be as much of a concern as in other areas of the country with shale gas development, such as the Barnett Shale in Texas. That is, even in times of shortage, shale gas development may be able to continue in the Marcellus Shale region because riparian users reduce water usage proportionally and may still receive enough for supply requirements of the development process. However, whether the amount of water required for hydraulic fracturing processes would be considered "reasonable" remains unclear. As shale gas development continues to draw on water resources in riparian states, this question may become a significant factor in the public debate over hydraulic fracturing.

Because of the general recognition of the riparian doctrine in the region, the states in the area of shale development apply surface and groundwater regulations similarly. Some states have specific regulatory programs in place, however, and gas producers using fresh water for drilling and

[107] *See generally* A. Dan Tarlock, "Law of Water Rights and Resources, ch. 3," Common Law of Riparian Rights.

[108] *Id.* at §3:12.

[109] *See generally id.* at ch. 5, "Prior Appropriation Doctrine." The prior appropriation system limits users to the quantified amount of water the user secured under a state permitting process with a priority based on the date the state conferred the water right. Because of this priority system, the phrase "first in time, first in right" has sometimes substituted for appropriative rights. Some states have implemented a dual system of water rights, assigning rights under both doctrines.

[110] The distinction between these doctrines arises primarily from the historic availability of water geographically. In the generally wetter, eastern riparian states, water users share the water resources because water availability historically did not pose a problem to settlement and development. In the drier, western states that experience regular water shortages, the prior appropriation system provides a definitive hierarchy that allows users to acquire well-defined rights to water as a limited resource that requires planning to avoid scarcity.

development must comply with state and local administration of water rights (as well as any relevant interstate water compacts). Examples of water supply regulations in the Marcellus Shale states are discussed below, but a comprehensive analysis of state water regulation schemes is beyond the scope of this report.

Some states have implemented permit programs that require certain water users who wish to withdraw large amounts of water resources to register with the appropriate state agency. For example, New York requires users of water for public water supply, irrigation, and specific projects designated by law (unrelated to shale development) to acquire a permit.[111] However, under that program, water users pursuing shale development appear to remain unregulated. Other states have adopted permit programs that require water users who withdraw in excess of a set threshold (e.g., 10,000 gallons per day) to obtain approval from the state.[112]

Other states have undertaken various planning and reporting programs to monitor water use in the state, but do not generally require a permit.[113] For example, by statute, West Virginia requires certain users of water resources whose withdrawals exceed 750,000 gallons in any month to register with the Department of Environmental Protection.[114] Water users must provide information about the sources of withdrawals, anticipated volumes, and the time of year of withdrawals.[115] The goal is to ensure that water withdrawal from ground or surface waters does not exceed sustainable volumes.[116] State officials have introduced measures that would impose a lower threshold for registration on the use of water in gas development projects.[117] In 2011, West Virginia enacted the Natural Gas Horizontal Wells Control Act, which mandates that certain horizontal well applications used for fracturing include a water management plan.[118] The water management plan is required for applications for a well work permit if the fracturing of the well requires more than 210,000 gallons of water during any 30-day period.[119] The plan must identify information about the use of water, including the type of water source, and the anticipated volume and time of withdrawal.[120]

States may implement a variety of these programs concurrently. For example, Pennsylvania implements both a permit program and a planning and reporting program, in addition to specific requirements imposed on drillers to include water use management plans with applications for drilling permits. Under the permit program, public water supply agencies must receive approval from the state's Department of Environmental Protection.[121] Other users do not appear to be covered by a permit program outside of the Susquehanna and Delaware River Basins. Under the

[111] N.Y. Envtl. Conserv. Law §15-1501.

[112] See 9 Va. Admin. Code §25-210-60.B; 401 Ky. Admin. Regs. 4:010.

[113] See 27 Pa.C.S. §3101 et seq.

[114] W. Va. Code Ann. §22-26-3.

[115] State of West Virginia, Department of Environmental Protection, Office of Oil and Gas, "Industry Guidance, Gas Well Drilling/Completion, Large Water Volume Fracture Treatments," January 8, 2010, http://www.dep.wv.gov/oil-and-gas/GI/Documents/Marcellus%20Guidance%201-8-10%20Final.pdf.

[116] *Id.*

[117] See also W. Va. S.B. 424 (introduced February 4, 2011), http://www.legis.state.wv.us/bill_status/bills_text.cfm?billdoc=sb424%20intr.htm&yr=2011&sesstype=RS&i=424.

[118] H.B. 401, 80th Leg., 4th Spec. Sess. (W. Va. 2011).

[119] *Id.* at §22-6A-7(e).

[120] *Id.*

[121] 32 Pa. Stat. Ann. §636.

reporting program, users must report withdrawals that on average exceed 10,000 gallons per day in a 30-day period.[122] Users are required to report information including source of water supply, location, and the amount of withdrawals.[123] Additionally, Marcellus Shale drillers must develop and submit a water use management plan, which, once approved, becomes a condition of a shale well permit.[124]

Interstate Compacts in the Marcellus Shale Region

The Marcellus Shale region includes parts of Kentucky, Maryland, New York, Ohio, Pennsylvania, Virginia, and West Virginia.[125] Several of these states include watersheds that are subject to specific regulations, usually resulting from the adoption of an interstate compact. Three interstate compacts may have a direct impact on potential water resources for the development process: the Delaware River Basin Compact, the Susquehanna River Basin Compact, and the Great Lakes-St. Lawrence River Basin Water Resources Compact.

The Delaware River Basin Commission (DRBC) governs water resource issues in the Delaware River Basin, which includes parts of Delaware, New Jersey, New York, and Pennsylvania.[126] The Susquehanna River Basin Commission (SRBC) governs water resource issues in the Susquehanna River Basin, which includes parts of Maryland, New York, and Pennsylvania.[127] (See **Figure 7**.) Both the DRBC and the SRBC regulate water use through requirements imposed on any entity—public or private—whose use would affect the respective basins.

The Great Lakes-St. Lawrence River Basin Water Resources Compact governs management of the Great Lakes and St. Lawrence River Basin, which includes parts of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin.[128] This basin overlies a small portion of the Marcellus Shale, but includes other shale formations, including the Utica Shale. The Great Lakes-St. Lawrence compact imposes requirements on the states (as parties to the compact) to adopt standards of regulation for water use within the basin. Rules governing these compacts have increasingly included requirements to regulate the water use of hydraulic fracturing projects.

[122] *See* 27 Pa. Cons. Stat. Ann. §3118.

[123] *Id*.

[124] The Pennsylvania Department of Environmental Protection has issued detailed instructions on how to complete a water management plan, which is available at http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/marcellus/marcellus.htm.

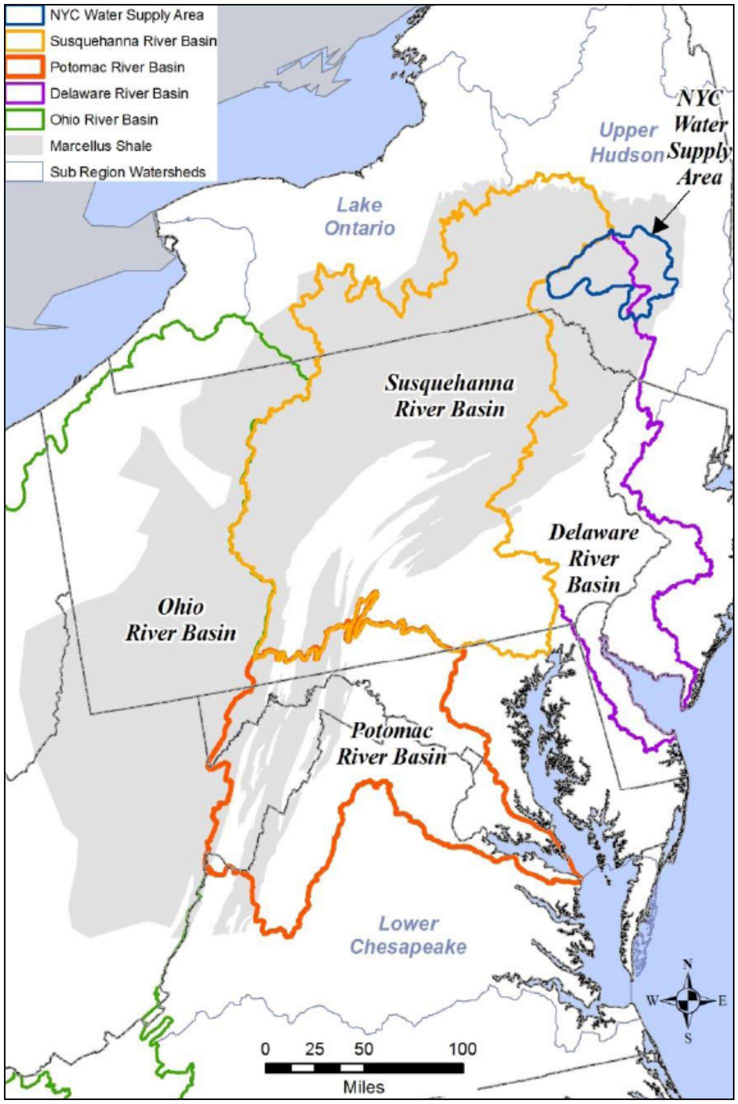
[125] See USGS, Assessment of Undiscovered Oil and Gas Resources of the Devonian Marcellus Shale of the Appalachian Basin Province, August 2011, http://pubs.usgs.gov/fs/2011/3092/pdf/fs2011-3092.pdf.

[126] P.L. 87-328, 75 Stat. 688 (1961).

[127] P.L. 91-575, 84 Stat. 1509 (1970).

[128] P.L. 110-342, 122 Stat. 3739 (2008).

Figure 7. Major River Basins and Sub-Basins Overlying the Marcellus Shale



Source: J.D. Arthur, M. Uretsky, and P. Wilson (ALL Consulting). "Water Resources and Use for Hydraulic Fracturing in the Marcellus Shale Region." Prepared in conjunction with the New York State Energy Research and Development Authority, Susquehanna River Basin Commission, and the Delaware River Basin Commission and others under U.S. Department of Energy Research Project DE-FE0000797.

Note: The Great Lakes-Saint Lawrence River Basin overlaps with the north edges of the Marcellus region.

The DRBC imposes limits on projects that have "a substantial effect on the water resources of the basin" and requires that any person or entity seeking to undertake such a project obtain prior approval.[129] The DRBC is directed to approve projects if it finds the project "would not substantially impair or conflict with the comprehensive plan" for managing the basin.[130] Certain projects are exempt from the requirement for prior approval, including water withdrawals and

[129] Delaware River Basin Compact, art. 3, §3.8, *available at* http://www.state.nj.us/drbc/regs/compa.pdf. See also art. 10, §10.3.

[130] *Id.* at §3.8.

diversions that do not exceed an average of 100,000 gallons per day.[131] Specific regulatory requirements apply to applications for withdrawals in excess of 1 million gallons on average per day, including monitoring requirements, contingency plans for emergency conservation, and reporting requirements.[132] The DRBC has issued draft regulations to protect the basin's resources relating to the development of natural gas projects.[133] Under the proposed regulations, DRBC approval is required before water sources in the basin may be used for the purpose of natural gas development projects.[134]

A similar regulatory scheme was established in the Susquehanna River basin. The SRBC also imposes approval requirements for certain projects affecting the water resources of the basin.[135] Among the projects generally requiring prior approval from the SRBC are new and increased consumptive use projects using an average of 20,000 gallons per day or more; new and increased withdrawals of an average of 100,000 gallons per day or more; and diversions into or out of the basin of an average of 20,000 gallons per day or more.[136] In addition to these general requirements, the SRBC has adopted regulations specific to the Marcellus Shale, which require approval for "any natural gas well development project in the basin targeting the Marcellus or Utica shale formations, or any other formation …, for exploration or production of natural gas involving a withdrawal, diversion or consumptive use, regardless of the quantity."[137]

Lying along the northwestern perimeter of the Marcellus Shale region is the Great Lakes-St. Lawrence River Basin. Approved by Congress in 2008, the Great Lakes-St. Lawrence River Basin Water Resources Compact includes monitoring, registration, and reporting requirements to protect the use of water resources within this basin.[138] Within five years of the compact taking effect, any withdrawal of an average of 100,000 gallons per day or more and any diversion must be registered with the proper administering authority.[139] Each party must be notified of and given the opportunity to comment on any proposal for a consumptive use of 5 million gallons per day or more.[140] Under the compact, diversions of water resources out of the basin are generally prohibited with few exceptions.[141] Each state is required to adopt a regulatory program for withdrawals and consumptive uses within five years of the effective date of the compact, which sets a threshold level of regulation at an average of 100,000 gallons per day or more.[142]

[131] 18 C.F.R. §401.35.

[132] 18 C.F.R. §401.36.

[133] Revised Draft Natural Gas Development Regulations (November 8, 2011), http://www.state.nj.us/drbc/notice_naturalgas-draftregs.htm.

[134] Natural Gas Development Regulations §§7.3(b) and 7.4 (November 8, 2011), http://www.state.nj.us/drbc/naturalgas-REVISEDdraftregs110811.pdf.

[135] Susquehanna River Basin Compact, art. 3, §3.10, http://www.srbc.net/about/srbc_compact.pdf.

[136] 18 C.F.R. §806.4(a)(1), (2), and (3).

[137] 18 C.F.R. §806.4(a)(8). An amendment has been proposed that would broaden the applicability of this provision. If adopted as a final rule, "any unconventional natural gas development project in the basin involving a withdrawal, diversion or consumptive use, regardless of the quantity," would require SRBC approval. Susquehanna River Basin Commission, "Review and Approval of Projects," 76 *Federal Register* 41154-57 (July 13, 2011).

[138] Great Lakes-St. Lawrence River Basin Water Resources Compact, *available at* http://www.cglg.org/projects/water/docs/12-13-05/Great_Lakes-St_Lawrence_River_Basin_ Water_Resources_Compact.pdf.

[139] Great Lakes–St. Lawrence River Basin Water Resources Compact, art. 4, §4.1, paragraph 3.

[140] Great Lakes–St. Lawrence River Basin Water Resources Compact, art. 4, §4.6, paragraph 1.

[141] Great Lakes–St. Lawrence River Basin Water Resources Compact, art. 4, §§4.8–4.9.

[142] Great Lakes –St. Lawrence River Basin Water Resources Compact, art. 4, §4.10.

Congressional Interest

The Marcellus Shale formation represents one of the largest unconventional or conventional natural gas resources in the United States. Current and planned projects to develop Marcellus Shale gas are apparent across the six-state region that overlies the resource. For example, gas producers have reportedly planned over 2,000 gas wells just in West Virginia, and the state's Oil and Gas Commission estimates that, based on current information, there could be a well on every 40 acres in the state. Throughout the region, this activity is placing increasing demands on regulatory agencies—especially state agencies—for necessary licensing, permitting, inspections, and enforcement, and also for revising regulations. Because of questions related to water supply and wastewater disposal, some state agencies and DRBC have been cautious about granting permits until these issues are resolved. New York, in particular, is taking a cautious approach and has accepted, but not processed, permits pending completion of a state Supplemental Generic Environmental Impact Statement. At the same time, there is counter-pressure from companies, drillers, and landowners to move forward with developing the gas resource. The success of planned development activities could depend, in part, on the capacity of regulatory agencies to provide the administrative and oversight resources to support such plans.

The development of the Marcellus Shale and other unconventional natural gas resources, and the use of hydraulic fracturing in particular, has generated considerable debate in Congress and has been the topic of hearings and legislation. Industry and many state agencies are arguing against broad federal regulation of hydraulic fracturing under the SDWA, and noting a long history of the successful use of this practice in developing oil and gas resources. A typical horizontal well is estimated to cost between $3 million and $5 million,[143] and industry representatives argue that more federal regulation is unnecessary and would likely slow domestic gas development and increase energy prices. At the same time, the amount of natural gas produced from unconventional formations that rely on hydraulic fracturing continues to grow. Moreover, drilling and reservoir stimulation methods have changed significantly over time as they have been applied to more challenging formations, increasing markedly the amount of water and fracturing fluids involved in production operations. It is the rapidly increasing and geographically expanding use of hydraulic fracturing and directional drilling, along with a number of citizen complaints of water contamination and other environmental problems attributed to this practice—and to shale gas development more broadly—that has led to calls for greater state and/or federal environmental oversight of this activity.

Pending Federal Legislation

In March 2011, the Fracturing Responsibility and Awareness of Chemicals Act of 2011 (FRAC Act) was introduced in the House (H.R. 1084) and Senate (S. 587). The bills are substantively similar and would amend the Safe Drinking Water Act to revise the definition of underground injection to include hydraulic fracturing, and to create a new disclosure requirement for the chemicals used in hydraulic fracturing. Under both bills, the definition of "underground injection" that was amended in 2005 to exclude most hydraulic fracturing would be amended again to

[143] Larry Wickstrom, et al., *The Marcellus and Utica Shale Plays in Ohio*, Ohio Department of Natural Resources, Division of Geological Survey, March 11, 2011, http://www.dnr.state.oh.us/portals/10/energy/Marcellus_Utica_presentation_OOGAL.pdf.

include "the underground injection of fluids or propping agents pursuant to hydraulic fracturing operations related to oil or gas production activities."[144]

The FRAC Act also would require anyone conducting hydraulic fracturing to disclose to the state (or EPA if EPA has primary enforcement responsibility), before starting hydraulic fracturing operations, a list of chemicals intended for use in any underground injection during the operations.[145] The information must include identification of the chemical constituents of mixtures, Chemical Abstracts Service numbers for each chemical and constituent, material safety data sheets when available, and the anticipated volume of each chemical. Additionally, within 30 days after the end of any hydraulic fracturing operations, the operator must provide information on the chemicals and amounts actually used.[146]

The bills would also require that the state or EPA make the disclosure of chemical constituents public, including posting the information on a website. The bills specify that the disclosure requirements do not authorize the state or EPA to require the public disclosure of proprietary information. This language attempts to protect proprietary business information, that is, "secret" formulas of the chemical constituents being used in hydraulic fracturing or practices that drilling companies believe they should not be required to disclose to regulators or the public. Increasingly, state oil and gas production laws and rules are requiring disclosure to regulators of the chemical constituents being used in hydraulic fracturing, while extending similar protections for proprietary business information.[147]

Furthermore, the FRAC Act would require operators to disclose proprietary chemical information to treating medical professionals in cases of medical emergencies.[148] Although most state oil and gas rules do not require disclosure of proprietary chemical information to medical professionals, such disclosure broadly parallels federal requirements under the Occupational Safety and Health Act (OSHAct).[149] Nonetheless, the OSHAct requirements were not designed for environmental

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[144] H.R. 1084, at §2(a). S. 587 is similar but does not include geothermal production activities.

[145] The lack of information regarding chemicals used in hydraulic fracturing has made investigations of contamination difficult, as well owners and state regulators typically have not known which chemicals to test for to determine whether a fracturing fluid has migrated into a water source. In April 2011, the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission launched a hydraulic fracturing chemical registry website where companies voluntarily post information on chemicals used in hydraulic fracturing on a well-by-well basis. The website covers wells fractured since January 1, 2011. The website also includes state oil and gas regulations and other information. See http://fracfocus.org/.

[146] *Id.* at §2(b).

[147] The Pennsylvania Department of Environmental Protection (DEP) requires drilling companies to disclose the names of all chemicals to be stored and used at a drilling site as part of the permit application process. The information is kept on file with DEP and is available to landowners, local governments, and emergency responders. Ohio and West Virginia also have adopted hydraulic fracturing reporting and disclosure requirements. New York's RDSGEIS also contains disclosure requirements. In April 2011, the Ground Water Protection Council and the Interstate Oil and Gas Conservation Commission launched a website that provides a public registry of chemicals used in hydraulic fracturing, with companies voluntarily identifying chemicals used in fracturing individual wells. The site also includes state regulations and other information. See http://fracfocus.org/.

[148] H.R. 1084, §2(b).

[149] The Occupational Safety and Health Administration has promulgated a set of regulations under the Occupational Safety and Health Act (OSHAct; 29 USC §651 et seq.), referred to as the Hazard Communication Standard (29 C.F.R. §1910.1200). Additionally, OSHAct regulations require operators to maintain Material Safety Data Sheets (MSDS) for hazardous chemicals at the job site. The federal Emergency Planning and Community Right to Know Act (EPCRA) requires that facility owners submit an MSDS for each hazardous chemical present that exceeds an EPA-determined threshold level, or a list of such chemicals, to the local emergency planning committee (LEPC), the state emergency (continued...)

investigation purposes, and the provided information may not be suited for such purposes. Consequently, calls for disclosure of hydraulic fracturing chemicals have increased as homeowners and others express concern about the potential presence of unknown chemicals in tainted well water near oil and gas operations.

Other bills in the 112th Congress also address hydraulic fracturing. H.R. 2133, the Fulfilling U.S. Energy Leadership (FUEL) Act, recognizes the role of the states in regulating oil and natural gas production and declares a sense of Congress that "the Safe Drinking Water Act (42 U.S.C. 300f et seq.) was not intended to regulate natural gas and oil well construction and stimulation." The bill further notes that industry should be encouraged to voluntarily disclose chemicals used in the hydraulic fracturing process and that the information should be made available to the public. Reported bill H.R. 1425 (Section 514) would amend the Small Business Act[150] to direct federal agencies to give funding preference for research on reducing the environmental (including water quality) impact of the use of hydraulic fracturing during natural gas exploration activities.

Conclusion

Natural gas locked in tight, impermeable shale has been uneconomical to produce until recently. Advances in directional well drilling and reservoir stimulation have dramatically increased the production from these unconventional shales. However, the development of the Marcellus and other shales comes with some challenges and controversy.

The Marcellus Shale formation represents one of the largest unconventional or conventional natural gas resources in the United States. The natural gas produced from the eastern portion of the formation is pipeline quality, requiring no upgrading. Although the gas transmission pipeline network needed to supply the residential, retail, and commercial customers in the northeast United States is largely in place, gas producers would need to construct an extensive network of gathering pipelines and supporting infrastructure to move the gas from the new well fields to the transmission pipelines, as is the case for developing any new well field. The lack of such infrastructure may limit or delay gas production in some areas of the region.

Shale gas development has stirred concerns regarding water consumption and potential groundwater and water well contamination from hydraulic fracturing, and surface water contamination from disposal of the fracturing fluids. The process of developing a shale gas well is an issue of concern for increasing the risk of water contamination, and concerns about contamination of fresh surface water or groundwater must be addressed during three phases of gas well development: (1) drilling through an overlying aquifer, completing and casing the well, (2) stimulating the well via hydraulic fracturing, and (3) flowback of fluids to the surface during development of the well and production of the gas). If contamination of fresh water supplies from shale gas development is suspected, each of these three phases must be carefully examined to ensure that each is conducted without causing undue environmental impacts.

(...continued)

response commission, and the local fire department. For non-proprietary information, EPCRA generally requires a LEPC to provide an MSDS to a member of the public on request.

[150] 15 U.S.C. §638.

1. *Drilling and well construction through an aquifer*: A properly cased well allows gas production up through the well to the surface, while preventing drilling fluids, hydraulic fracturing fluids, or natural gas from leaking into the permeable aquifer and contaminating groundwater. Construction of an oil and gas well of any type generally requires penetration of near-surface fresh water aquifers, and the application of rigorous drilling and well completion techniques is vital during this phase of production. These activities are regulated by the states.
2. *Hydraulic fracturing*: Hydraulic fracturing does induce new fractures into the Marcellus Shale, and may lengthen existing fractures. The chances of creating or extending fractures linking the Marcellus Shale to an overlying aquifer appear remote, however, because the vertical distance separating the Marcellus Shale from most aquifers is typically much greater than the length of the fractures generally induced during hydraulic fracturing. Hydraulically fractured gas production wells are subject to state regulations, but legislation has been introduced to authorize EPA to regulate broadly hydraulic fracturing under SDWA, which likely would affect state requirements.
3. *Flowback of fracking fluids and produced waters*: The flowback water pumped back to the surface after fracturing poses a significant environmental management challenge in the Marcellus Shale region. The flowback and produced water's high content of salts, minerals, and other contaminants must be disposed of or adequately treated before discharged to surface waters. State laws and the federal Clean Water Act regulate the discharge of this flowback water and other drilling wastewater to surface waters, while the Safe Drinking Water Act regulates deep well injection of such wastewater.

Cumulatively, the concerns about the potential water quality and other environmental impacts of unconventional gas exploration and development, including in the Marcellus Shale, have prompted close examination at a number of levels.

- Congress has directed EPA to "review the risks that hydraulic fracturing poses to drinking water supplies, using the best available science, as well as independent sources of information."[151] EPA expects to report on the interim research results in 2012, and issue a follow-up report in 2014.
- In March 2011, President Obama announced a broad "Blueprint for a Secure Energy Future." In it, the President asked the DOE Secretary to identify steps that can be taken to improve the safety and environmental performance of shale gas production, and to develop consensus recommendations on practices to ensure the protection of public health and the environment, including water quality.[152] In

[151] P.L. 111-88, H.Rept. 111-316. The report accompanying the Department of the Interior, Environment, and Related Agencies Appropriations Act, FY2010 (H.R. 2996, H.Rept. 111-180), includes the following provision:

> Hydraulic Fracturing Study.—The conferees urge the Agency to carry out a study on the relationship between hydraulic fracturing and drinking water, using a credible approach that relies on the best available science, as well as independent sources of information. The conferees expect the study to be conducted through a transparent, peer-reviewed process that will ensure the validity and accuracy of the data. The Agency shall consult with other Federal agencies as well as appropriate State and interstate regulatory agencies in carrying out the study, which should be prepared in accordance with the Agency's quality assurance principles.

[152] See http://www.whitehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf.

November, the Secretary of Energy Advisory Board (SEAB) Shale Gas Subcommittee issued a final report, with recommendations for state and federal governments and industry. Water quality recommendations, aimed mainly at the states, include (1) adopting best practices for well construction (casing, cementing, and pressure management), (2) adopting requirements for background water quality measurements, (3) manifesting all water transfers across various locations, and (4) measuring and publicly reporting the composition of water stocks and flow throughout the fracturing and cleanup process. The SEAB also suggested that states review and modernize rules and enforcement practices.[153]

- In April 2011, the New York State Attorney General stated he would sue the federal government if an environmental review of natural gas drilling in the Delaware River Basin was not conducted under the National Environmental Policy Act (NEPA).[154] Also in April, a coalition of environmental advocates, including the Chesapeake Bay Foundation, petitioned the White House to conduct an environmental impact analysis on the effects that natural gas drilling and production may have within the Marcellus Shale region.[155]
- In October 2011, EPA initiated a rulemaking to set technology-based pre-treatment standards to regulate discharges of shale gas wastewaters to publicly owned treatment works.
- Across the region, state oil and gas regulators and environmental regulators have been evaluating and revising regulations to strengthen water quality protections during shale gas exploration and production.

Shale gas development using high-volume horizontal drilling and hydraulic fracturing has been done for only about a decade and is increasing rapidly, catching states and communities at various states of preparedness. The industry's growth has created new regulatory, enforcement, and oversight challenges for state officials, and often new concerns for landowners and communities in the Marcellus Shale region. The growing number of gas wells and related infrastructure and land-use changes has drawn attention to the adequacy of regulatory oversight governing this industry.

Natural gas production has long been regulated by the states. State oil and gas and environmental protection agencies widely support keeping responsibility for regulating oil and gas production generally, and hydraulic fracturing specifically, with the states. The Interstate Oil and Gas Compact Commission (IOGCC), representing the oil and gas producing states, adopted a resolution urging Congress not to remove the fracturing exemption from provisions of the SDWA, noting that the process is a temporary injection-and-recovery technique and does not fit the UIC program which EPA generally developed to address the permanent disposal of wastes.

If Congress were to require EPA to regulate all hydraulic fracturing of oil and gas wells, a key issue would involve EPA's capacity to assume such a role. EPA likely would require substantial

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[153] U.S. Department of Energy, The Secretary of Energy Advisory Board, Shale Gas Production Subcommittee, Second Ninety Day Report—November 18, 2011, http://www.shalegas.energy.gov/.

[154] Eric T. Schneiderman, New York State Attorney General, *Schneiderman to Feds: Commit to Study Safety Impacts of "Fracking" in Delaware River Basin or I'll Sue*, Press Release, Office of the Attorney, April 18, 2011.

NEPA is codified at 92 U.S.C. §§4321-4347.

[155] See http://www.cbf.org/document.Doc?id=640.

new resources and technical staff to oversee major elements of oil and gas production and to directly implement any new rules in non-primacy states. For example, unless Pennsylvania and New York assumed primacy for the UIC program, EPA would have responsibility for permitting and overseeing all hydraulically fractured wells in those states, while the wells remained subject to state permitting requirements and regulations. This scenario has raised concerns from states and industry regarding the potential benefits, costs, and redundancies that may result from such an approach.

Nonetheless, given the concern about potential water contamination expressed by citizens and communities, and uneven regulation across the states, some continue to urge greater federal involvement. The American Water Works Association (AWWA, representing drinking water professionals and public water suppliers), various towns, and environmental groups support the FRAC Act.

EPA currently is developing new measures to protect water quality during shale gas development.[156] The agency is developing regulations under the Clean Water Act to regulate flowback and produced water discharges to municipal wastewater treatment plants.[157] Also, EPA is writing guidance under the SDWA UIC program to assist states with permitting hydraulic fracturing operations that use diesel fuel. The pending diesel guidance may provide insight into how the agency might regulate hydraulic fracturing broadly, if directed to do so by Congress.

Currently, there is little agreement as to the potential risks that shale gas development poses to water resources across the region. Given the level of debate, it appears that the understanding of the risks could benefit from a better scientific foundation. Congress has urged EPA to study the relationship between hydraulic fracturing and drinking water. The results of the EPA study, along with work being done by the states, interstate commissions, industry, and others, should enable a better assessment of the risks that unconventional shale development may pose to water resources, and help inform any potential congressional action. In the meantime, states across the Marcellus Shale region continue to review and revise regulatory programs in response to robust growth in the shale gas industry.

[156] On federal lands, the Bureau of Land Management (BLM), within the Department of the Interior, administers oil and gas leasing and coordinates planning and permitting with other federal agencies, as appropriate. The BLM also is reviewing and revising its oil and gas regulations to reflect changes in production technologies and processes.

[157] Additionally, on July 28, 2011, EPA proposed new regulations to reduce air pollution from upstream oil and natural gas production sources currently unregulated at the federal level. The proposed rules include (1) a new source performance standard for volatile organic compounds; (2) a new source performance standard for sulfur dioxide; (3) an air toxics standard for oil and natural gas production; and (4) an air toxics standard for natural gas transmission and storage. An extension to the original consent decree requires EPA to take final action on these regulations by April 3, 2012. See U.S. Environmental Protection Agency, "Oil and Natural Gas Sector: New Source Performance Standards and National Emission Standards for Hazardous Air Pollutants Reviews," 76 *Federal Register* 52738, August 23, 2011, http://www.gpo.gov/fdsys/pkg/FR-2011-08-23/pdf/2011-19899.pdf.

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