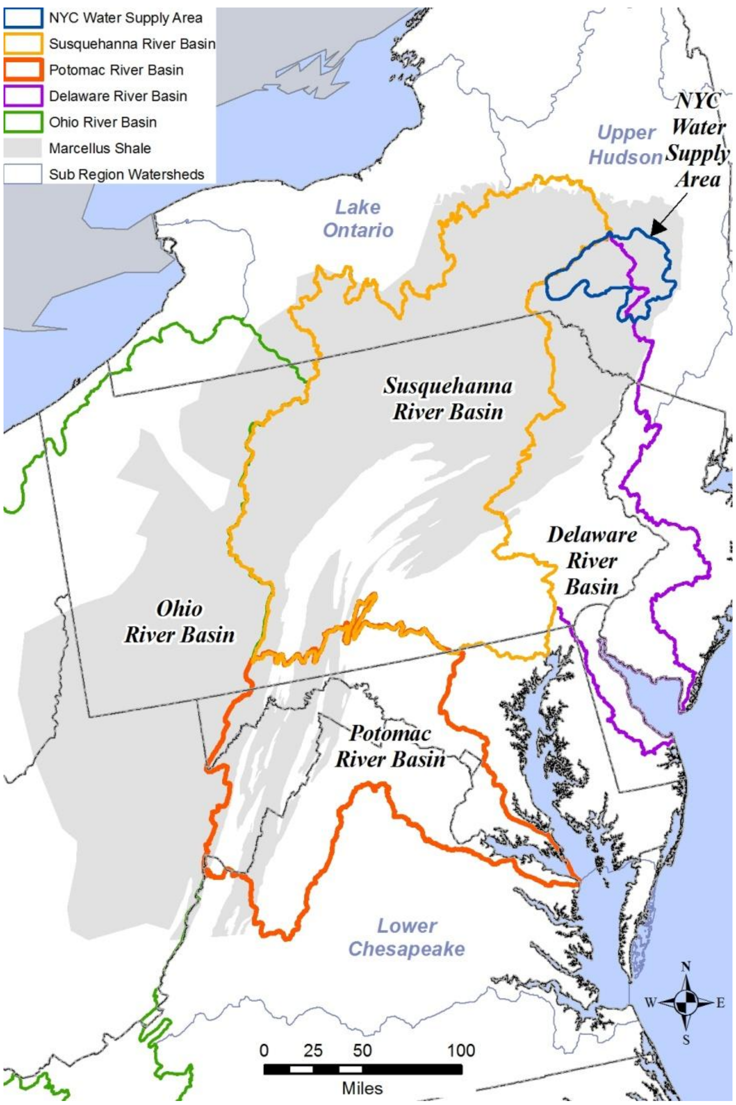
Water Resources and Use for Hydraulic Fracturing in the Marcellus Shale Region

J. Daniel Arthur, P.E., SPEC; Mike Uretsky, PhD.; Preston Wilson – ALL Consulting, LLC

1 Introduction

Natural gas plays a key role in meeting U.S. energy demands. Natural gas, coal and oil supply about 85 percent of the nation's energy, with natural gas supplying about 22 percent of the total.[1] Proportionally, this is expected to remain fairly constant for the next twenty years. Much of the technically recoverable natural gas in North America is present in unconventional reservoirs such as tight sands, shale, and coal beds. Natural gas production from tight shale formations, known as "shale gas," is one of the most rapidly expanding trends in onshore domestic oil and gas exploration and production. According to the Energy Information Administration, by 2011 the majority of U.S. gas reserves growth will come from shale gas plays and by 2035 more than 35 percent of domestic production will be supplied from shale gas.[2] In some cases, this has included bringing drilling and production to regions of the country where little or no such activity has occurred in the past.

Exhibit 1. Map Showing the Extent of the Marcellus Shale



Shale formations can provide access to very large quantities of natural gas. A number of factors have combined to focus considerable attention on this source of gas – continued growth in energy demand; the need for energy sources having a smaller "carbon footprint"; proximity of major shale plays to major consumer markets; and most significantly, advances in existing technologies that allow shale gas to be economically recoverable.[3]

The Marcellus Shale is a geologic formation underlying an area from West Virginia in the south to New York in the north, an area of approximately 95,000 square miles (Exhibit 1).[4] The Marcellus Shale is a low permeability (tight) formation, categorized as an unconventional gas reservoir, with approximately 489 trillion cubic feet (tcf) of technically recoverable natural gas resources.[5]

Two technologies – horizontal well drilling and hydraulic fracture stimulation – have been crucial in facilitating the expansion of shale gas development. Horizontal drilling involves drilling vertically, until reaching a point above the target formation where the drill bit is then turned through a 90-degree arc to allow advancing the borehole horizontally through the target ("pay") formation. This approach allows for a greater contact length between the wellbore and the producing formation than is traditionally achieved through vertical drilling. Because of this increased exposure to the pay zone, a volume of gas similar to what can be produced by numerous vertical wells can potentially be produced by significantly fewer horizontal wells.[6]

Hydraulic fracturing is required for tight formations such as shale, because they do not have the necessary natural permeability to allow a sufficient quantity of natural gas to flow freely to the wellbore. For horizontal wells, this involves pumping large volumes of a water-sand-chemical mix down a well under high pressure to fracture the formation, thus providing pathways for the natural gas to flow to the wellbore. A typical hydraulic facture operation may require 3 to 5 million gallons of water per well.[7]

Development of the Marcellus Shale natural gas play in New York, Pennsylvania, and West Virginia has come under intense scrutiny by regulators, NGOs, and the public in regard to the potential environmental impacts from the water withdrawals necessary to support drilling and hydraulic fracturing. Considerations in evaluating water needs include the location of the need, the seasonal timing of the need, the location of available water, and the regulations governing water withdrawals.

In general, the area overlying the Marcellus Shale has abundant precipitation, making water readily available. Although many streams, rivers, and lakes may be theoretically viable as water sources based on available volume alone, a much smaller subset of water bodies may have practical potential for use by the natural gas industry, based on the distance to a given well. The costs of transporting water from the source to the well site can quickly and dramatically exceed the simple cost of obtaining the water. Natural gas companies (operators) will work to minimize these costs by securing permitted withdrawals as close as possible to their planned development areas. Furthermore, operators with large lease holdings may need to evaluate and secure not one, but several, water sourcing take points in order to minimize environmental impacts while still meeting the water needs of their development plans.

Thus, ground and surface water sources most proximal to the well sites are most desirable. Consequently, a primary issue for water withdrawal will be the regulations governing permitting procedures including the passby flow requirements and their impact on the seasonality of permitted withdrawals from the water bodies nearest the wells. In New York, Pennsylvania and West Virginia, withdrawal permitting is regulated by a matrix of state and interstate regulatory agencies, whose regulations reflect the needs of individual states or watersheds. Consequently, operators must focus on the specific issues and approaches to permitting that are unique to each location.

This paper addresses three overlapping topics, each with a bearing on water sourcing within the three primary states:

- A description of the major water resources associated with the Marcellus Shale areas of New York, Pennsylvania and West Virginia;
- A description of the regulatory structure in New York, Pennsylvania and West Virginia, as well as the two major river basin commissions in the area: the Susquehanna River Basin Commission and the Delaware River Basin Commission; and
- A description of the metrics used by each of these organizations to regulate water use.

2 Water Sourcing Issues for the Natural Gas Industry

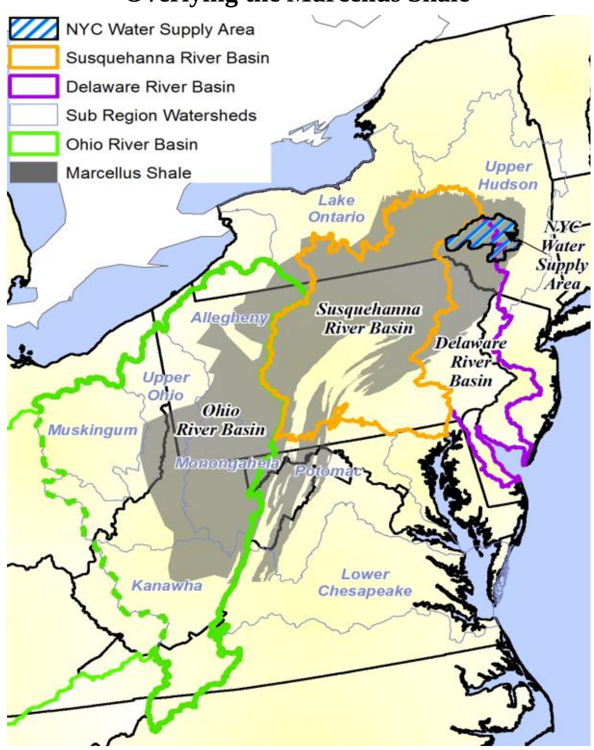
As noted above, a typical hydraulic facture operation may require 3 to 5 million gallons of water per well.[8] The actual volume of water needed may vary substantially between wells. While the water volumes needed to drill and stimulate shale gas wells are large, they generally represent a small percentage of the total water resource use in the shale gas basins. Estimates of peak drilling activity in New York, Pennsylvania, and West Virginia indicate that maximum water use in the Marcellus, at the peak of production for each state, assuming 5 million gallons of water per well, would be about 650 million barrels per year.[9,10,11] This represents less than 0.8 percent of the 85 billion barrels per year used in the area overlying the Marcellus Shale in New York, Pennsylvania, and West Virginia.[12]

The volume required for shale gas is small in terms of the overall water availability in the area. To put shale gas water use in perspective, the consumptive use of fresh water for electrical generation in the Susquehanna River Basin alone is nearly 150 million gallons per day, while the projected total demand for peak Marcellus Shale activity in the same area is only 8.4 million gallons per day.[13] Other water consumers that also affect water use in some parts of the Marcellus Shale include golf courses and agricultural producers; each golf course requires between 100,000 and 1,000,000 gallons of water per week.[14] One factor in shale gas water use is that operators need this water when drilling and hydraulic fracturing activities are occurring, requiring that the water be procured over a relatively short period of time, and these activities will occur year-round. Water withdrawals during periods of low stream flow could affect municipal water supplies and industries such as power generation, as well as recreation, and aquatic life. Thus, in order to have adequate water during periods of low streamflow or drought, operators may need to make withdrawals during periods of high stream flow and store the water for later use. Another consideration is that while the region may have abundant water supplies, any given well site may not be near a large stream or lake. To avoid adversely affecting a given water source, operators may need to consider withdrawals from multiple near-by sources or explore other options such as overland piping for more distant sources.

3 Water Basins Overlying the Marcellus Shale

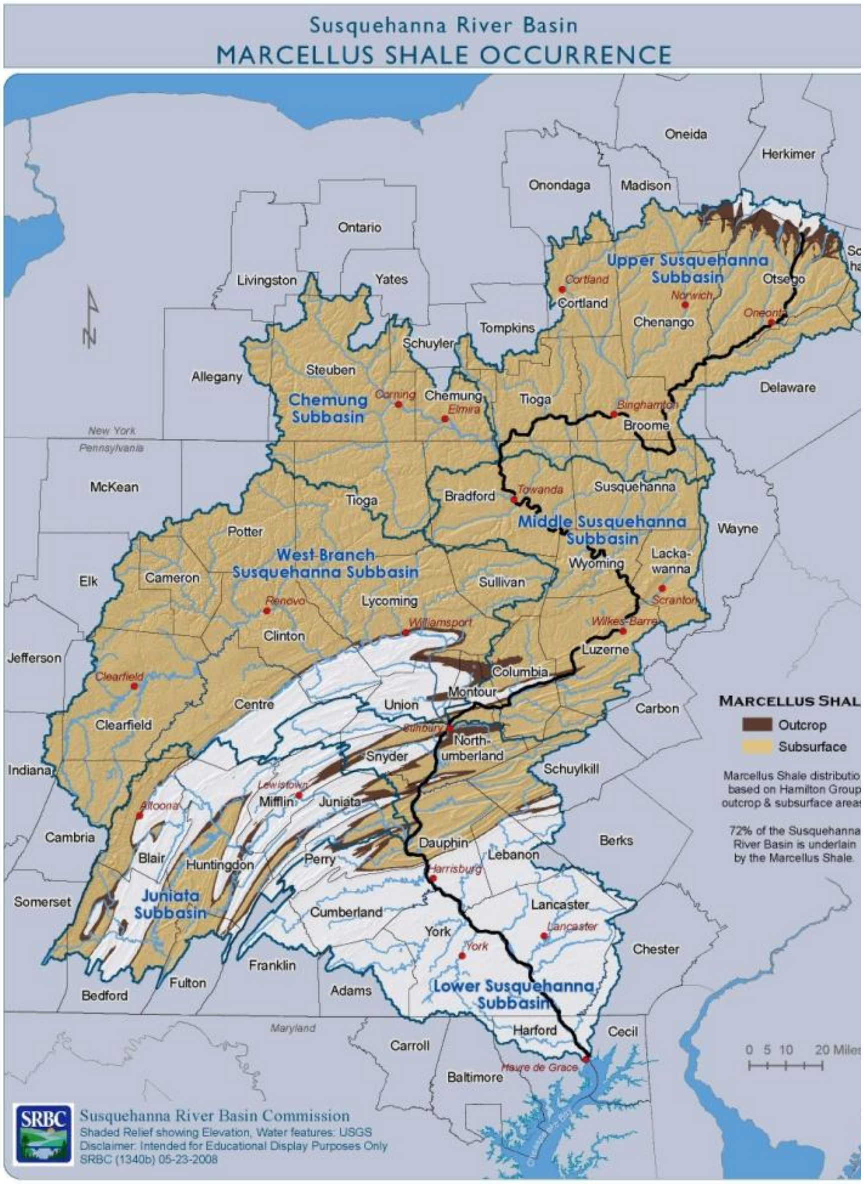
From an overall perspective, there are plentiful water resources overlying the Marcellus Shale deposits. These deposits are found beneath a vast area of the northeastern United States, primarily within the boundaries of the Susquehanna, Delaware, and Ohio River Basins (Exhibit 2). The Susquehanna, Delaware, and Ohio River Basins overlap the States of New York, Pennsylvania, and West Virginia. This paper focuses on these three river basins within these three states; together they comprise an area receiving the most attention from the point of view of both exploration and regulatory issues.

Exhibit 2. Map of All River Basins and Sub-Basins Overlying the Marcellus Shale



3.1 The Susquehanna River Basin

Exhibit 3. Map Showing the Marcellus Shale within SRB Boundaries



The Susquehanna River Basin (SRB) is located within New York, Pennsylvania, and Maryland. It includes the total area of rivers, streams, and tributaries draining into the Susquehanna River. The Susquehanna River flows a total of 444 miles from Otsego Lake in Cooperstown, New York, to Havre de Grace, Maryland, where it enters the Chesapeake Bay (Exhibit 3[15]). The basin itself drains 27,510 square miles, covering approximately half of the land area of Pennsylvania and portions of New York and Maryland.[16] It comprises 43 percent of the Chesapeake Bay's drainage area and contributes nearly half of the Bay's freshwater inflow.[17] Seventy-two percent of this basin is underlain by the Marcellus Shale (Exhibit 3) at depths ranging from approximately 4,000 to 8,500 feet.[18]

The vast area of the SRB includes many major population centers, such as Harrisburg, Lancaster, Scranton and York, Pennsylvania, and Binghamton and Elmira, New York. According to the 2000 census, there are approximately 4.2 million people living within the boundaries of the SRB. In addition to supplying water to people residing within this area, waters from the SRB are diverted for public use to the City of Baltimore, Maryland, which is located outside of the SRB boundary.

There are eight major rivers flowing into the Susquehanna River. These rivers include the Chemung River, Chenango River, Juniata River, Sangerfield River, Tioga River, Tioughnioga River, Unadilla River and West Branch Susquehanna River. These rivers and their tributaries equate to a total of 31,193 miles of rivers and streams within the SRB.[19]

The SRB is divided into six sub-basins: Chemung, Juniata, and the Lower, Middle, Upper and West Branch Susquehanna River sub-basins[20] as depicted in Exhibit 4.[21] These sub-basins are then divided further into 88 watersheds.[22] The major streams and rivers of the SRB are potential surface water withdrawal sources. Each sub-basin has several lakes which have also been identified as potential surface water sources for Marcellus Shale development. The total surface area covered by all the lakes, ponds, and reservoirs throughout the basin is 79,687 acres.[23] Some of the more notable lakes in the SRB are Blanchard Reservoir, Lake Clarke, Cowanesque Lake, Otsego Lake, Raystown Lake, and Whitney Point Lake.

Exhibit 4. Map of the Six Sub-basins of the Susquehanna River Basin

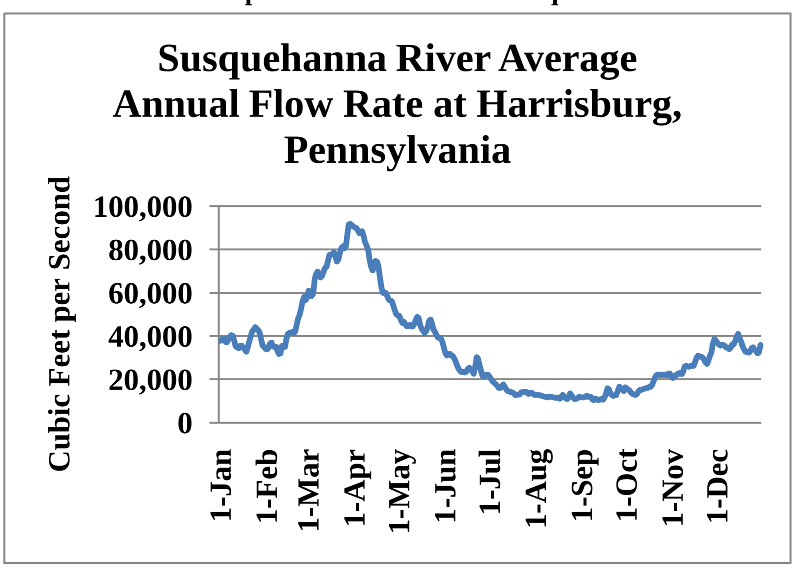
Exhibit 5[a] summarizes the major characteristics of the area comprising the SRB.

Exhibit 5. Susquehanna River Basin Geographic Statistics

Basin Population[24]		4.2 million
Basin Surface Area[25]		27,510 sq. mi.
-	New York	6,327 sq. mi.
-	Pennsylvania	20,908 sq. mi.
-	Maryland	275 sq. mi.
Water Sub-basins[26]		
-	Chemung	2,604 sq. mi.
-	Upper Susquehanna	4,944 sq. mi.
-	Middle Susquehanna	3,755 sq. mi.
-	West Branch Susquehanna	6,992 sq. mi.
-	Juniata	3,406 sq. mi.
-	Lower Susquehanna	5,809 sq. mi.
Total miles of rivers and streams[27]		31,193.0 mi.
-	Miles of perennial rivers/streams	26,064.0 mi.
-	Miles of intermittent streams	5,500.7 mi.
-	Miles of ditches and canals	45.3 mi.
-	Border miles of shared rivers/streams	0 mi.
Total inches of precipitation per year[28]		39.51 in./yr.
Numbers of lakes/reservoirs/ponds[29]		2,293
Acres of lakes/reservoirs/ponds[30]		79,687 acres
Square miles of estuaries/harbors/bays[31]		0 sq. mi.
Miles of ocean coast[32]		0 mi.
Acres of wetlands[33]		Unknown
Land Use[34]		
-	Forested	(63.1%) or 17,362 sq. mi.
-	Urban	(9.3%) or 2,560 sq. mi.
-	Pasture	(6.7%) or 1,845 sq. mi.
-	Cropland	(19.4%) or 5,338 sq. mi.
-	Water	(1.5%) or 405 sq. mi.

Evaluating water adequacy requires both a means for measuring water availability and recognition that this availability may sometimes be reduced by seasonally low water or drought. Overall water availability is frequently ascertained by measuring the stream flow at selected points. Harrisburg, Pennsylvania, is often used as a base for analyzing stream flow for the SRB because it is located downstream of the confluences with the major tributaries of the Susquehanna River. In Harrisburg, the Susquehanna River has an average flow of 34,580 cubic feet per second, based on the United States Geologic Survey's (USGS) gauging data. Exhibit 6[35]

Exhibit 6. Graph of Flow Rate in the Susquehanna River

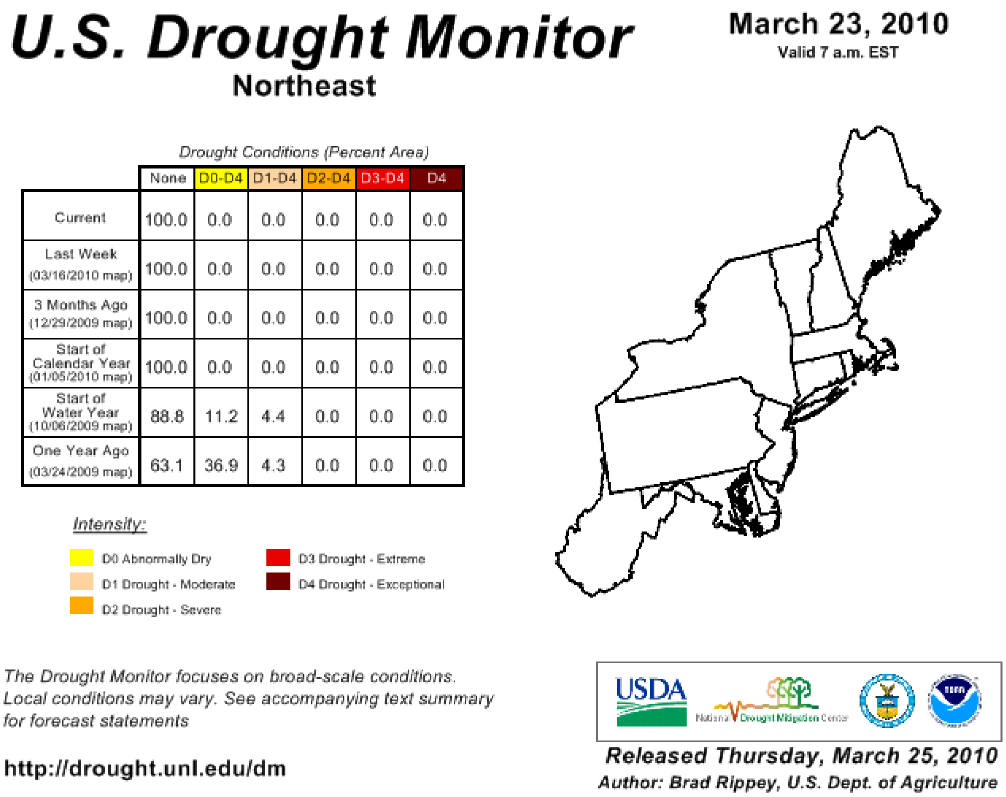


[a] This table is derived from a chart used in the 2008 Susquehanna River Basin Water Quality Assessment Report. (SRBC, The 2008 Susquehanna River Basin Water Quality Assessment Report, Publication No. 25531 – Mar. 2008).

shows the average daily flow rate based on 118 years of records collected at Harrisburg. Average flow is greatest in the early Spring and least in the late Summer and early Fall.

Average annual flow rates alone do not provide the complete picture. At any point in time, a given area may be under drought conditions. These conditions are reflected in the U.S. Department of Agriculture (USDA) Drought Monitor (Exhibit 7[36]) showing conditions of the northeastern U.S. as of March 23, 2010. Thus, while these areas of the country were not within drought conditions as of the date of this paper, they were within abnormally dry to moderate drought conditions in 2009.

Exhibit 7. USDA Drought Conditions as of March 23, 2010



	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	100.0	0.0	0.0	0.0	0.0	0.0
Last Week (03/16/2010 map)	100.0	0.0	0.0	0.0	0.0	0.0
3 Months Ago (12/29/2009 map)	100.0	0.0	0.0	0.0	0.0	0.0
Start of Calendar Year (01/05/2010 map)	100.0	0.0	0.0	0.0	0.0	0.0
Start of Water Year (10/06/2009 map)	88.8	11.2	4.4	0.0	0.0	0.0
One Year Ago (03/24/2009 map)	63.1	36.9	4.3	0.0	0.0	0.0

3.2 Delaware River Basin

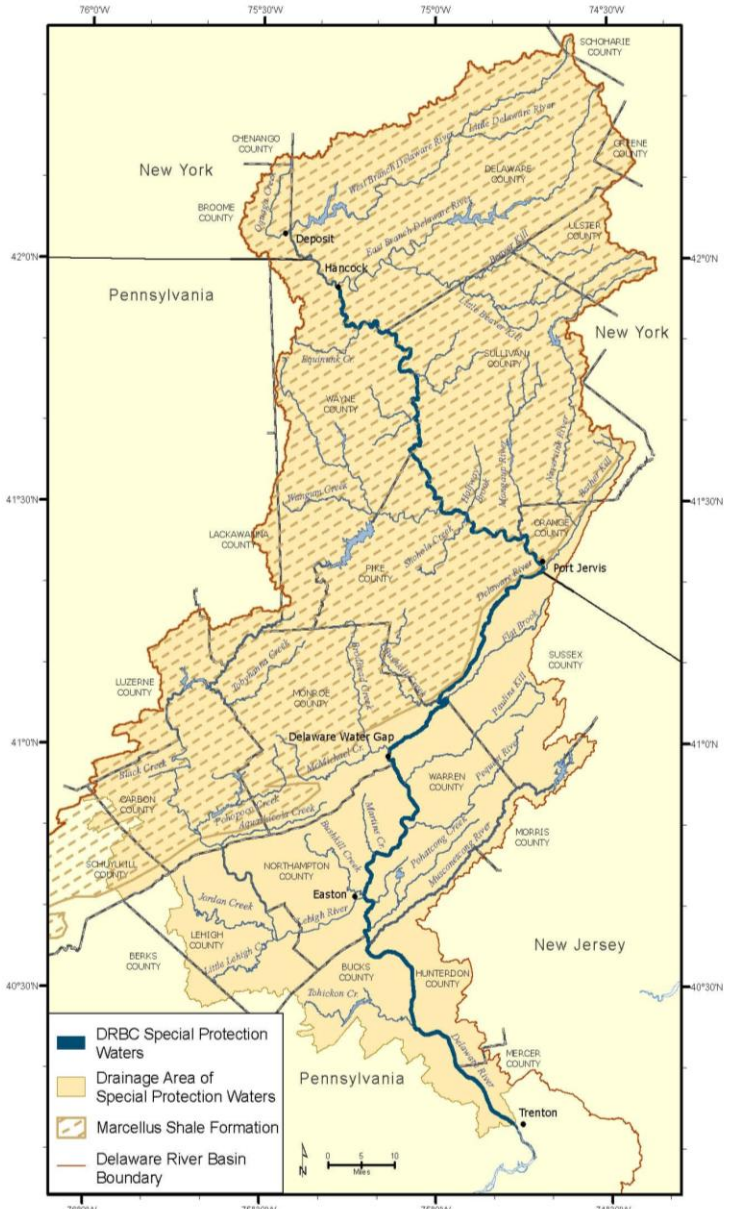
The Delaware River Basin (DRB) is located within New York, Pennsylvania, New Jersey, and Delaware, with a very small area of the basin lying in Maryland. The Delaware River's east and west branches form in the Catskill Mountains in New York, flowing west and then converging at Hancock, New York (Exhibit 8[37]).[38] From there it flows 330 miles south, forming the boundary between Pennsylvania and New York and also the boundary between Pennsylvania and New Jersey before entering the Delaware Bay.[39] The basin comprises the total area of rivers, streams, and tributaries draining into the Delaware River, an area encompassing 13,539 square miles.[40] The Delaware River is the longest undammed waterway east of the Mississippi River.[41]

Exhibit 8. Map of the Delaware River Basin

The Marcellus Shale underlies approximately 36 percent of the DRB, mainly in the northern sections of the basin, with depths of approximately 4,500 to 8,000 feet. Exhibit 9[42] shows the boundaries of the Marcellus Shale in comparison to the DRB boundaries; the areas designated as Special Protection Waters by the Delaware River Basin Commission (see section 3.5.3) are also shown .

The DRB includes many major population centers, e.g., Allentown, Easton, Philadelphia, Pottstown, and Reading, Pennsylvania; Camden, Salem, and Trenton, New Jersey; Hancock and Port Jervis, New York; and Dover and Wilmington, Delaware. The DRB is divided into four subregions known as the Upper, Central, Lower and Bay Regions.[43] These regions are shown on the map in Exhibit 10[44] and are divided further into ten regional watersheds.

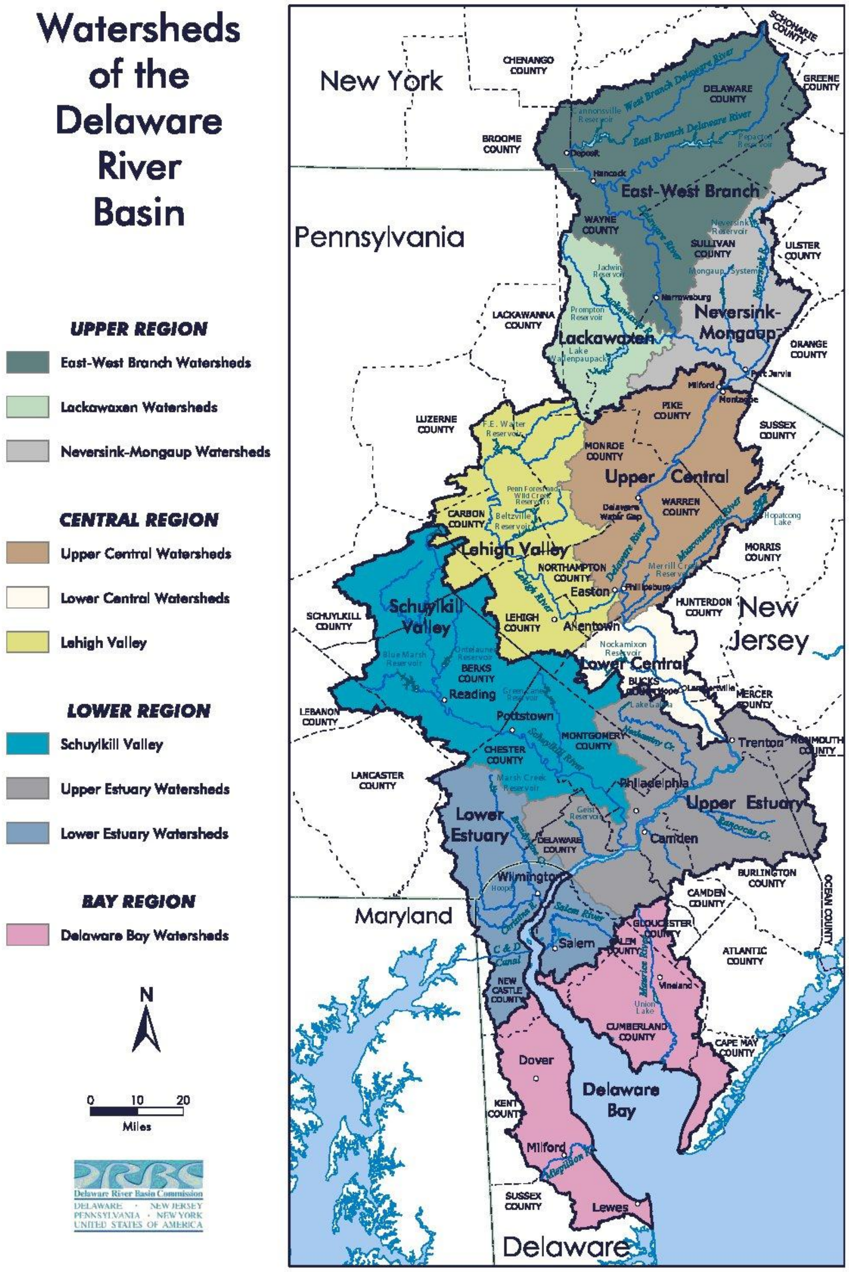
Exhibit 9. Map of Marcellus Shale Overlying the Northern Portion of the Delaware River Basin



The basin recieves 40.33 inches of rainfall per year based on an average taken from the National Weather Service and Delaware River Master statistical data.[45] The DRB has half (50.3 percent) of its total land drainage area in Pennsylvania, approximately one-fourth (23.3 percent) in New Jersey, one-fifth (18.8 percent) in New York and the remainder (7.9 percent) within the state of Delaware.[46] The Delaware River has two major tributaries, the Lehigh and the Schuylkill Rivers; together the rivers within the DRB supply the majority of the freshwater entering the Delaware Bay (Exhibit 10).[47]

Although the DRB includes less land area than the SRB, it has a larger population living within its boundaries. The total population living within the boundaries of the DRB is approximately 7.6 million people but the basin itself provides drinking water to over 15 million people.[48] The additional 8 million are people living in the New York City metro area (NYC).

Exhibit 10. Map of the Watersheds in the Delaware River Basin



NYC withdraws its drinking water supply from two watersheds: the Catskill/Delaware Watershed (northernmost portion of the DRB) and the Croton Watershed (a portion of the Hudson River Basin).[49] These two watersheds have been identified as containing all of the waters used in NYC and its surrounding areas, including northern New Jersey, and comprise a distinct watershed for regulatory purposes. The NYC watershed is 1,972 square miles in area, representing 3.3 percent of the State of New York's total surface area.[50]

The Catskill/Delaware Watershed is located at the headwaters of the Delaware River in the Catskill Mountains and is the larger of the two watersheds in the NYC drinking water supply area.[51] This watershed includes Ashokan, Cannonsville, Neversink, Pepacton, Rondout and Schoharie Reserviors which together supplied 98.3 percent of the water used in 2008 by the NYC service area.[52] The remaining 1.6 percent comes from the Croton Watershed which served as the original water supply of NYC and is located within the Hudson River Basin.[53]

The water flows from these reservoirs into aqueducts, and then into NYC water tunnels for distribution.[54] NYC's water supply is unfiltered. The NYC metro area is allowed to divert a maximum of 800 million gallons of water per day from the DRB.[55] Portions of the NYC watershed directly overlays areas of the Marcellus shale. Exhibit 11[b] summarizes the major characteristics of the area comprising the DRB.

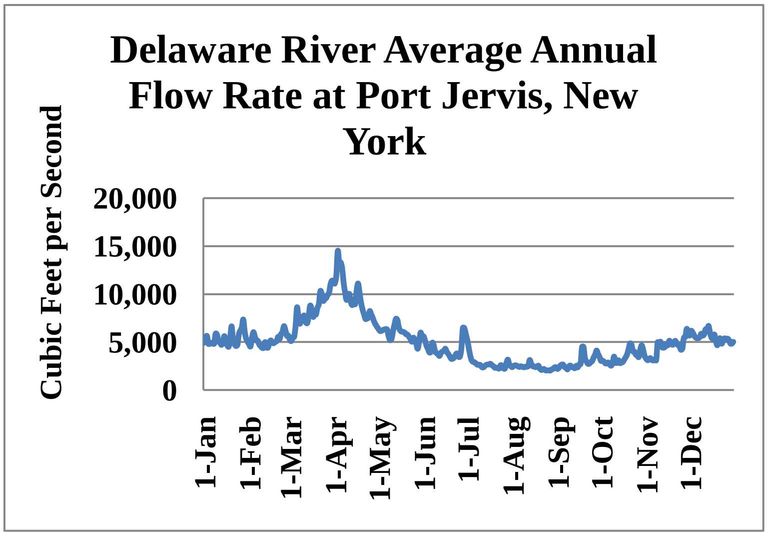
Exhibit 11. Delaware River Basin Geographic Statistics

Basin Population[56]		7.6 million
Basin Surface Area		12,862 sq. mi.
-	New York	2,393 sq. mi.
-	Pennsylvania	6,471 sq. mi.
-	New Jersey	3,014 sq. mi.
-	Delaware	961 sq. mi.
-	Maryland	8 sq. mi.
Water Sub-basins[57]		
-	Upper Region	3,443 sq. mi.
-	Central Region	3,342 sq. mi.
-	Lower Region	4,654 sq. mi.
-	Bay Region	1,423 sq. mi.
Total miles of rivers and streams		18,368 mi.
-	Miles of perennial rivers/streams	14,413 mi.
-	Miles of intermittent streams	3,955 mi.
-	Miles of ditches and canals	871 mi.
-	Border miles of shared rivers/streams	0 mi.
Total inches of precipitation per year[58]		40.33 in./yr.
Numbers of lakes/reservoirs		921
Acres of lakes/reservoirs/ponds		61,656 acres
Square miles of estuaries/harbors/bays		1,504 sq. mi.
Miles of ocean coast[31]		17 mi.
Acres of wetlands[31]		293,819 acres
Land Use[59]		
-	Forested	(54.8%) or 7,036 sq. mi.
-	Urban	(14.5%) or 1,862 sq. mi.
-	Pasture	(0.4%) or 51 sq. mi.
-	Cropland	(26.0%) or 3338 sq. mi.
-	Water	(4.4%) or 565 sq. mi.

[b] This table is derived from a chart used in the 2008 Susquehanna River Basin Water Quality Assessment Report. (SRBC, The 2008 Susquehanna River Basin Water Quality Assessment Report, Publication No. 25531 – Mar. 2008).

Overall water availability is ascertained by measuring the stream flow at selected points. Port Jervis, New York, is often used as a base for analyzing minimum stream flow for the DRB because it is located downstream of the withdrawal points for New York City but before the major tributaries enter into the main channel. This point was also selected as the best location to analyze flow parameters that show a baseline for the prevention of saltwater encroachment (see Section 4.5.1). The Delaware River has an average flow rate of 4,985 cubic feet per second based upon the USGS stream station data. Exhibit 12[60] shows the average daily flow rate based on 45 years of records collected at Port Jervis. Average flow is greatest in the early Spring and least in the late Summer and early Fall.

Exhibit 12. Graph showing flow rate of Delaware River



3.3 Ohio River Basin

The Ohio River Basin (ORB) is located within southwestern New York, western Pennsylvania, and much of West Virginia. It comprises all of the major rivers and streams that flow directly or indirectly into the Ohio River. The Ohio River forms from the convergence of the Monongahela and Allegheny Rivers in Pittsburgh, Pennsylvania, and it then flows 1,310 miles to its confluence with the Mississippi River in Cairo, Illinois.[61]

The ORB has a larger drainage area than the DRB and SRB combined. The entire ORB drains an area of approximately 203,000 square miles through portions of fourteen states in the central United States; this includes the Tennessee River Basin.[62] The Marcellus Shale underlies approximately 10 percent of the ORB in the states of Maryland, New York, Ohio, Pennsylvania, and West Virginia.

The ORB waters underlain by Marcellus Shale are comprised of the sub-regional river basins of the Allegheny, the Monongahela, the Upper Ohio and the New-Kanawha Rivers.[c] Each sub-region's major rivers, streams and tributaries are the main surface water resources available for industrial use water withdrawals. The three main sub-regional river basins focused on in this study are the Allegheny, Monongahela, and the New-Kanawha River

Exhibit 13. Ohio River Basin and Sub-basins Overlying the Marcellus Shale

[c] The Marcellus Shale underlies small portions of the Muskingum River Basin and thusly will not be discussed.

Exhibit 14. Portions of the Ohio River Basin with Limited Marcellus Potential

River Basins		Total Square Miles	Marcellus Shale Square Miles within the Basin	Percentage of Shale within the River Basin	Marcellus Shale in river basin versus total play extent
Ohio River Basin		~203,000	20,300	~10%	22%
-	Allegheny River Basin	11,660	6,900	59%	7%
-	Monongahela River Basin	7,375	7,375	100%	8%
-	New-Kanawha River Basin	12,290	2,275	18%	3%
-	Upper Ohio River Basin	13,355	4,405	33%	4%

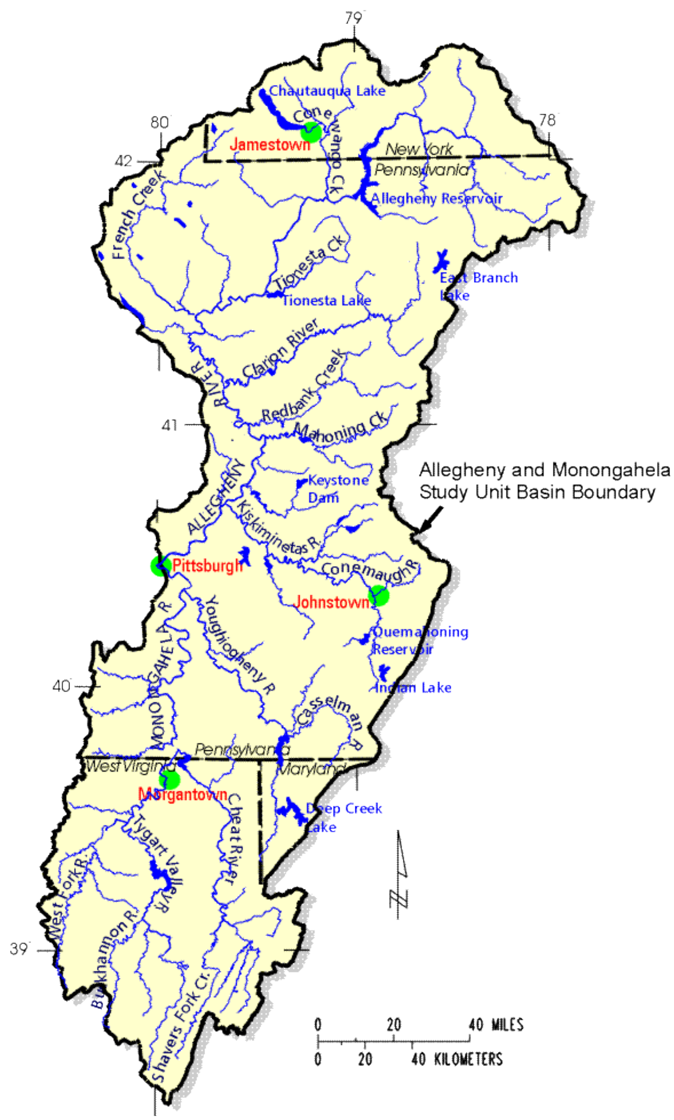
Basins; the Upper Ohio is considered to be a direct portion of the ORB and is not discussed separately. The areas of the ORB outside of the area defined in Exhibit 14 are not currently seen as potential Marcellus Shale development areas.

3.3.1 Allegheny and Monongahela River Watersheds

The Allegheny and Monongahela River sub-basins lie almost entirely within the Appalachian Plateaus[63] and comprise a combined total land area of 19,145 square miles in Maryland, New York, Pennsylvania, and West Virginia.[64] The Allegheny River sub-basin drains 11,805 square miles. Its headwaters are in Coudersport, Pennsylvania, from which it flows north into New York before turning back south.[65] It travels a total of 295 miles before its confluence with the Monongahela River in Pittsburgh, Pennsylvania.[66] Approximately 6,900 square miles or 59 percent of the Allegheny River Basin is underlain by the Marcellus Shale.

The Monongahela River (often referred to locally as the "Mon") sub-basin is 7,340 square miles and lies within portions of Maryland, Pennsylvania, and West Virginia.[67] The Monongahela River begins in Fairmont, West Virginia, and flows 116 miles north before combining with the Allegheny River at Pittsburgh, Pennsylvania (Exhibit 15[68]).[69] Approximately 100 percent of the Monongahela River Basin is underlain by the Marcellus Shale.

Exhibit 15. Allegheny and Monongahela River Sub-basins



3.3.2 New-Kanawha River Watershed

The New-Kanawha River Basin lies in southern West Virginia and western Virginia. The Kanawha River and its major tributary, the New River, drain 12,223 square miles in West Virginia, Virginia, and small sections of northwestern North Carolina.[70] The Kanawha River flows 97 miles after forming from the confluence of the Gauley and New Rivers.[71] Approximately 2,275 square miles or 19 percent of the New-Kanawha River Basin is underlain by the Marcellus Shale primarily in West Virginia, with minor amounts in Virginia and Ohio and none in North Carolina.

4 Regulatory Agencies and Withdrawal Requirements

State agencies reviewed for this study include the New York State Department of Environmental Conservation (NYSDEC), the Pennsylvania Department of Environmental Protection (PADEP), and the West Virginia Department of Environmental Protection (WVDEP).

Beyond the state requirements, there are separate, and in many areas more stringent, regulations enforced by the Susquehanna River Basin Commission (SRBC) and the Delaware River Basin Commission (DRBC). Additionally, the New York City Department of Environmental Protection (NYCDEP) has regulatory authority over the city's drinking water supply, which is within the jurisdictional authority of both the NYSDEC and the DRBC. The requirements described below are the general requirements for the individual state or river basin commission. In each jurisdiction, additional requirements may apply to specially designated streams or stream segments based on ecological, recreational, or aesthetic values.

4.1 New York State Department of Environmental Conservation

The NYSDEC is the agency responsible for establishing regulatory standards for water quality, water withdrawals and effluent releases in the areas of New York State that are not within the SRB and DRB.[d] New York currently regulates public drinking water supply withdrawals through the public water supply permit program.[72] The NYSDEC also specifically regulates all public drinking water groundwater withdrawals for any purpose. Except for Long Island (a sole source aquifer area outside of the Marcellus study area), surface water and groundwater withdrawals require reporting when in excess of 100,000 gallons per day (gpd).

Recently passed legislation, which will go into effect December 31, 2012,[73] requires any entity that withdraws, or has the capacity to withdraw, groundwater or surface water in quantities greater than 100,000 gallons per day to file an annual report with the NYSDEC.[74] Surface water withdrawals are subject to the recently enacted narrative water quality standard for flow promulgated at *6NYCRR 703.2*. This water quality standard prohibits any alteration in flow that would impair a designated best use for a fresh surface water body.[e] As shown in Exhibit 16,[75] New York State also issues guidelines for determining passby flows during surface water withdrawals.

[d] Note: The Great Lakes Commission has authority over the areas in New York which fall into their jurisdictional boundaries. Due to the very small overlap of the jurisdictional boundaries of the Great Lakes Commission and the areas which overlay the Marcellus Shale, this agency was not included in this study.

[e] The NYSDEC primarily addresses the withdrawal of water and its potential impacts in the following regulations:

- 6 NYCRR 601: Water Supply
- 6 NYCRR 675: Great Lakes Withdrawal Registration Regulations.

Exhibit 16. NYSDEC Methods for Determining Passby Flow

Data Availability	Method for Determination of Passby Flow Minimums	
For locations where at least 10 recent years of gauging data are available	A passby flow shall be calculated for each month of the year using a combination of 30% of Average Daily Flows (ADF), and 30% of Average Monthly Flows, (AMF). For any given month the proposed passby flow must be the greater of either the 30% ADF or 30% AMF flow.	
For locations where less than 10 recent years of gauging data are available	0.5 cfs/mi^2 of drainage area during summer	1.0 cfs/mi^2 of drainage area during winter
In addition, for locations known to support naturally reproducing trout populations, where less than 10 recent years of gauging data are available	4.0 cfs/mi^2 of drainage area during the spring (March 1 through May 31)	

4.2 Pennsylvania Department of Environmental Protection

The Pennsylvania Department of Environmental Protection (PADEP) is the main agency responsible for regulatory standards regarding water quality and effluent releases for the Commonwealth of Pennsylvania. All surface waters must meet protected water uses for aquatic life, water supply (potable, industrial, livestock, and wildlife), and recreation (boating, fishing, water contact sports, and aesthetics).[76]

The Commonwealth of Pennsylvania does not have regulatory passby flow requirements. Recommendations in this area are similar to standards used by the SRBC, but they are guidelines that do not have the same impact as rules. A few state statutes have been interpreted to impose regulations and permit requirements on withdrawals from specified sources and particular uses.[77] The PA Water Resources Planning Act (Act 220) requires registration and reporting of water withdrawals in excess of 10,000 gpd (averaged over 30 days).[78] Pennsylvania also requires that the operator submit a Water Management Plan outlining the cradle-to-grave disposition of water use including the sourcing of water for drilling and fracturing activities.[79] The PADEP considers such requests, in conjunction with other water withdrawals on the same body of water, for passby flow. The Pennsylvania Fish and Boat Commission (PFBC) also requires a permit to withdraw water from impoundments inhabited by fish.[80]

4.3 West Virginia Department of Environmental Protection

The West Virginia Department of Environmental Protection (WVDEP) is the main agency in charge of regulatory standards of water withdrawal, water quality and effluent releases. West Virginia has recently passed the Water Resources Protection Act. This Act establishes a regulatory program which requires registration for surface water or groundwater withdrawals of 750,000 gallons over a period of one calendar month.[81] This Act also requires an Addendum to be submitted with any Marcellus Shale Drill Permit. This Addendum requires operators to identify the amount of water to be used, the specific location of water sources, the time period expected for water withdrawal, the types of water to be used (surface water, groundwater, recycled, etc.), the volume of each type of water to be used, the location and size of centralized impoundments, water disposal location, and the methods to be used for disposal.[82]

WVDEP establishes and regulates water quality standards for all streams in West Virginia including effluents released to surface waters. WVDEP rules state that "water quality standards shall apply at all times when flows are equal to or greater than the minimum mean seven (7) consecutive day drought flow with a ten (10) year return frequency (7Q10)."[83] Similarly, if flows fall below the 7Q10 standard then water quality standards will not apply.[84]

West Virginia has an internet-based reporting system for tracking water, from withdrawals to the disposal or reuse of produced water, after the hydraulic fracturing process has occurred.[85] WVDEP also has specific requirements relating to minimum flow levels for certain rivers within the state. For example, WVDEP rules stipulate that the main stem of the Kanawha River shall have a minimum flow rate of 1,896 cfs at mile point 72.[86] These requirements are designed to ensure that enough water will remain in the system to protect the aquatic ecosystems of West Virginia.

4.4 The Susquehanna River Basin Commission

The Susquehanna River Basin Commission (SRBC) is the primary agency overseeing water-related activities in the SRB. It came into existence in December 1970 through the adoption of the Susquehanna River Basin Compact by the 91st U.S. Congress and the legislatures of New York, Pennsylvania, and Maryland.[87] A compact is an agreement between states, under the consent of Congress, which forms an independent regulatory body tasked with the management of a resource shared by the member states. This compact created the SRBC as a separate regulatory agency with the power to write and enforce its own laws and regulations within the jurisdictional boundaries of the SRB.[88] The Commission has a representative from each of the three states within the SRB – Maryland, New York, and Pennsylvania – and one representative from the federal government.[89] The representative from the federal government is the Division Engineer from the North Atlantic Division of the United States Army Corp of Engineers (NAD-USACE).[90] In addition to creating legally binding regulations, the commissioners have the power to appoint investigators to enforce the Compact's regulations. An investigator is vested with all the powers as a peace officer in the state in which they are assigned.

4.4.1 Regulations in the Susquehanna River Basin

The SRBC's authority to create and enforce regulations makes it notably different from most other organizations that have been established to manage water resources. This authority is granted to the SRBC by the Susquehanna River Basin Compact which entitles the SRBC's four acting officers to create laws and appoint investigators for enforcing those laws. Regulations in other parts of the country are typically managed solely by the state agencies which oversee the watersheds, not by multi-state jurisdictional commissions.

The individual state environmental agencies and some commissions regulate water quality and water withdrawals for the watersheds overlying Marcellus Shale. The SRBC's regulations are similar to those of the state environmental agencies, but they have been specifically modified to serve its jurisdictional area. The following points focus on selective regulations that relate to Marcellus Shale development enforced by the SRBC.

4.4.2 Withdrawal Regulations

For industries other than natural gas extraction in the Marcellus and Utica shales, withdrawals for non-consumptive use must be approved by the SRBC if the volume withdrawn will exceed 100,000 gpd for 30 days. Withdrawals for consumptive use must be approved if the volume withdrawn will exceed 20,000 gpd for 30 days.

Withdrawals for natural gas extraction in the Marcellus and Utica shales, however, are regulated separately. All groundwater and surface water withdrawals for use in natural gas extraction from the Marcellus and Utica shales, regardless of volume, must be approved by the SRBC.[91]

In reviewing shale gas water withdrawal applications, the SRBC considers both the aquifer and associated surface water impacts of all proposed well development projects.[92] The SRBC reviews groundwater withdrawals to determine if a withdrawal is significant. This review requires a 72-hour, constant-rate aquifer test to determine the availability of water from the groundwater source. The lowest rate of flowing water over a 10-year period is treated as the baseline measure for the 72-hour aquifer tests and determines the maximum rate of withdrawal allowed.[93]

For surface water, SRBC evaluates proposed withdrawals based on passby flow requirements. The SRBC requirement for passby flow in streams and rivers is as follows:

> "A passby flow is a prescribed quantity of flow that must be allowed to pass a prescribed point downstream from a water supply intake at any time during which a withdrawal is occurring. The SRBC enforces passby flow requirements when withdrawing more than 10 percent of the natural or continuously augmented 7-day, 10-year low flow (Q7-10) of the stream or river. Q7-10 is the lowest average, consecutive 7-day flow that would occur with a frequency or recurrence interval of one in ten years. A 10-year low flow event has a 10 percent chance of occurring in any one year."[94]

SRBC is currently evaluating alternative methods to determine the best parameters to be used for passby flow requirements.

For all water withdrawal approvals, SRBC also requires shale gas operators to submit an estimate of consumptive use and requires operators to certify that produced water (including flowback) was disposed of in compliance with applicable laws.

4.5 Delaware River Basin Commission

The Delaware River Basin Commission (DRBC) is the primary agency overseeing water-related activities in the DRB. The DRBC was established on November 2, 1961, with the signing of the Delaware River Basin Compact by President John F. Kennedy and the governors of Delaware, New Jersey, New York, and Pennsylvania.[95] Creation of DRBC was the first time legislation gave a regional body the authority to provide a unified approach to managing a river system without regard to political boundaries.[96] Activities of the DRBC are overseen by appointed representatives from the four governors and the Division Engineer from the NAD-USACE representing the federal government.[97] The same federal government appointee fills the federal commissioner positions for both the SRBC and DRBC.

The DRBC's primary responsibilities include water quality protection, water supply allocation, regulatory review/permitting, water conservation initiatives, watershed planning, drought management, flood damage reduction, and recreation.[98]

4.5.1 Regulations in the Delaware River Basin

Through the establishment of the Delaware River Basin Compact, the DRBC became the primary regulatory authority for water in the DRB. The Compact allows the DRBC to establish and enforce regulations on the waters inside their jurisdictional boundaries. In general, the DRBC, the SRBC, and state and federal agencies have similar requirements for water withdrawals, transfers, water use and quality. DRBC decisions may involve the issue of supplying water to New York City and the surrounding metropolitan areas. As a result, the DRBC must carefully balance water use allocations by industrial/commercial activities, including large withdrawals such as the volumes required for hydraulic fracturing of the Marcellus Shale.

DRBC manages withdrawal allocations to avoid saltwater encroachment into the Delaware River from the Delaware Bay. If too much freshwater is taken out of the basin, there is a risk that saltwater from

Delaware Bay may extend further upstream and impinge on fresh water-dominated ecosystems. The biota (aquatic organisms, streamside vegetation, algae, etc.) present in these freshwater areas of the river system rely on a high balance of freshwater. If saltwater encroaches, it may impact both the streamside vegetation and the freshwater aquatic community.

4.5.2 Regulated Volumes

The DRBC requires approval for surface water withdrawals exceeding 100,000 gpd, based on a 30-day average.[99,100] They also require approval for a withdrawal from groundwater wells in the DRB exceeding 100,000 gpd, based on a 30-day average, outside of the Southeastern Pennsylvania Groundwater Protection Area.[101] The Southeastern Pennsylvania Groundwater Protection Area is categorized differently from other areas in the DRB. "Lowered water tables in the [Southeastern Pennsylvania Groundwater] Protected Area have reduced flows in some streams and dried up others. This reduction in baseflows affects downstream water uses, negatively impacts aquatic life, and can reduce the capacity of waterways in the region to assimilate pollutants."[102] For this reason the area has special withdrawal regulations. Within the Southeastern Pennsylvania Groundwater Protection Area, the DRBC requires approval for withdrawals exceeding 10,000 gpd, based on a 30-day average.[103]

The DRBC also requires that any diversion or transfer of water into or outside of the DRB which exceeds 100,000 gpd be brought to the commission for approval.[104]

5 Summary

Considerable attention is being focused on Marcellus Shale as a major source of natural gas. This has several important implications:

- The Marcellus Shale is located within or nearby highly populated areas of the northeast where the general populace has little or no previous experience with oil or gas development.

- The use of horizontal drilling and hydraulic fracturing focuses regulatory and NGO attention on issues surrounding the withdrawal of large volumes of water from sources sufficiently close to the gas exploration sites.

- The regulatory framework for water withdrawals is complicated with a combination of states managing water within their state along with commissions (who have authority over entire river basins) that are looking at regional, interstate issues. This requires that water sourcing and use be viewed in the larger context of full lifecycle water management. Gas well operators new to the Marcellus region may find water management planning and permitting challenging because multiple approvals may be required, first by a river basin commission (if one is applicable to the location in question) then by a state agency. Once an operator becomes familiar with the process it should become relatively straightforward; however, the time required for the additional approvals must be factored into an operator's development schedule.

The primary considerations in evaluating water needs are the location of the need, the seasonal timing of the need, the location of available water, and the regulations governing water withdrawals. In general, the Marcellus region has ample precipitation, making water readily available, and withdrawals for shale gas development will be a small part of the overall regional water demand. However, it is important to understand that while shale gas withdrawals may be small on a regional level, withdrawals at any given point must be managed to ensure the ecological health of the water body and to provide for other industrial or recreational uses.

Operators will work to minimize water transportation costs by securing permitted withdrawals as close as possible to their planned development areas. Therefore, it is the groundwater and surface water sources most proximal to the well sites that will be most desirable. Operators may need to evaluate and secure several water sourcing take points in order to minimize environmental impacts while still meeting the water needs of their development plans.

A major consideration in planning water withdrawals will be the regulations governing permitting procedures, especially the passby flow requirements and their impact on the seasonality of permittable withdrawals for the water bodies most proximal to development. This, combined with the fact that water withdrawal permitting is regulated by a matrix of state and interstate regulatory agencies, whose regulations reflect the needs of individual states or watersheds, requires that shale gas operators be keenly aware of the specific permitting requirements for each location.

---

[1] U.S. Energy Information Administration (EIA), *Annual Energy Outlook 2010Early Release Overview* (December 14, 2009), http://www.eia.doe.gov/oiaf/aeo/index.html (accessed April 2010).

[2] EIA, *Annual Energy Outlook 2010Early Release Overview*.

[3] ALL Consulting and the Groundwater Protection Council (GWPC), *Modern Shale Gas Development in the United States: A Primer*, prepared for the U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory, Washington, DC (April 2009).

[4] ALL Consulting and GWPC, *Modern Shale Gas Development in the United States*.

[5] Terry Engelder, "Marcellus 2008: Report Card on the Breakout Year for Gas Production in the Appalachian Basin," *Fort Worth Basin Oil & Gas Magazine* (August 2009): 18-22, available at http://www.geosc.psu.edu/~engelder/references/link155.pdf.

[6] GWPC, *Modern Shale Gas Development in the United States: A Primer*, 2009

[7] ALL Consulting and GWPC, *Modern Shale Gas Development in the United States*.

[8] ALL Consulting and GWPC, *Modern Shale Gas Development in the United States*.

[9] New York State Department of Environmental Conservation (NYSDEC), Division of Mineral Resources, "Well Permit Issuance for horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," in *Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program* (September 2009), available at http://www.dec.ny.gov/energy/58440.html.

[10] T. Considine, R. Watson, R. Entler, and J. Sparks, *An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play*, The Pennsylvania State University College of Earth & Mineral Sciences, Department of Energy and Mineral Engineering (July 24, 2009), 29.

[11] ALL Consulting, "Projecting the Economic Impact of Marcellus Shale Gas Development in West Virginia: A Preliminary Analysis Using Publicly Available Data," (March 31, 2010), 27, available at http://www.netl.doe.gov/energy-analyses/refshelf/detail.asp?pubID=305.

[12] J. Satterfield, M. Mantell, D. Kathol, F. Hiebert, K. Patterson, and R. Lee, "Managing Water Resource's Challenges in Select Natural Gas Shale Plays," presented at the GWPC Annual Meeting, September 2008.

[13] A. Gaudlip, L. Paugh (SPE, Range Resources Appalachia LL), and T. Hayes (Gas Technology Institute), "Marcellus Shale Water Management Challenges in Pennsylvania," presented at the SPE Shale Gas Production Conference, November 2008.

[14] Alliance for Water Efficiency, "Golf Course Water Efficiency Introduction" (2009), http://www.allianceforwaterefficiency.org/golf_course.aspx (accessed April 2010).

[15] Susquehanna River Basin Commission (SRBC), "SRBC Maps & Data Atlas: Basinwide Maps & GIS Data" http://www.srbc.net/atlas/bwmg.asp (accessed April 2010).

[16] SRBC, "Marcellus Shale Occurrence" (2009), http://www.srbc.net/atlas/downloads/BasinwideAtlas/PDF/1340b_MarcellusShale.pdf (accessed April 2010).

[17] R. Timothy Weston, "Development of the Marcellus Shale – Water Resource Challenges" (2008), available at http://www.wvsoro.org/resources/marcellus/Weston.pdf.

[18] SRBC, "Natural Gas Well Development in the Susquehanna River Basin" (2009), http://www.srbc.net/programs/docs/ProjectReviewMarcellus%20Shale12-2008.pdf (accessed April 2010).

[19] U.S. Environmental Protection Agency (U.S. EPA), *Total Waters Estimates for United States Streams and Lakes: Total Waters Database and Reporting Program*, Monitoring Branch Assessment and Watershed Protection Division, Office of Wetlands, Oceans, and Watersheds, Office of Water, Washington, D.C., 1993.

[20] SRBC, "Information Sheet: Susquehanna River Basin" (revised November 2006), http://www.srbc.net/pubinfo/docs/Susq%20River%20Basin%20General%20%2811_06%29.PDF (accessed April 2010).

[21] SRBC, "Subbasin Information," http://www.srbc.net/subbasin/subbasin.htm (accessed April 2010).

[22] SRBC, "SRBC Maps & Data Atlas."

[23] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[24] U.S. Bureau of the Census, *Census of Population and Housing: 2000* (Washington, D.C.: U.S. Government Printing Office, 2000).

[25] Susquehanna River Basin Study Coordination Committee, "Susquehanna River Basin Study, Preview and Appendixes A-K" (1970).

[26] SRB Study Coordination Committee, "Susquehanna River Basin Study."

[27] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[28] Kevin H. McGonigal, SRBC, "Summary for Annual Precipitation for Selected Areas in the Susquehanna River Basin, Calendar Year 2007," Table 4 in *Nutrients and Suspended Sediment Transported in the Susquehanna River Basin, 2007, and Trends, January 1985 through December 2007* (December 31, 2008), 8.

[29] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[30] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[31] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[32] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[33] U.S. EPA, *Total Waters Estimates for United States Streams and Lakes*.

[34] A. N. Ott, C.S. Takita, R.E. Edwards, and S.W. Bollinger, *Loads and Yields of Nutrients and Suspended Sediment Transported in the Susquehanna River Basin, 1985–1989* (Harrisburg, PA: Susquehanna River Basin Commission Publication No. 136, 1991).

[35] U.S. Geological Survey (USGS), "USGS 01570500 Susquehanna River at Harrisburg, PA" (last updated March 17, 2010), http://waterdata.usgs.gov/pa/nwis/uv/?site_no=01570500&PARAmeter_cd=00065,00060,00010 (accessed April 2010).

[36] Anthony Artusa, NOAA/NWS/NCEP/CPC, "U.S. Drought Monitor" (March 23, 2010), http://drought.unl.edu/dm/monitor.html (accessed April 2010).

[37] DRBC, "Delaware River Basin Map," http://www.state.nj.us/drbc/maps/relief2.htm (accessed April 2010).

[38] Delaware River Basin Commission (DRBC), "The Delaware River Basin," http://www.state.nj.us/drbc/thedrb.htm (accessed April 2010).

[39] DRBC, "The Delaware River Basin."

[40] Weston, "Development of the Marcellus Shale."

[41] DRBC, "The Delaware River Basin."

[42] DRBC, map of the Marcellus Shale, http://www.state.nj.us/drbc/maps/SPW-MarcellusShale.pdf (accessed April 2010).

[43] DRBC, *Delaware River State of the Basin Report 2008*, http://www.state.nj.us/drbc/SOTB/introduction.pdf (accessed April 2010).

[44] DRBC, *Delaware River State of the Basin Report 2008.*

[45] DRBC, "Precipitation at Selected Stations in the Delaware River Basin (Inches)" (2009), http://www.state.nj.us/drbc/precip.htm (accessed April 2010).

[46] DRBC, "The Delaware River Basin."

[47] DRBC, *Delaware River State of the Basin Report 2008.*

[48] U. S. Bureau of the Census, *Census of Population and Housing: 2000.*

[49] New York City Department of Environmental Protection (NYCDEP), "History of New York City's Water Supply System" (2010), http://www.nyc.gov/html/dep/html/drinking_water/history.shtml (accessed April 2010).

[50] NYCDEP, *New York City 2008 Drinking Water Supply and Quality Report* (2008), available at http://www.nyc.gov/html/dep/pdf/wsstate08.pdf.

[51] NYCDEP, "History of New York City's Water Supply System."

[52] NYCDEP, *New York City 2008 Drinking Water Supply and Quality Report.*

[53] NYCDEP, *New York City 2008 Drinking Water Supply and Quality Report.*

[54] Jad Mouawad and Clifford Krauss, "Gas Company Won't Drill in New York Watershed," *New York Times* (October 27, 2009), http://www.nytimes.com/2009/10/28/business/energy-environment/28drill.html (accessed April 2010).

[55] Mouawad and Krass, "Gas Company Won't Drill in New York Watershed."

[56] U. S. Bureau of the Census, *Census of Population and Housing: 2000.*

[57] DRBC, *Delaware River State of the Basin Report 2008*; and DRBC, "Indicator Watersheds," GIS data acquired directly from the DRBC by ALL Consulting (December 2009).

[58] DRBC, "Precipitation at Selected Stations in the Delaware River Basin (Inches)."

[59] DRBC, *Delaware River State of the Basin Report 2008.*

[60] USGS, "USGS 01434000 Delaware River at Port Jervis NY," (last updated March 17, 2010), http://waterdata.usgs.gov/nwis/uv?01434000 (accessed April 2010).

[61] U.S. Army Corps of Engineers (USACE), Pittsburgh District, "Ohio River Information" (updated January 28, 2010), http://www.lrp.usace.army.mil/nav/ohioback.htm (accessed April 2010).

[62] J. C. Kammerer, "Largest Rivers in the United States," USGS (revised May 1990), http://pubs.usgs.gov/of/1987/ofr87-242/ (accessed April 2010).

[63] Robert M. Anderson, Kevin M. Beer, Theodore F. Buckwalter, Mary E. Clark, Steven D. McAuley, James I. Sams, III, and Donald R. Williams, "Water Quality in the Allegheny and Monongahela River Basins: Pennsylvania, West Virginia, New York, and Maryland, 1996-98," *U.S. Geological Survey Circular 1202* (2000), 3, available at http://pubs.usgs.gov/circ/circ1202/.

[64] Anderson, et al., "Water Quality in the Allegheny and Monongahela River Basins," 1.

[65] USGS, "ALMN NAWQA Study Unit Environmental Setting," http://pa.water.usgs.gov/almn/almn_sudesc.html (accessed April 2010).

[66] USGS, "ALMN NAWQA Study Unit Environmental Setting."

[67] USGS, "ALMN NAWQA Study Unit Environmental Setting."

[68] USGS, "ALMN NAWQA Study Unit Environmental Setting."

[69] "Monongahela Watershed Atlas," *WatershedAtlas.org*, http://www.watershedatlas.org/monongahela/fs_stats0.html (accessed April 2010).

[70] Terence Messinger and C. A. Hughes, "Environmental Setting and Its Effects on Water Quality, Kanawha-New River Basin—West Virginia, Virginia, North Carolina," National Water-Quality Assessment Program, U.S. Geological Survey Water-Resources Investigations Report 00–4020 (2000).

[71] Dennis Matlock and Randy Sturgeon, "Kanawha River Site EE/CA Study – 'Eleven Principle,'" Memo to EPA Contaminated Sediment Technical Advisory Group (April 14, 2004), available at http://www.epa.gov/reg3hwmd/super/sites/WVSFN035516/Kanawha_CSTAG_eleven_principle_memo_april_2004.pdf.

[72] New York, Environmental Conservation Law, Article 15, Title 15, *Laws of New York*, available at http://public.leginfo.state.ny.us/menugetf.cgi?COMMONQUERY=LAWS.

[73] New York, Environmental Conservation Law, Article 15, Title 33.

[74] New York Governor's Program Bill No. 51, "Water Withdrawal Regulation," Legislative Bill Drafting Commission 12079-03-9, available at http://www.state.ny.us/governor/bills/pdf/gpb_51.pdf.

[75] NYSDEC, *Draft Supplemental Generic Environmental Impact Statement.*

[76] Jennifer L. R. Hoffman, SRBC, *The 2008 Susquehanna River Basin Water Quality Assessment Report* (March 31, 2008), available at http://www.srbc.net/programs/docs/305breport2008.pdf.

[77] Weston, "Development of the Marcellus Shale."

[78] Pennsylvania Department of Environmental Protection (PA DEP), *Instructions: Chapter 110 Water Withdrawal and Use Registration* (August 2009), http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-76104/3920-FM-WM0048%20Instructions.pdf (accessed April 2010).

[79] PA DEP, *Water Management Plan Example Format Instructions for Marcellus Shale Gas Well Development*, form 5500-PM-OG0087 (April 2009), http://www.dep.state.pa.us/dep/deputate/minres/oilgas/new_forms/marcellus/marcellus.htm (accessed March 2010).

[80] Pennsylvania Code, Title 58, Chapter 51, Subchapter I, "Permits to draw Off Impounded Waters" (58 Pa. Code § 51.81) (2008).

[81] West Virginia Code Chapter 22. Environmental Resources. Article 26. Water Resources Protection Act. §22-26-2(i) http://www.legis.state.wv.us/WVCODE/ChapterEntire.cfm?chap=22&art=26 (Accessed: May 12, 2010)

[82] West Virginia Code Chapter 22. Environmental Resources. Article 26. Water Resources Protection Act. §22-26-8(c)(2) http://www.legis.state.wv.us/WVCODE/ChapterEntire.cfm?chap=22&art=26 (Accessed: May 12, 2010)

[83] West Virginia Department of Environmental Protection (WV DEP), *Water Resources: Title 47 – Series 2 – Requirements Governing Water Quality Standards*, 7.2.b.

[84] WV DEP, *Water Resources: Title 47 – Series 2 – Requirements Governing Water Quality Standards*, 7.2.c.1.

[85] WV DEP, Frac Water Reporting Form, http://www.dep.wv.gov/WWE/wateruse/Pages/FracWaterReportingForm.aspx (Accessed: May 12, 2010).

[86] WV DEP, *Water Resources: Title 47 – Series 2 – Requirements Governing Water Quality Standards* (effective August 9, 2009), 7.2.d.20.1, available at http://www.epa.gov/waterscience/standards/wqslibrary/wv/wv_require.pdf.

[87] SRBC, "Overview," http://www.srbc.net/about/geninfo.htm (accessed April 2010).

[88] SRBC, *Susquehanna River Basin Compact* (May 1972), Article 3, available at http://www.srbc.net/about/srbc_compact.pdf.

[89] SRBC, *Susquehanna River Basin Compact*, Article 2, Section 2.2.

[90] SRBC, "Commission By-Laws" (revised March 12, 2009), available at http://www.srbc.net/about/meetings/ByLawsandProceduresFINAL031209.PDF.

[91] SRBC, 18 CFR 806.5, December, 2008

[92] Weston, "Development of the Marcellus Shale."

[93] SRBC, "Aquifer Testing Guidance," Policy No. 2007-01 (December 5, 2007), http://www.srbc.net/programs/AQUIFER_TESTING_GUIDANCE.htm (accessed April 2010).

[94] SRBC, "Guidelines for Using and Determining Passby Flows and Conservation Releases for Surface-Water and Ground-Water Withdrawal Approvals," Policy No. 2003-01 (November 8, 2002), http://www.srbc.net/policies/docs/Policy%202003_01.pdf (accessed April 2010).

[95] DRBC, *Delaware River State of the Basin Report 2008.*

[96] DRBC, "DRBC Overview," http://www.state.nj.us/drbc/over.htm (accessed April 2010).

[97] DRBC, "DRBC Overview."

[98] DRBC, "DRBC Overview."

[99] DRBC, "DRBC Eliminates Review Thresholds for Gas Extraction Projects in Shale Formations in Delaware Basin's Special Protection Waters," News Release (May 19. 2009), http://www.state.nj.us/drbc/newsrel_naturalgas.htm (accessed April 2010).

[100] DRBC, *Administrative Manual – Part III: Water Quality Regulations (with Amendments through July 16, 2008)*, 18 CFR Part 410, Article 3.10.4 (September 12, 2008), available at http://www.state.nj.us/drbc/regs/WQRegs_071608.pdf.

[101] DRBC, "DRBC Eliminations Review Thresholds."

[102] DRBC, "Southeastern Pennsylvania Ground Water Protected Area," http://www.state.nj.us/drbc/pagwpa.htm (accessed April 2010).

[103] DRBC, "DRBC Eliminations Review Thresholds."

[104] DRBC, "DRBC Eliminations Review Thresholds."