

NEW YORK CITY DEPARTMENT OF ENVIRONMENTAL PROTECTION

DEP

New York City
Department of Environmental Protection

RAPID IMPACT ASSESSMENT REPORT
Impact Assessment of Natural Gas Production in the New York City Water Supply Watershed

September 2009

HAZEN AND SAWYER
Environmental Engineers & Scientists

a joint venture

Impact Assessment of Natural Gas Production
in the New York City Water Supply Watershed

Rapid Impact Assessment Report

September 2009

HAZEN AND SAWYER
Environmental Engineers & Scientists
A joint venture

Table of Contents

List of Figures

List of Tables

Executive Summary

In recognition of increased natural gas development activity in New York State and its potential to impact New York City's water supply, the New York City Department of Environmental Protection (DEP) has undertaken the project, *Impact Assessment of Natural Gas Production in the NYC Water Supply Watershed*. The overall goal of the project is to assure the continued reliability and high quality of New York City's water supply by providing a balanced, objective assessment of the potential impacts of natural gas development activities within or near the NYC watershed on NYC water quality, water quantity, and water supply infrastructure

This report is specifically focused on identifying *potential* impacts to the NYC water supply. It is acknowledged that there are over 400,000 producing natural gas wells in the U.S., most of which have been drilled without reported impact. It is further recognized that the NYC watershed is a working watershed that supports multiple uses, and that the risk from watershed activities will never be zero.

This report is limited to evaluating the potential impact of natural gas development activities on three core elements critical to the integrity of the NYC water supply: water quality, water quantity, and water supply infrastructure. This report does *not* purport to identify or characterize the range of additional potential impacts that may be associated with natural gas development (e.g. traffic, noise, air pollution, habitat disruption, induced growth, etc.), though it is acknowledged that such impacts, were they to occur, could alter the character of the watersheds that comprise NYC's unfiltered West of Hudson water supply.

Background

Much of the focus of current natural gas development interest is the Marcellus Shale Formation, which extends from eastern Kentucky, through West Virginia, Ohio and Pennsylvania into southern/central New York. In New York the formation lies beneath all or part of 29 counties, including the entire NYC West of Hudson watershed and portions of DEP aqueducts located outside of the watershed. The Marcellus Shale Formation is one of the largest new potential sources of gas in the U.S. and is estimated to contain 200-500 trillion cubic feet (tcf) of gas, enough to supply U.S. demand for up to 20 years.

The Marcellus and other similar shale formations have only recently become economically viable for production due to advances in horizontal drilling and hydraulic fracturing technology. Although current interest in natural gas development is focused on the Marcellus Shale, other gas-bearing formations underlying the watershed are anticipated to be targeted for development in the future (e.g., Utica Shale, Oriskany Sandstone, and the Oswego Formation).

Concurrent with this project, the New York State Department of Environmental Conservation (DEC) is developing a Supplemental Generic Environmental Impact Statement to review the potential impacts associated with recent advancements in drilling and stimulation technologies (i.e., horizontal drilling and hydraulic fracturing) which were not addressed in its 1992 Generic Environmental Impact Statement.

Report Description

The objective of this report is to provide a detailed review of natural gas development activities and characterize their potential impacts to the NYC water supply system. Major components of the assessment conducted for this report include:

- Description of natural gas development activities and impacts;
- Analysis of regional hydrogeology;
- Review of available data on drilling and fracturing fluids;
- Review of natural gas development incidents in other states; and
- A preliminary risk evaluation for major DEP infrastructure.

Major activities associated with natural gas development are summarized below, along with a brief identification of their potential impacts to the NYC water system.

Well Siting

Drilling companies typically pursue mineral leases on properties in a targeted area, which may increase demand for property and could increase costs for DEP's land acquisition program. In order to develop the property, approximately two to five acres of land are typically cleared and graded for the wellpad, and additional area is cleared and graded for access roads. Primary impacts may include habitat destruction and erosion. The area of land assigned to a well is called a spacing unit, and the number of wells that may be drilled in an area is based on NYSDEC spacing unit regulations. A minimum spacing unit of 40 acres is required for a single well, and a 640 acre spacing unit is required for multiple wells drilled from a common wellpad.

Well Drilling

Once the site is prepared and the wellpad is completed, operators begin drilling the well. One or more wells may be drilled from a single wellpad. In the NYC watershed area, the well would likely consist of a 3,000 to 7,000 feet deep vertical section that extends from the surface to the target formation, plus a horizontal section that extends out laterally for an additional 2,000 to 6,000 feet. The lateral section is not allowed to extend beyond a specified setback from the spacing unit boundary.

Construction of gas wells in the Marcellus Shale will require drilling through shallow aquifers and penetrating formations that may contain high levels of total dissolved solids, hydrocarbons, heavy metals, radionuclides or other potential contaminants. The wellbore creates a conduit for fluid flow between these previously isolated geologic formations. Multiple casings and grouting of annular spaces are provided to prevent such migration. Casing and/or grouting failures can result in contamination of shallow groundwater or surface water resources with drilling/fracing fluids and formation material.

Well Development and Stimulation

Once the well is drilled, grouted, and cased, a service crew proceeds with hydraulic fracturing operations to stimulate gas production within the target formation. The process entails injecting a mixture of water, sand, and chemicals into the well at high pressure to create fractures in the gas-bearing formation, thus increasing permeability and releasing the gas for collection. An average fracturing operation may require on the order of three to nine million gallons of water, 1% to 2% of which reportedly consists of various products and chemicals designed to control fluid properties and facilitate fracturing.

Drilling and fracturing typically occurs 24 hours a day until the well is finished, which may take on the order of four to eight weeks. During this time there is significant truck traffic to and from the site (on the order of 800 or more trips) to deliver and remove the necessary equipment, supplies, water, and wastewater. The cumulative impact from trips to tens or hundreds of wells in an area could cause substantial additional stress on transportation infrastructure, resulting in increased erosion, repair costs for damage to DEP-maintained roads or bridges, and potential access problems to DEP facilities.

Once drilling and stimulation are complete, the drill rig and equipment are removed, the well is capped, and pumping and treatment equipment are installed. Additionally, pipelines are constructed to deliver the gas from the well site to regional distribution pipelines. Pipeline construction may cause erosion; pipeline failures could potentially result in explosions or fires.

Aging wells may need to be re-stimulated after approximately 5 to 10 years to maintain production over the life of the well, which is on the order of 20 years. Impacts from these activities are generally similar to the initial fracturing process. Eventually the well will cease production, and the owner may plug and abandon the well. Improper plugging may fail to isolate geologic strata, resulting in communication pathways that may lead to groundwater contamination.

Hydrogeologic Analysis

In order to determine the potential for contamination from well drilling and subsequent hydraulic fracturing, a conceptual hydrogeologic model was developed using site-specific geology, hydrogeology and hydrogeochemical data. The model relies on surface and subsurface water quality data to develop signatures of different water types occurring within the West of Hudson watershed. The model was used to characterize regional groundwater flow patterns and identify mechanisms by which disruption of existing subsurface flow regimes could impact shallow groundwater and surface water quality.

Groundwater occurring within very deep formations is generally not potable and does not typically mix directly with shallow, fresh groundwater and surface water bodies. This is due to the barrier provided by approximately 2,000 to 7,000 feet of rock between fresh water aquifers and the Marcellus Shale. This protection may be compromised during gas well drilling and stimulation. Casing or grouting failures, existing subsurface fractures, and fractures created during stimulation that propagate beyond the target formation can create or enhance hydraulic pathways between previously isolated formations. These pathways can allow drilling and fracturing chemicals or formation material (e.g., hydrocarbons or saline water) to contaminate shallow groundwater and surface water resources.

In particular, existing fractures may provide a major route for groundwater discharge from the bedrock into the overlying shallow groundwater and surface waters. Increased potential for enhanced groundwater movement may occur where these fractures intersect one another and/or local bedding planes. In the case of shale units like the Marcellus and the intermittent, locally occurring coal-bearing strata, a step-like pattern is commonly formed by the intersection of horizontal bedding planes and vertical fractures. Upward vertical migration through extensive, open fractures or an improperly sealed gas well can allow for the discharge of high salinity and gas-enriched groundwater directly to the ground surface, or into shallower flow regimes. Under these conditions, the discharged groundwater could occur at a considerable distance from the corresponding source area and formation.

Documented cases from other states indicate that drilling and fracturing operations have been associated with the movement of natural gas and contaminants into aquifers or surface water bodies.

NYC Infrastructure

Compared to other major unconventional gas plays, the NYC system presents what is believed to be a unique situation in that the rock overlying the Marcellus Formation would need to be relied upon to protect not just groundwater resources, but reservoirs and tunneled aqueducts as well, both from structural effects, and the risk of infiltration by pressurized poor quality groundwater and/or natural gas.

Accordingly, a preliminary assessment of the relative susceptibility of DEP’s subsurface water supply infrastructure to such impacts was conducted. This assessment relied on regional estimates of geologic conditions, estimated depth contours for the Marcellus Formation, plotting of known faults and brittle rock zones, and review of drawings and construction data for DEP’s West of Hudson dams and aqueducts. DEP infrastructure records were reviewed to determine risk factors such as proximity to gas-bearing formations and the presence of subsurface conditions that could indicate existing pathways to deeper formations.

The review revealed that substantial portions of DEP’s West of Hudson aqueducts and tunnels, as well as two reservoirs, are constructed within 500 to 1,500 feet vertical distance of the Marcellus Shale Formation. In two locations near the edge of the Marcellus Formation, portions of the Catskill Aqueduct and the Rondout-West Branch Tunnel of the Delaware Aqueduct are in direct contact with the Marcellus Formation. It is also important to note that some tunnel sections located outside the NYC watershed boundaries are in proximity to areas of significant gas leasing activity.

The primary subsurface risk to DEP infrastructure is considered to be the potential for the inadvertent establishment of flow pathways between natural gas wells (or underground injection wells) and the water supply structures. Flow paths could be established via existing faults or poorly constructed wells. Numerous occurrences of faults crossing beneath reservoirs, watershed boundaries, streams, and tunnels illustrate the potential for below-grade flow transmission across surface boundaries. Undetected faults and improperly abandoned wells also present opportunity for the development of unanticipated gas or contaminant migration pathways.

Subsurface conditions are not static, and faults can develop or widen over time. Natural gas development activities may increase the likelihood of movement of existing, naturally occurring faults. Induced seismicity is known to be associated with injection wells, and has reportedly been linked with hydrofracturing operations. Given the widespread use of injection wells for disposal of wastes in other regions, the possibility of causing or accelerating changes in subsurface faults and fractures, and the creation of new or enhanced flow paths, is considered a potential risk to water supply infrastructure.

Infrastructure impacts also include the slight but real potential for inadvertent penetration of a NYCDEP tunnel or aqueduct during vertical or horizontal drilling operations.

Fracturing Chemicals

A wide array of products is used during drilling and fracturing operations. These products are proprietary and typically protected by trade secret laws, and disclosure requirements are limited. Consequently, very little data is available on the types or amounts of specific chemicals that could be used during drilling and fracturing operations in or near the NYC watershed.

A database of fracturing chemicals that have been used in other locations was reviewed to characterize the chemicals that could potentially be introduced into the watershed. The database identifies 435 products composed of over 340 individual chemical constituents. Very little is known about most of the products: the exact chemical composition of over 90% of the products in the database is unknown. Many of the constituents that have been identified are recognized as hazardous to water quality and health (e.g., benzene, xylene, ethylene glycol, diesel fuel).

While a single chemical/fracturing waste spill or subsurface contamination incident is not expected to cause an imminent public health threat via the water supply system, such an occurrence could be expected to have a negative impact on the perceived quality and integrity of New York's unfiltered drinking water supply.

Water Diversions

Depending on the scale of natural gas development activities, surface and groundwater withdrawals for drilling and fracturing could potentially impact the operations and reliability of the NYC water supply system, particularly during droughts. Water withdrawals for fracturing could impact DEP by directly reducing inflows to NYC reservoirs, and/or by requiring additional reservoir releases to meet downstream flow targets. The Delaware River Basin Commission has the authority to permit water withdrawals from the Delaware River watershed, which also has an established basin-level planning framework. The Catskill watershed lacks such protection and is more vulnerable to excessive withdrawals. Further, DEC currently only regulates water withdrawals and diversions related to community water supply use. As such, water withdrawals associated with gas well drilling and hydraulic fracturing are not regulated by the state.

Wastewater Management

In the process of drilling and fracturing a well, millions of gallons of wastewater and chemicals must be managed. Drilling fluid, fracturing fluid, drill cuttings, and saline groundwater must all be stored at the surface and subsequently transported off-site for treatment and ultimate disposal. Treatment and disposal of fracturing wastewater is complicated by the presence of constituents that are not amenable to conventional treatment (e.g. high salinity, chemical residues, radionuclides). In New York, the wastes can only be accepted at conventional treatment plants with approved pretreatment programs. There are currently no specialized treatment plants in the region designed to treat these wastes.

Wastes can also be disposed of via deep underground injection wells, which can lead to contamination if not properly designed and managed. Limited disposal options and/or high costs may lead to illicit disposal of wastes. Cost and capacity issues may be addressed as specialized treatment plants and injection wells are constructed in the region.

Improper waste management can lead to water quality problems at local or regional scales. Localized impacts could occur due to isolated incidents such as on-site spills, hauling accidents, or illicit disposal. Water quality impairment at a larger spatial scale could occur due to systemic waste management failures such as cumulative impacts from the lack of sufficient regional treatment and disposal capacity. Incidents of both localized and widespread contamination have been documented in other states. Human error or unforeseen circumstances were generally the cause for most localized incidents. Larger scale contamination incidents have resulted from poor management practices stemming from inadequate regulation. Overall, waste management failures were responsible for the majority of documented water contamination incidents related to natural gas development.

Summary of Findings

Numerous activities during all phases of natural gas development have the potential to contaminate groundwater or surface water supplies. Fracturing operations in proximity to DEP infrastructure could compromise water quality and potentially damage infrastructure. High levels of water withdrawals during periods of hydrologic stress could impact reservoir operations and impair water supply reliability.

Effective regulation, inspection programs, inter-agency coordination, and regional planning could reduce the risk of such impacts, and with proper protections in place it is possible that some level of natural gas development could occur in or near the NYC watershed without causing substantial adverse impacts to the NYC water supply. However, it is also important to note that risks to the water supply cannot be eliminated entirely, and that water quality incidents (e.g. spills, leaks) should be anticipated. While such events may not pose a direct or immediate public health threat, they can be expected to require a rapid operational response, and they may reduce public confidence in NYC's unfiltered water supply. Overall, the pace of gas well development in the region and the ability of regulatory agencies to manage the process will have a substantial influence on the resulting level of risk to the NYC water supply system.

Section 1: Introduction

In recognition of increased natural gas development activity in New York State and its potential to impact New York City's water supply, the New York City Department of Environmental Protection (DEP) has undertaken the project, *Impact Assessment of Natural Gas Production in the NYC Water Supply Watershed*. Natural gas development activities have the potential to impact the quality and quantity of NYC's water supply through land disturbance, toxic chemical usage, disruption of groundwater flow pathways, water consumption, and waste generation. The overall goal of the project is to identify potential threats to the continued reliability and high quality of New York City's water supply by providing an assessment of the potential impacts of future natural gas development activities in or near the NYC watershed on water quality, water quantity, and water supply infrastructure.

The project is conducted in two stages. The Rapid Impact Assessment provides an identification and preliminary evaluation of the potential impacts of natural gas development activities on the NYC water supply. The Final Impact Assessment will provide additional detail on those activities and impacts considered to be of major concern, and will identify strategies for minimizing impacts to the NYC water supply.

1.1 The New York City West of Hudson Water Supply

Approximately 90% of New York City's water supply is drawn from the West of Hudson (WOH) watersheds. Roughly 50% of system demand is supplied by the Delaware System, major components of which include Cannonsville, Pepacton, Neversink, and Rondout Reservoirs, and the West Delaware, East Delaware, Neversink, and Rondout-West Branch Tunnels. Roughly 40% of system demand is supplied by the Catskill System, major components of which include Schoharie and Ashokan Reservoirs, the Shandaken Tunnel, and the Catskill Aqueduct (Figure 1). The balance of demand is supplied by the Croton System, which is located east of the Hudson River and is not under consideration for natural gas production.

Due to the high quality of the West of Hudson water supplies and the extensive watershed protection efforts of NYCDEP and numerous stakeholders, EPA has determined in successive Filtration Avoidance Determinations (FADs) that NYC's Catskill and Delaware supplies satisfy the requirements for unfiltered surface water systems established in the Surface Water Treatment Rule and the Interim Enhanced Surface Water Treatment Rule. The most recent FAD was issued in 2007 and establishes requirements for continued watershed protection efforts through 2017. A core requirement for filtration avoidance is a watershed control program that can identify, monitor, and control activities in the watershed which may have an adverse effect on source water quality. The focus of the FAD watershed control requirements is on protecting the microbiological quality of the source water. New York City is the only major unfiltered water supply with major gas play potential within its watershed.

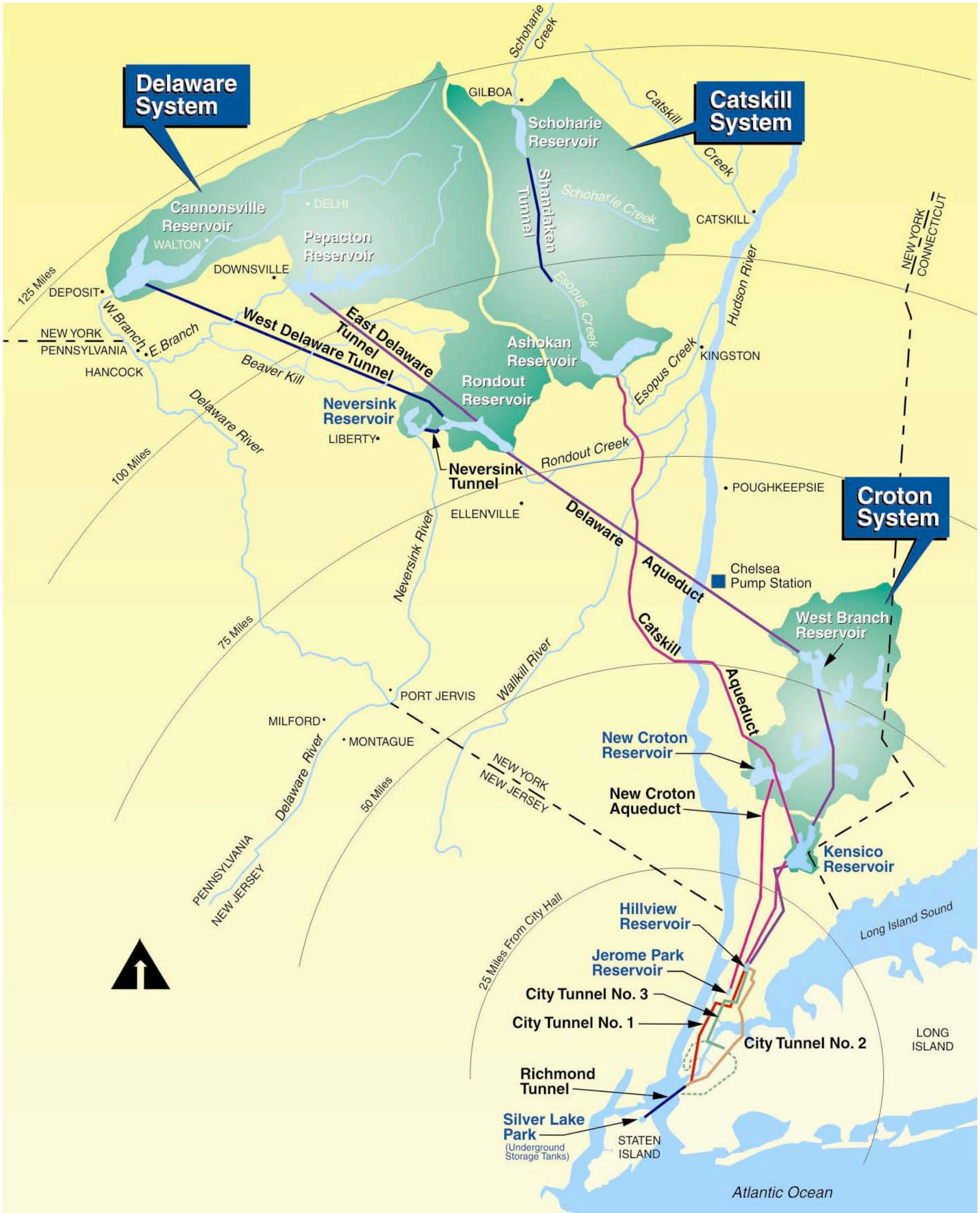

Figure 1: New York City Water Supply System

1.2 Natural Gas and the Marcellus Shale Formation

The Marcellus Shale is an organic shale member of the Middle Devonian Hamilton Group (about 380 million years old) that extends from eastern Kentucky, through West Virginia, Ohio and Pennsylvania and into southern/central New York (approximately 95,000 square miles). While exposed at the surface north of the Finger Lakes region and along a line that roughly parallels the New York State Thruway, the Marcellus Shale occurs as deep as 7,000 feet along the Delaware River at the New York - Pennsylvania border. In New York the formation lies beneath all or part of 29 counties. The entire West of Hudson watershed's 1,580 square mile area is underlain by the Marcellus Shale (Figure 2) at depths ranging from approximately 1,000 to 4,500 feet. The Marcellus Shale is overlain and underlain by sedimentary rock units (e.g., sandstone, shale, siltstone and limestone) of varying gas and petroleum yielding potential.

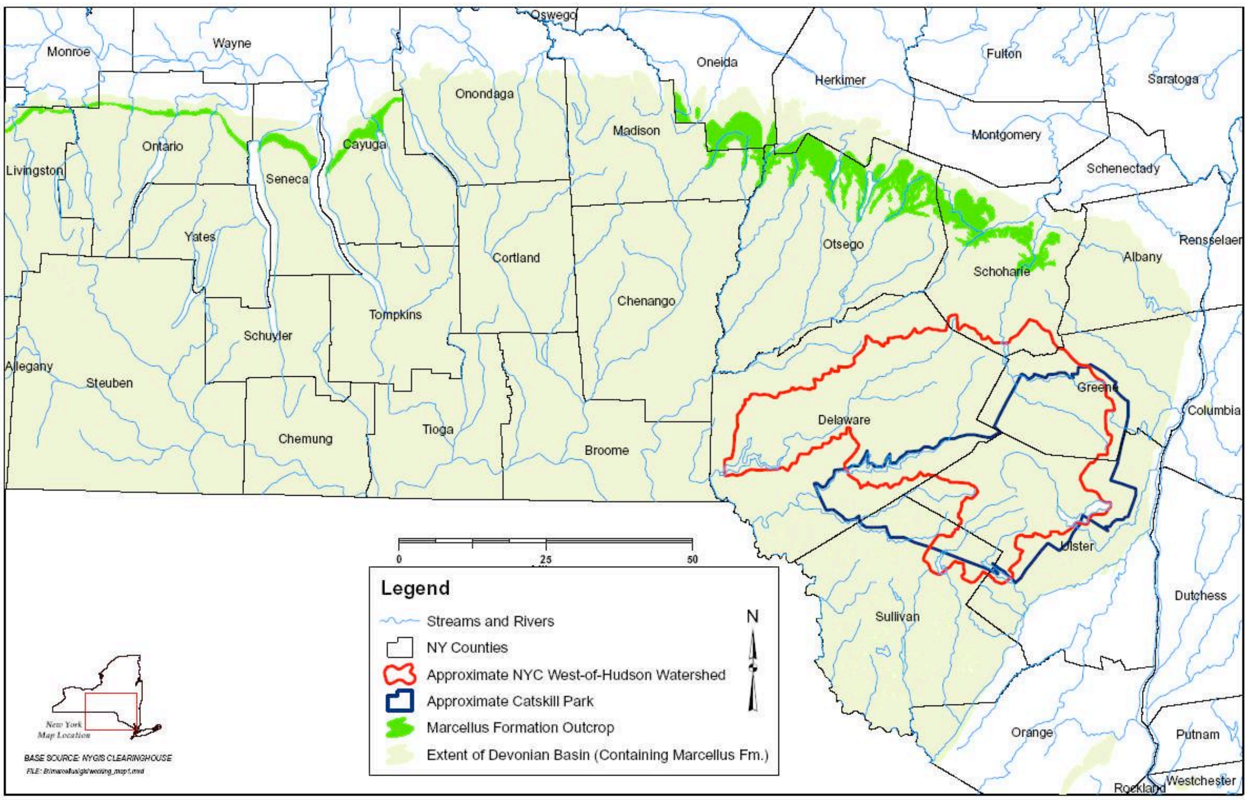

Figure 2: Extent of Marcellus Shale in eastern New York

The Marcellus Shale Formation is estimated to contain 200-500 trillion cubic feet (tcf) of gas reserves and represents one of the largest new potential sources of energy in the U.S., capable of supplying up to 20 years of the nation's demand for natural gas.[1] The amount of recoverable gas in the New York State area has not been established. The Marcellus Shale is a "tight" formation, meaning it has limited permeability, which commonly requires hydraulic fracturing to enhance the movement of gas to a well-bore. In addition, the formation is generally of limited thickness with its greatest thickness reportedly occurring in the eastern Catskill region (on the order of 500

---

[1] Navigant Consulting, Inc. (2008). *North American Natural Gas Supply Assessment*, Prepared for: American Clean Skies Foundation.

to 600 feet thick). As such, horizontal drilling and hydraulic fracturing recovery stimulation techniques are currently being pursued in order to extract commercially viable quantities of natural gas from the Marcellus Shale and possibly similar formations such as the Utica Shale. Such techniques have proven successful elsewhere in the country where similar geologic conditions exist (e.g., the Barnett Shale of Texas).

1.3 Regulatory Context

A summary of applicable regulations are described, in order to provide background on the regulatory environment for oil and gas development in New York.

1.3.1 Federal

Natural gas exploration and production (E&P) is generally regulated at the state level. However, many activities associated with natural gas development have the potential to pollute air or water and therefore fall under the jurisdiction of a number of federal environmental regulations. Interstate natural gas transmission, rates, and markets are regulated by the Federal Energy Regulatory Commission (FERC), which includes interstate pipeline construction and environmental compliance. FERC has no authority over natural gas E&P. Examples of federal laws that may be applicable to natural gas activities are listed below.

1. The Clean Water Act (CWA) National Pollution Discharge Elimination System (NPDES) regulates stormwater discharges to prevent pollution of the nation's waters.
2. The Safe Drinking Water Act (SDWA) is designed to ensure drinking water quality. The Underground Injection Control (UIC) Program, which regulates subsurface injection of wastes, is part of the SDWA. The UIC program does not regulate the injection of chemicals during the natural gas drilling and fracturing process because the materials are not being injected for waste disposal purposes.
3. The Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulate hazardous substances. Both laws generally exempt any oil or gas waste that is removed from the well itself, including injected chemicals returned to the surface.
4. The Emergency Planning and Community Right-to-Know Act (EPCRA) was enacted in 1986 to help inform citizens about the amounts and types of chemicals used in their communities and facilitate emergency management plans. EPCRA requires Tier II reports listing the volumes of hazardous chemicals (above a minimum threshold volume) stored at a facility.
5. The Energy Policy Act of 2005 contains various energy-related laws, including exemptions for hydraulic fracturing from regulation under the SDWA and exemptions for oil and gas construction sites from NPDES requirements of the CWA.

1.3.2 State

Natural gas E&P in New York is regulated by the New York State Department of Environmental Conservation (DEC). In 1992, DEC finalized a Generic Environmental Impact Statement (GEIS) on the Oil, Gas and Solution Mining Regulatory Program as part of the SEQRA process.[2] At the time the GEIS was drafted, the use of horizontal wells for oil and gas extraction in shale and tight sandstone reservoirs (such as those that underlie New York State) was not technologically feasible. In 2008, Governor Paterson directed DEC to prepare a supplemental GEIS (SGEIS) to review potential additional impacts related to natural gas E&P using high volume hydraulic fracturing. DEC has indicated a draft SGEIS will be released in the summer of 2009.

DEC derives jurisdiction over oil and gas activities from the Environmental Conservation Law (ECL). The ECL requires prevention of both pollution of and waste of natural resources, while protecting the rights of producers. Article 23 of the ECL supersedes all local laws for regulating oil and gas E&P. The ECL also regulates water diversions (groundwater and surface water) for public water supplies or agricultural irrigation. The diversion of water for oil and gas E&P is subject to reporting requirements but not otherwise regulated under the current New York State regulatory structure.

In addition to the ECL, there are a number of other New York laws and regulations that apply to various aspects of gas development and drinking water protection.

- In New York a waste injection well requires a State Pollution Discharge Elimination System (SPDES) permit in addition to a federal UIC permit. Applicants are required to demonstrate the waste will remain in the target formation and not migrate to drinking water aquifers.
- Wastewater treatment plants are required to have an approved pretreatment program and an approved headworks analysis prior to accepting wastewater from hydrofracturing operations.[3]
- State-owned lands in the Catskill (and Adirondack) Forest Preserves are required to be kept "forever wild" and are expressly prohibited from being leased or sold without a constitutional amendment.
- The New York Public Services Commission (PSC) regulates major natural gas pipelines, similar to FERC's role at the federal level. Pipeline regulations under the jurisdiction of PSC will not be covered in the SGEIS according to the scoping document.
- New York dam safety regulations require a dam permit for impoundments greater than 10 feet tall or holding more than one million gallons. Surface waste impoundments are exempt from these regulations.

Additionally, wells developed in areas of primary or principal aquifers have additional drilling requirements. Primary aquifers are those "presently utilized as sources of water supply by major municipal water supply systems." Principal aquifers have the potential to be utilized for water supply, but are not currently utilized for major municipal water supply. Portions of the WOH watershed are considered principal aquifers, which are in the process of being mapped by USGS.

---

[2] Under some circumstances a site-specific SEQRA determination is required for an individual well, such as when it is within 1,000 feet of a municipal water-supply well.

[3] Fuchs, A. (2008). "Pretreatment requirements for hydrofracturing gas well facilities." New York State Department of Environmental Conservation Division of Water Memo from A. Fuchs, Director, Bureau of Water Permits, NYSDEC Division of Water to Permittee, dated December 8, 2008.

1.3.3 Local/Regional

NYC watershed regulations include restrictions on the construction of impervious surfaces near reservoirs, streams, and wetlands. A stormwater pollution prevention plan is also required for most land-disturbing activities. NYC watershed regulations have a number of other sections that apply to use and transport of radioactive material or petroleum products within the watershed. However, language is included in these sections allowing for an affirmative defense for activities permitted or not prohibited at the state or federal level.

Water withdrawals in the NYC Delaware watershed are subject to review and approval processes established by the Delaware River Basin Commission (DRBC). Specifically, DRBC approval is required for projects that may have a "substantial effect on the water resources of the basin."[4] DRBC is currently developing new regulations pertaining to oil and gas development in the watershed. Interim provisions require review of all aspects of natural gas extraction in areas draining to Special Protection Waters, which includes the Delaware Basin in New York.[5]

Local laws regulating oil and gas development are specifically superseded by the ECL. However local jurisdictions retain authority over local roads. The SGEIS is expected to explore mitigation measures for impacts associated with increased volumes of heavy truck traffic.

1.4 Report Organization

The remainder of this report is organized as follows:

- Section 2 (Hydrogeologic Setting) describes the geological and hydrogeological setting for the region, and presents a conceptual hydrogeologic model describing the interaction between surface and groundwater for the possible flow regimes existing in the watershed.
- Section 3 (Natural Gas Development Activities and Potential Impacts) presents a comprehensive listing and description of the activities associated with natural gas development and the potential impacts to water quality or reliability of the NYC water supply.
- Section 4 (Natural Gas Development Incidents and Case Studies) summarizes documented incidents from natural gas development in other states that have the potential to cause water quality, reliability or infrastructure problems for DEP.
- Section 5 (Subsurface Risks to NYCDEP Infrastructure) presents a preliminary review of risks to major NYCDEP structures (e.g., tunnels, dams, aqueducts) from natural gas development in the region.
- Section 6 (Summary and Findings) summarizes potential impacts to the NYC water supply system from natural gas development.

---

[4] Delaware River Basin Compact Section 3.8.

[5] DRBC Press Release (5/19/09).

Section 2: Hydrogeologic Setting

The objective of this section is to characterize the effects of the regional geology and hydrogeology on water quality and surface water flow in the NYC watershed. This section also describes mechanisms by which natural gas development could impact the NYC water supply by altering existing subsurface flow regimes. Finally, a methodology is presented for using water quality and flow data to establish baseline water quality characteristics that can be used to assess potential impacts from future natural gas development activities.

A conceptual hydrogeologic model (CHM) was developed to characterize the groundwater resources of the region based on inter-formational and surface-subsurface hydraulic connectivity and water-quality conditions. The CHM uses available water quality, surface water flow, geologic, and topographic data to identify baseline hydrogeochemical signatures of the comprising waters (surface water and shallow and deep groundwater) in the Catskill Mountain Region of New York (the Region)[6]. This information is in turn used to describe the naturally-occurring modes of hydraulic communication and the flow regimes that can typically influence these signatures. Once established, these signatures can be used to help identify water quality variations due to anthropogenic activity.

The following sources of information were collected and reviewed to develop the CHM:

- Geologic, hydrogeologic, and hydrogeochemical logs from water supply and gas wells;
- Published geologic maps and reports;
- Groundwater (wells) and surface water (rivers, streams, reservoirs) sample analyses; and
- Regional GIS data.

The utilized data was collected from the DEP, the United States Geological Survey (USGS), the New York State Geological Survey, and DEC. Typical water and gas well construction and water supply development practices used in the Region were also reviewed and considered relative to influences on local groundwater movement. Resource extraction in the Region was reviewed with respect to water quality concerns, with special attention to those formations with fossil fuel-bearing potential (e.g., natural gas, coal, and oil reservoirs) and the overlying formations that would be penetrated in order to access the resources.

2.1 Study Area

2.1.1 Geography

The Region occupies the northeastern portion of the Catskill Delta, which refers to a geologically widespread[7] sequence of sedimentary rocks that were deposited into the Kaskaskian Sea primarily during the Devonian period (ca. 408 to 360 million years ago). The topography of the

---

[6] A limited amount of information for other areas in the New York State portion of the Appalachian Basin, where similar geologic and hydrogeologic conditions are anticipated to occur, but generally at shallower depths, was also used for refinement of the CHM. These areas include portions of western and central New York that mark the periphery of the Region.

[7] The Catskill Delta occurs throughout the lower portion of New York State and extends as far south as Tennessee and westward into central Ohio and Kentucky.

Region reflects the geologically recent erosion of the relatively flat-lying but upland sedimentary deposits of the Catskill Mountain plateau (comprised of Catskill Delta rocks), which has also been sculpted to some extent by glacial events 10,000 or more years ago. The dissection of this plateau is generally manifested by dendritic drainage patterns that are locally influenced by laterally extensive vertical and subvertical fractures in the underlying bedrock.

2.1.2 Geology

The bedrock units underlying the region consist primarily of sedimentary units deposited on top of crystalline basement rocks with geologic features and topography reflective of the depositional environment and subsequent response to erosion and tectonic stresses (Figure 3, Figure 4, Figure 5, and Figure 6). Unconsolidated material, largely of glacial and fluvial origin, typically overlies the bedrock on the valley floors. In the upland areas and on valley sides, the bedrock is either exposed or typically overlain by glacial till ranging from several inches to several feet thick.

The shallowest sedimentary bedrock units that outcrop within and underlie the Region are composed primarily of sandstone and shale units belonging to the Canadaway, Sonyea, Genesee, and West Falls Groups of the Upper (Late) Devonian (over 360 million years old). Anthracite coal and methane associated with fossilized plant debris have been encountered in the bedrock units of the West Falls Group in the Region. The Upper Devonian formations are in turn underlain by Middle Devonian aged rocks of the Hamilton group (composed primarily of sandstones and shales), which includes the Marcellus Formation and the underlying Onondaga Formation (composed primarily of limestones). The Hamilton and Onondaga are in turn underlain by the older bedrock formations composed primarily of limestone, sandstone and shale formations which increase in age with depth from Lower (Early) Devonian through Cambrian age, and into the deepest and oldest bedrock comprising the Precambrian basement (meta-igneous rocks).

Bedrock Fractures and Hydrogeologic Influences

Many of the beds comprising the sedimentary rocks underlying the Region are typically separated by planar discontinuities formed during rock deposition and compaction (i.e., bedding planes). The bedding plane orientation for these formations, in general, slopes towards the southwest with an angle of about 15° from the horizontal. The relatively consistent orientation and irregularly spaced, though somewhat frequent, occurrence of the bedding planes imparts vertically heterogeneous hydraulic characteristics but relatively predictable hydrogeologic conditions in the comprising bedrock units.

In addition, these units are also broken by steeply-inclined to near-vertical fractures and faults formed in response to tectonic stresses. In many areas, the orientations of these fractures follow a regular pattern, which can be related to the intensity and direction of the formative stress field (e.g., faulting) (Figure 3). Locally, stress-relief fractures also form in the shallower and exposed portions of the comprising rock units in response to unloading of overlying rock and overburden due to glaciation, weathering, and erosion.

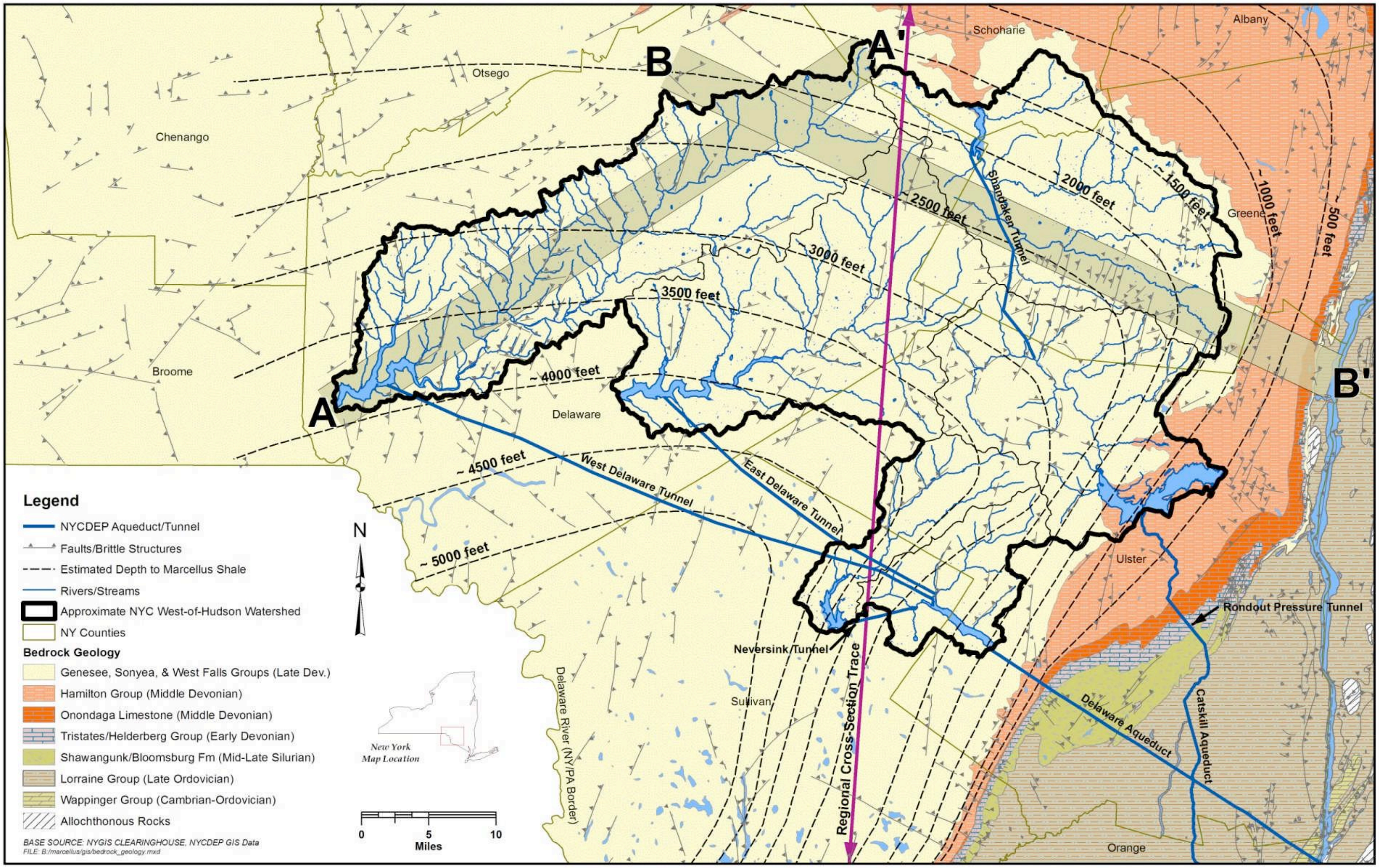

Figure 3: Bedrock geology of the Catskill region

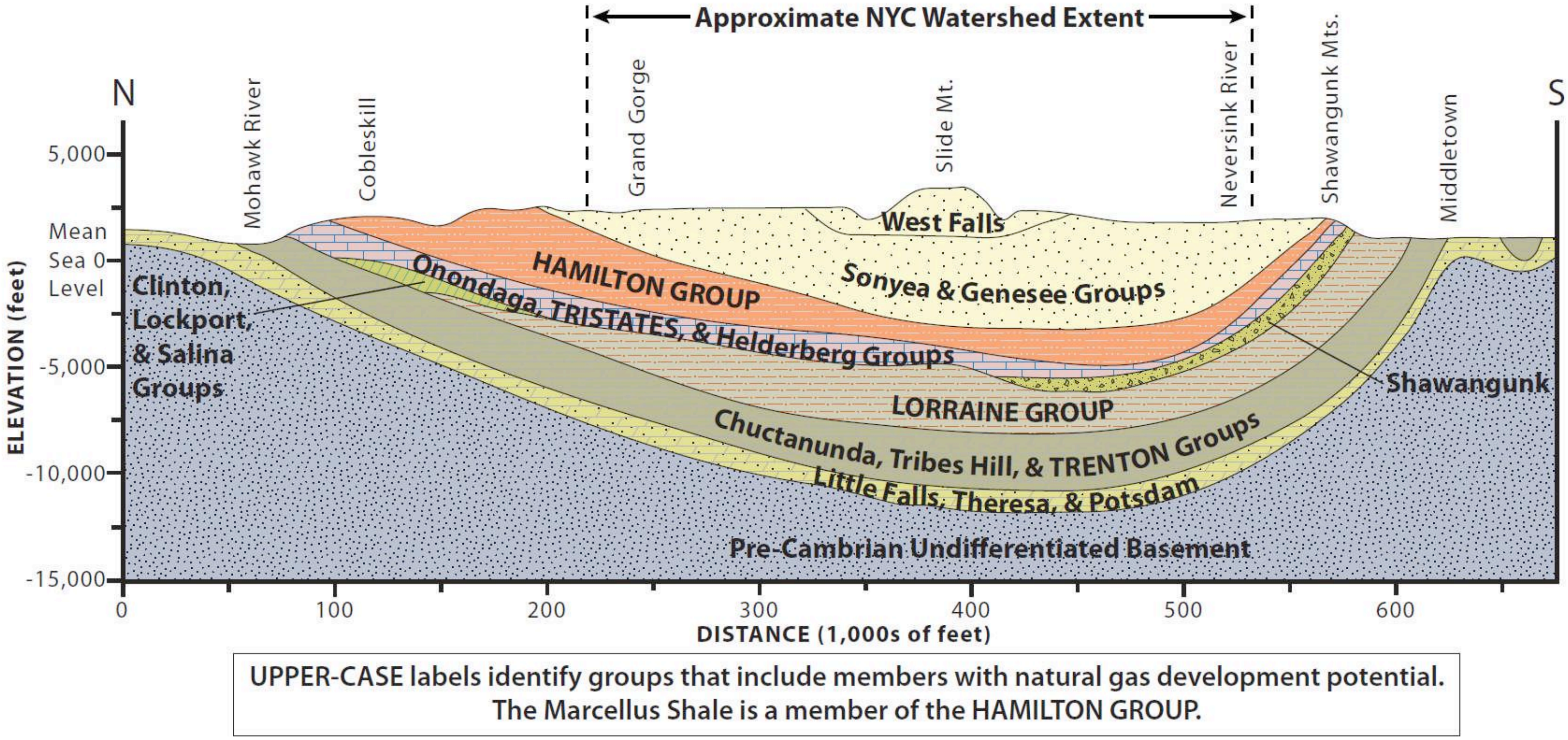

Figure 4: Cross-section through the Catskills showing the geometry of the Kaskaskian Depositional Basin

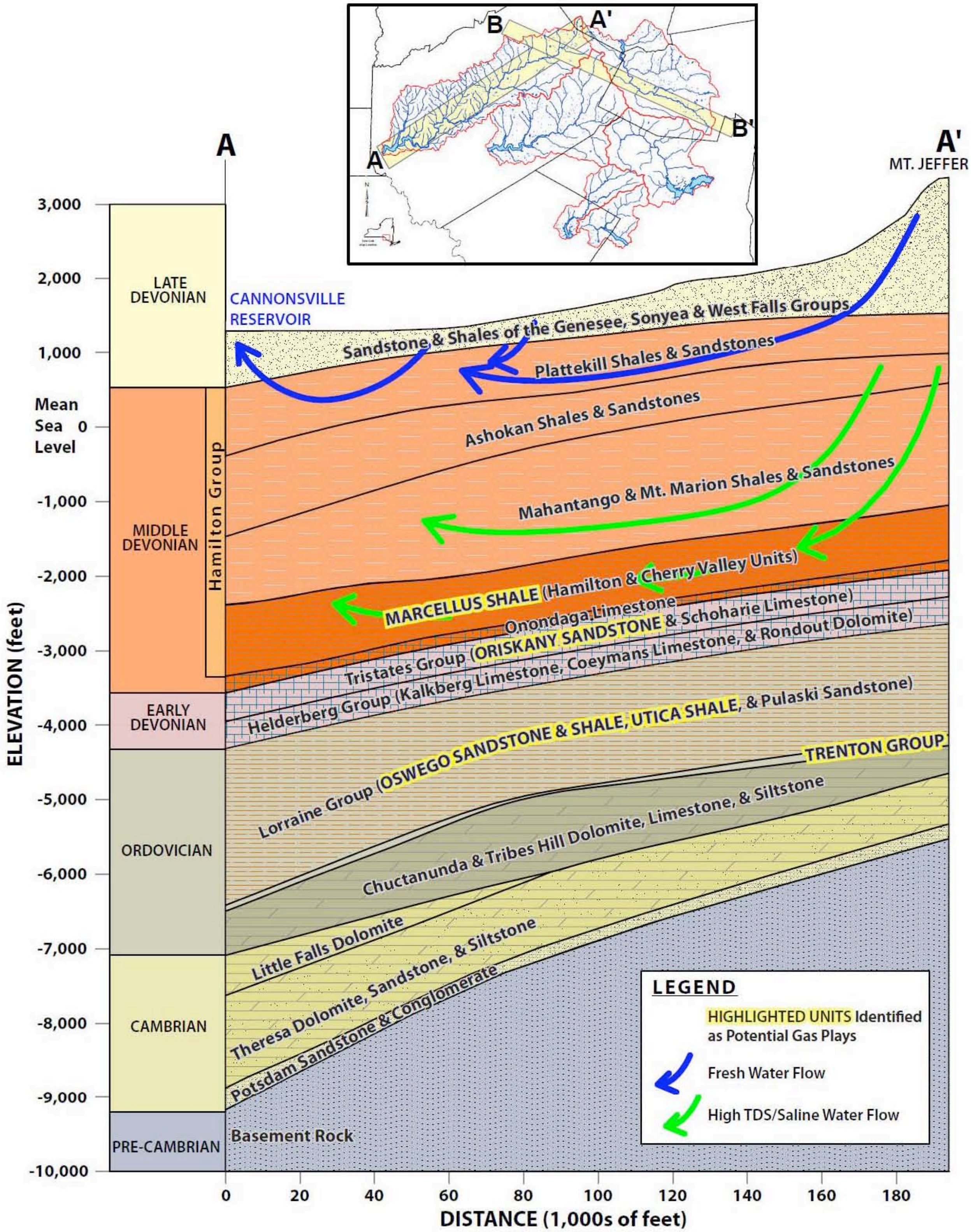

Figure 5: Generalized stratigraphy underlying the Region (cross-section A – A')

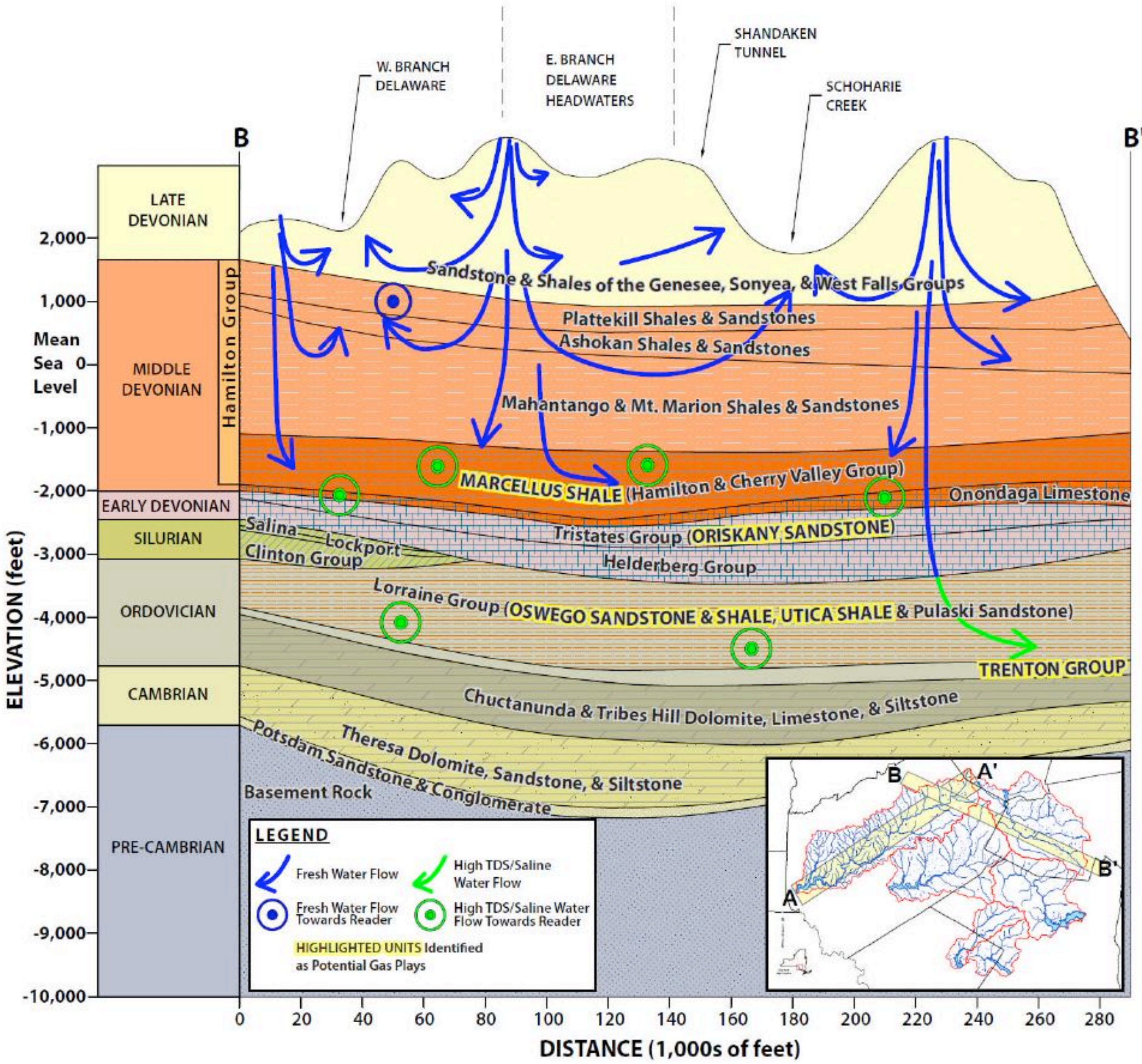

Figure 6: Generalized stratigraphy underlying the Region (cross-section B – B')

Bedding planes and fractures are important characteristics influencing the movement of groundwater and gas through the bedrock units that comprise the sedimentary formations underlying the Region. The overall direction of groundwater flow will be controlled by the prevailing hydraulic gradient and locally by the dominant fracture orientation. Because of this, fractures may provide a major route for groundwater discharge from the bedrock into the overlying surface waters. Increased potential for enhanced groundwater movement may occur where these fractures intersect one another and/or local bedding planes. In the case of shale units like the Marcellus and the intermittent, locally occurring coal-bearing strata, a step-like pattern is commonly formed by the intersection of bedding planes and vertical fractures.

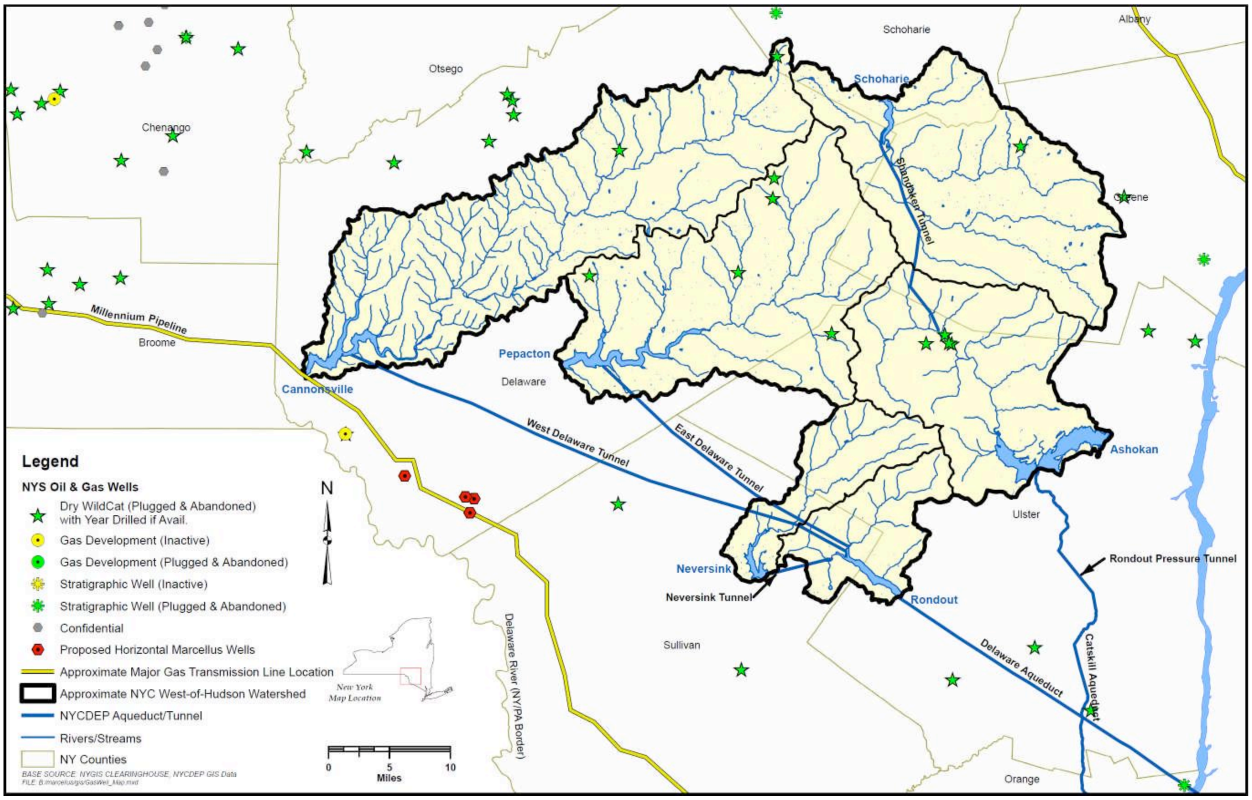

Figure 7: Gas wells in the NYCDEP West of Hudson region

Natural Gas Potential

Aside from groundwater, natural gas is one of the more abundant resources occurring within the geologic formations underlying the Region. Other fossil fuel resources of localized occurrence in the Region include petroleum and coal. Prospecting for gas in the Region is not a recent phenomenon. Figure 7 presents all gas wells in and around the Region as reported in DEC GIS data. Most of the wells drilled in the Region date back to the 1950's and have been abandoned.

Of the bedrock formations underlying the Region, several have been identified as limited sources of gas and other fossil fuels, while others are recognized as potentially viable for large scale extraction. The most notable such formation is the Marcellus Shale (a member of the Hamilton Group). Underlying the Marcellus Shale are several other bedrock formations that have been identified as gas plays that may be potential targets of future extraction in the Region (Figure 4, Figure 5, and Figure 6). These formations include (from geologically youngest to oldest): the Oriskany Sandstone, the Utica Shale, and the Trenton and Black River Group limestones (collectively identified as Silurian/Ordovician Age formations).

2.1.3 Water Resources

Information and data summarized in the following sections were developed from various County and Statewide hydrogeologic and geologic publications.[8,9,10]

Surface Water

The topography of the Region results in the formation of six wholly inclusive major drainage basins, each occupied by a NYC reservoir and its tributaries (Figure 3). The corresponding streams in each basin feed the respective down-gradient reservoirs. The three western-most drainage basins (Cannonsville, Pepacton, Neversink) comprise subwatersheds contributary to the Delaware River, while the remaining three (Rondout, Schoharie, Ashokan) are contributary to the Hudson River. The water occurring in these surface water bodies generally originates under natural conditions as precipitation that falls within the Region. Precipitation is either captured directly within the surface water body limits, or indirectly as surface and subsurface runoff and as groundwater discharge (i.e., baseflow).

The stream orders in the respective watersheds range from values of one (i.e., headwater level such as Sherruck Brook) to six (i.e., major streams such as Schoharie Creek). During normal hydrologic conditions, streamflow within the NYC reservoir system occurs as a combination of runoff/snowmelt and groundwater discharge (or baseflow). It has been estimated that baseflow accounts for approximately 70% of the total annual streamflow within the watersheds. During the periods when baseflow serves as the principal contributor to NYC reservoir inflows, streamflow is typically at its lowest and can range from about 10 cubic feet per second (cfs) or 4,500 gallons per minute (gpm) on a major stream like Schoharie Creek, to 0.02 cfs (10 gpm) on a headwater stream like the Sherruck Brook tributary near Trout Creek. Flows lower than these historic levels can be expected under extreme drought conditions.

The quality of surface water generally varies with source. Water quality of the runoff component is influenced by the materials and chemicals encountered along the ground surface and transported directly into the water of the receiving body. Water quality of the baseflow component is influenced by chemicals in the subsurface environment and the local hydrogeochemistry.

Groundwater

Groundwater occurs within the overburden (consisting of glacial deposits and recent alluvium) and the bedrock units underlying the Region. Both aquifer systems support potable water supplies developed by individual residents and communities throughout the Region, either directly from wells or indirectly from baseflow contributions to surface waters. This system is recharged by infiltrating precipitation and by groundwater flow from hydraulically connected geologic formations. Groundwater generally moves from areas of high elevation (e.g., recharge

---

[8] Berdan, J.M. (1954). *The ground-water resources of Greene County, New York*. New York State Department of Conservation Water Power and Control Commission, Bulletin GW-34.
[9] Soren, J. (1963). *The ground-water resources of Delaware County, New York*. U.S. Geological Survey and State of New York Department of Conservation Water Resources Commission Bulletin GW-50.
[10] Soren, J. (1961). *The ground-water resources of Sullivan County, New York*. U.S. Geological Survey and State of New York Department of Conservation Water Resources Commission Bulletin GW-46.

zones) to areas of low elevation (e.g., discharge zones), moving primarily through pore spaces or the network of lateral and vertical fractures that permeate the comprising aquifers. The yield potential is generally controlled by the local permeability and recharge capacity of the tapped aquifer.

The more permeable upper units of the bedrock formations comprise an extensive aquifer system underlying the Region and are significant from a regional water supply perspective. The hydrogeologic characteristics and yield potential of the Upper (Late) Devonian bedrock formations in the Region are favorable for developing both residential and public community supply wells. This is primarily due to the combination of their relatively shallow occurrence (typically the shallowest bedrock underlying the local overburden) and the granular, fractured nature of the rock units. The yields of wells tapping the Late Devonian formations reportedly range from 2 gpm to over 100 gpm. The yield of such wells is primarily dependent on, and directly related to, the number and extent of groundwater-bearing fractures penetrated by the respective open-borehole intake zones. Typically, the penetration of more extensive fractures results in greater groundwater yield potential. As an illustration, an extensive fracture system was penetrated in the Late Devonian bedrock units near the Neversink River and was reportedly capable of yielding in excess of 600 gpm.

In contrast, the potential of unconsolidated-deposit aquifers is typically limited by thickness and local areal extent, as well as available recharge. The more extensive unconsolidated-deposit aquifers in the Region are generally limited to the valley floors of the larger streams, such as Schoharie Creek. These aquifers are capable of supporting community and industrial supplies and can reportedly yield in excess of 500 gpm.

Under naturally occurring conditions, the groundwater quality in the geologic formations underlying the Region can vary with location, rock type, depth, and hydrologic conditions (e.g., precipitation patterns). Local variations can result in a range of concentrations of various constituents (e.g., iron, salinity, hydrogen sulfide, radon, etc.) resulting in reduced suitability for potable use. Many of these constituents are related to the deeper bedrock formations (e.g., Middle and Early Devonian Formations, the Salina Group), which are typically isolated from potable aquifers by impermeable bedrock units. The protection afforded by hydraulic separation between the deeper and shallower bedrock formations may be compromised in areas where natural or induced fracturing occurs.

2.2 Hydrogeologic Flow Regimes

Evaluating the potential impacts of natural gas production from the Marcellus Shale on groundwater quality or quantity in the NYC WOH watershed can be facilitated by the development of a conceptual model of the hydrogeologic flow regimes possible in the Region. To be useful, such a model needs to provide an understanding of the extent and types of influencing geologic formations, the lateral and vertical movement of groundwater, and the interaction between groundwater and surface water in the watershed. With this understanding, evaluation of how groundwater movement can influence, and be influenced by, naturally occurring geochemical variations and man-made activities (e.g., gas production) is possible.

Although cumulatively the underlying sedimentary geologic formations within the Region are thousands of feet thick, studies of supply wells completed in the associated aquifer system have shown that most of the water derived by pumping is generally produced from within 400 feet of the ground surface. This is attributed to the fact that the openings of fractures and bedding planes are typically wider near the ground surface where lithostatic force (the weight of the overlying rock) is less. As a result, the quality and quantity of water occurring within shallow geologic formations is most influenced by the prevailing hydrogeologic and hydrogeochemical conditions of the shallower portions of the respective bedrock aquifer. Surface waters such as lakes, streams, rivers, and reservoirs, as well as some of the unconsolidated aquifers are similarly influenced by these conditions to the extent that shallow bedrock groundwater contributes to these resources.

Depending on topographic location and depth, the groundwater levels in local aquifers typically occur at depths ranging from less than 10 feet to over 50 feet. It is reportedly not uncommon to encounter artesian conditions in both the unconsolidated deposits and bedrock aquifers. As such, the depth to groundwater initially encountered during the drilling of a well may be significantly deeper than after the well is established. The existence of such conditions illustrates the hydraulic mechanism by which deeper formations can influence the water levels and flow in shallower formations and surface water bodies, as well as the corresponding water quality.

Characterization of groundwater flow in a watershed requires an assessment of the presence and significance of local, intermediate and regional flow regimes. A generalized diagram of the occurrence of these groundwater flow regimes in a typical watershed is presented in Figure 8. As shown, these flow regimes reflect the relative distances and depths groundwater flow travels from the point of recharge to the point of discharge and typical water-quality signatures (e.g., local flow regime dominated by bicarbonate type water). Groundwater will ultimately flow from higher to lower elevations within the respective flow regimes.

The recharge areas are characterized by downward groundwater flow while discharge areas are characterized by upward groundwater flow converging toward the ground surface. Local flow regimes are characterized by flow originating in upland areas and discharging to 1st and 2nd order streams, while regional flow regimes are characterized by flow that continues to move downward into deeper formations and move laterally over longer distances before moving upward, typically discharging into higher order stream valleys. The flow that is neither a part of the local flow regime nor the regional flow regime is characterized as being part of the intermediate flow regime.

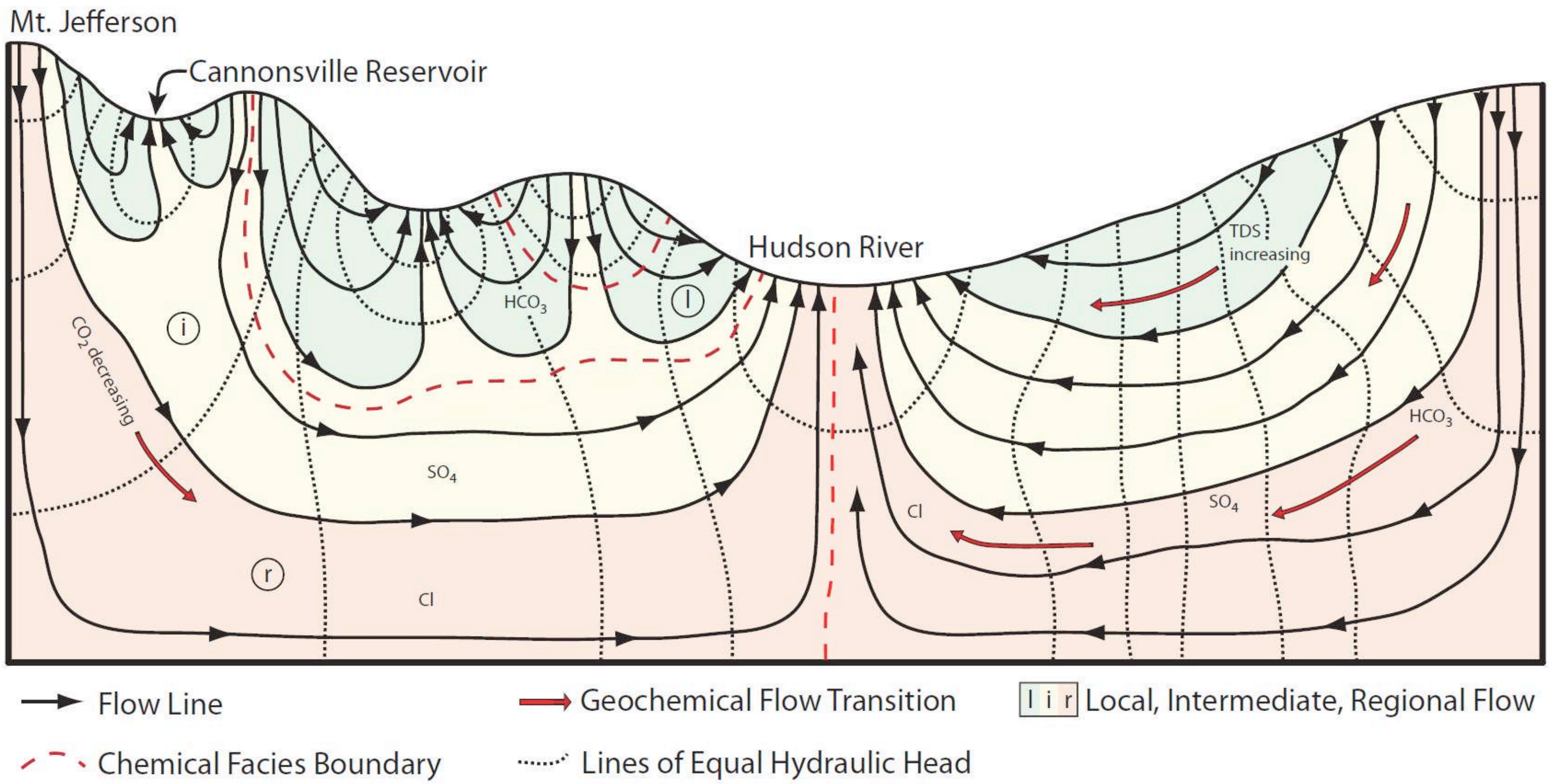

Figure 8: Conceptual representation of groundwater flow regimes

2.2.1 Study Area Flow Systems of the WOH Watershed

Based on the subsurface and geologic information gleaned primarily from available gas well logs and stratigraphic data[11,12,13,14,15,16,17] for the Region all three levels of flow regimes are anticipated to occur within the NYCDEP WOH watershed (Figure 5 and Figure 6). Recharge to the respective flow regimes occurs in the upland areas or headwaters of the individual watersheds (e.g., West Branch Delaware River or the East Branch Delaware River). Recharge to the uppermost, Late Devonian sandstone and shale units underlying the Region is initiated as downward flow through bedrock fractures exposed at the ground surface. Within local flow regimes, this recharge eventually discharges into the headwaters (1st and 2nd order streams) of the larger creeks (e.g., West Branch Delaware River, Schoharie Creek, etc.).

In the intermediate and regional flow regimes, recharge continues deeper through interconnected fractures into the shales and sandstones of the Middle Devonian formations. Some of this groundwater will discharge into the larger order streams, while some fraction will continue downward into the underlying Marcellus Shale. Groundwater flow occurring within the Marcellus Shale is not expected to discharge naturally to the surface within the Region but most likely outside of it in the valleys of major surface water bodies such as the lower (main stem) Delaware River or Hudson River. Because of its relative depth and related geologic conditions, any groundwater that has contacted the Marcellus Shale occurring in the Region is likely to exhibit high salinity and potentially contain dissolved natural gas.

Upward vertical migration through extensive, open fractures or an improperly sealed gas well can allow for the cross-formational migration of groundwater between flow regimes (i.e., short-circuiting). Such a migration can allow for the discharge of high salinity and gas enriched groundwater directly to the ground surface or into shallower (local or intermediate) flow regimes. Under these conditions, the discharged groundwater could occur at a considerable distance from the corresponding source area and formation.

---

[11] Bridge, J.S. and B.J. Willis. (1991). "Middle Devonian near-shore marine, coastal, and alluvial deposits, Schoharie Valley, central New York State." *New York State Geological Association Field Trip Guidebook*, pp. 131-160.

[12] Fisher, D. (1977). *Correlation of the Hadrynian, Cambrian, and Ordovician rocks in New York State*. State University of New York, New York State Museum Map and Chart Series Number 25.

[13] Griffing, D.H. and C.A. Ver Straeten, (1991). "Stratigraphy and depositional environments of the lower part of the Marcellus Formation (Middle Devonian) in eastern New York State." *New York State Geological Association Field Trip Guidebook*, pp. 205-249.

[14] Kreidler, W. L., A. M., Van Tyne, and K. M. Jorgansen. (1972). *Deep wells in New York State*. New York State Museum and Science Service; Bulletin Number 418A.

[15] Rickard, L. (1975). *Correlation of the Silurian and Devonian rocks in New York State*. State University of New York; New York State Museum Map and Chart Series Number 24.

[16] Rogers, W.B et al. (1990). *New York State Geological Highway Map*. University of the State of New York, New York Geological Survey, New York State Museum, Albany, NY.

[17] Soren, J. (1961). *The ground-water resources of Sullivan County, New York*. U.S. Geological Survey and State of New York Department of Conservation Water Resources Commission Bulletin GW-46.

2.3 Regional Hydrogeochemistry

The development of a conceptual hydrogeologic model for the Region not only requires an understanding of the geologic formations and comprising flow regimes, but also the related water quality conditions and influences. The shallow groundwater and surface water resources in the Region are generally replenished by water from relatively recent (within the last 1,000 years) and local precipitation events. Groundwater in the deeper underlying formations reflects recharge conditions associated with their respective geologic development (e.g., marine environment) and precipitation events occurring thousands to tens of thousands of years ago. These varied water-source origins and timeframes, along with the interaction between shallow and deep groundwater bearing formations and surface water bodies (flow regimes) help to form identifiable water-quality signatures that can be used as a tool for establishing natural baseline or background conditions.

The results of the literature and data review indicate groundwater quality in the Region is consistent with the conditions exhibited elsewhere in the Catskill Delta formation.[18] These conditions include the natural occurrence of groundwater with high (typically greater than 1,000 mg/l) levels of total dissolved solids (TDS) and hydrogeochemically developed gases such as methane and hydrogen sulfide. High TDS groundwater usually occurs at depths in excess of 1,000 feet below grade corresponding to intermediate and/or regional flow regimes, whereas methane and hydrogen sulfide occur at depths of more than several hundred feet below grade. In general, concentrations of these constituents tend to increase with depth.

2.3.1 Available Data

The baseline water quality conditions used to develop the hydrogeologic model of the Region were established using selected analytical data for locally collected groundwater and surface water samples. Data was obtained from the USGS[19] and the DEP,[20] and consisted of 678 surface water sampling locations, and 110 groundwater sampling locations (wells and springs). Of these locations, the analytical data for 94 surface water sampling locations and 84 groundwater sampling locations collected from 1959 through 2007 were utilized to determine the water quality baseline conditions in the Region. The geographic distribution of data points within the Region are presented in Figure 9.

The water quality data available from the USGS and DEP included analytical results for one to 250 analytes for the respective samples, as well as streamflow and well and spring completion information. Additionally, hydrogeologic and water quality data for Devonian bedrock units occurring outside of the NYC watershed area were used for comparison purposes. The concentrations of representative cations and anions were plotted on a trilinear (Piper) diagram and utilized to characterize baseline conditions considered most reflective of the naturally-occurring hydrogeochemistry of the geologic formations underlying the Region (Figure 10). Besides establishing baseline conditions, the Piper diagrams were also used to characterize the

---

[18] As documented elsewhere in New York, as well as Pennsylvania, West Virginia, Virginia, Ohio, and other Appalachian Basin states.

[19] U.S. Geological Survey. (2009). *National Water Information System (NWISWeb), USGS Water Quality Data for New York available on the World Wide Web at URL* http://waterdata.usgs.gov/ny/nwis/qw. Accessed on1/28/09.

[20] NYCDEP Watershed Water Quality Monitoring Data (1987-2008), provided by DEP, March 2009.

water quality conditions of the respective geologic units, and the influence of flow regime on water chemistry.

2.3.2 Surface Water Baseflow Chemistry

Surface water quality data corresponding to the lowest recorded flow measurements for the selected sample sites were considered to be reflective of baseflow conditions and used to determine whether a distinction in flow regimes was discernible based on corresponding stream-reach values. The trilinear diagram demonstrates that surface water from upper watershed areas are influenced primarily by local groundwater regimes, which is consistent with the conceptual hydrogeologic flow model (Figure 8). Therefore, it is anticipated that surface water samples collected from lower watershed areas (such as the lower Delaware or Hudson River) are reflective of influence primarily from intermediate and/or regional groundwater flow regimes. While there may be overlap between these two flow regime groups, the local regime will tend to be relatively higher in bicarbonate (HCO_3) while the intermediate regime will tend to be relatively higher in sodium, potassium and chloride. This difference is in part reflective of the influence of distance on the respective contributing groundwater flow paths.

2.3.3 Groundwater Geochemistry

The plotted groundwater data for selected sample locations in the Region and from several nearby areas northwest of the Region exhibit clustering reflective of geologic formations and their respective flow regimes.[21] Samples from the deeper bedrock formations[22] (e.g., the Ordovician/Silurian) generally exhibit cation and/or anion concentration relationships associated with the comprising rock mineralogy (i.e., lithologically controlled) and intermediate/regional flow influences (e.g., relatively high calcium and bicarbonate concentrations). Samples from the shallower bedrock units (i.e., Late Devonian) exhibit influences associated with the corresponding depositional environment (marine) from both the deeper (Hamilton Group) intermediate and local flow regimes. The samples from overburden aquifers tend to exhibit distinctive plot locations reflective of local flow regimes.

---

[21] Toth, J. (1980). "Cross-formational gravity-flow of groundwater: a mechanism of the transport and accumulation of petroleum (the generalized hydraulic theory of petroleum migration)." *Problems of Petroleum Migration*: American Association of Petroleum Geologists Studies in Geology Number 10, p. 121-167.

[22] Kantrowitz, I.H. (1970). *Ground-water resources in the eastern Oswego River Basin, New York*. Prepared for the Eastern Oswego Regional Water Resources Planning Board. State of New York Conservation Dept. Water Resources Commission, Basin Planning Report ORB-2.

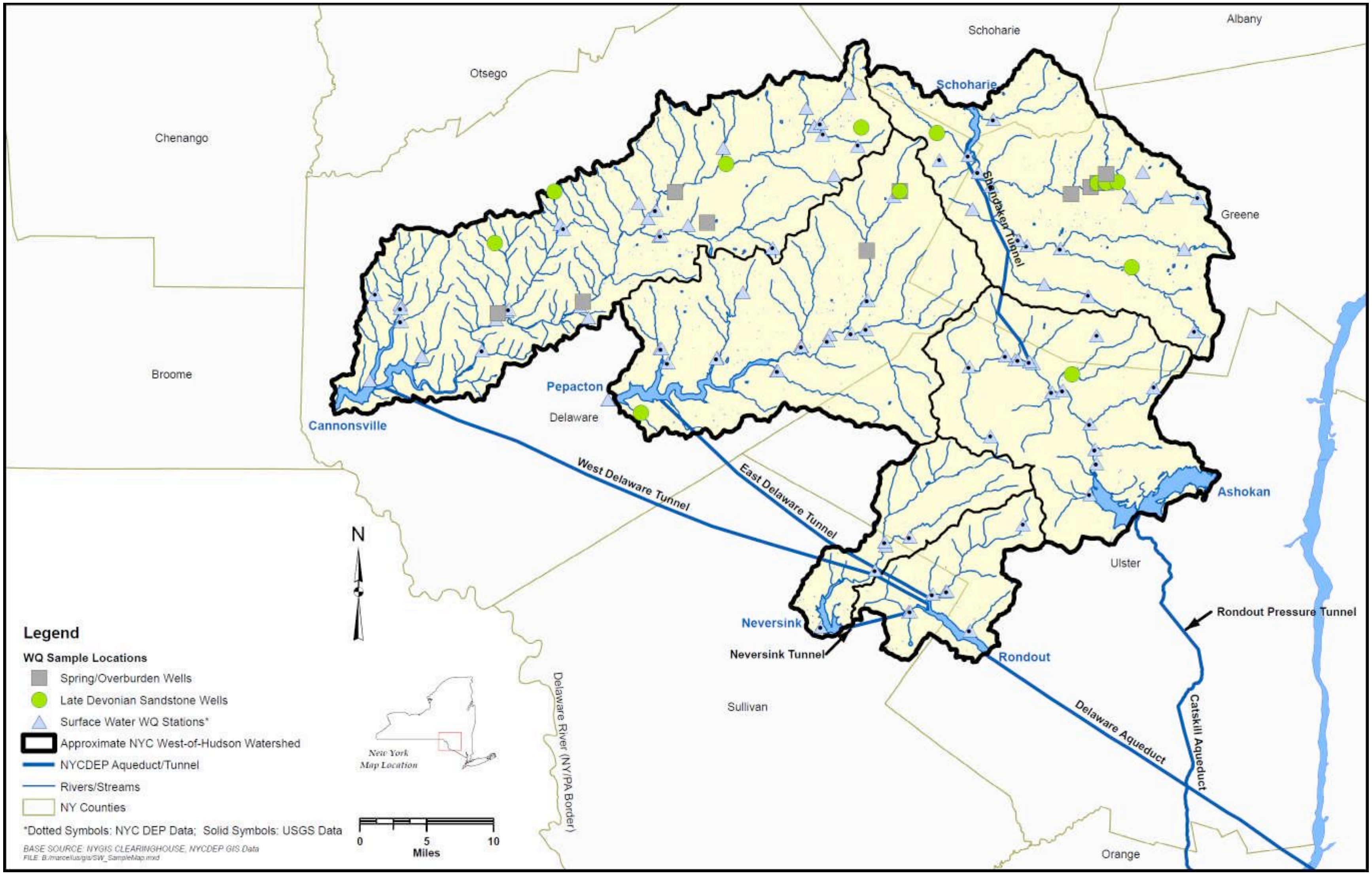

Figure 9: Water quality sample location map

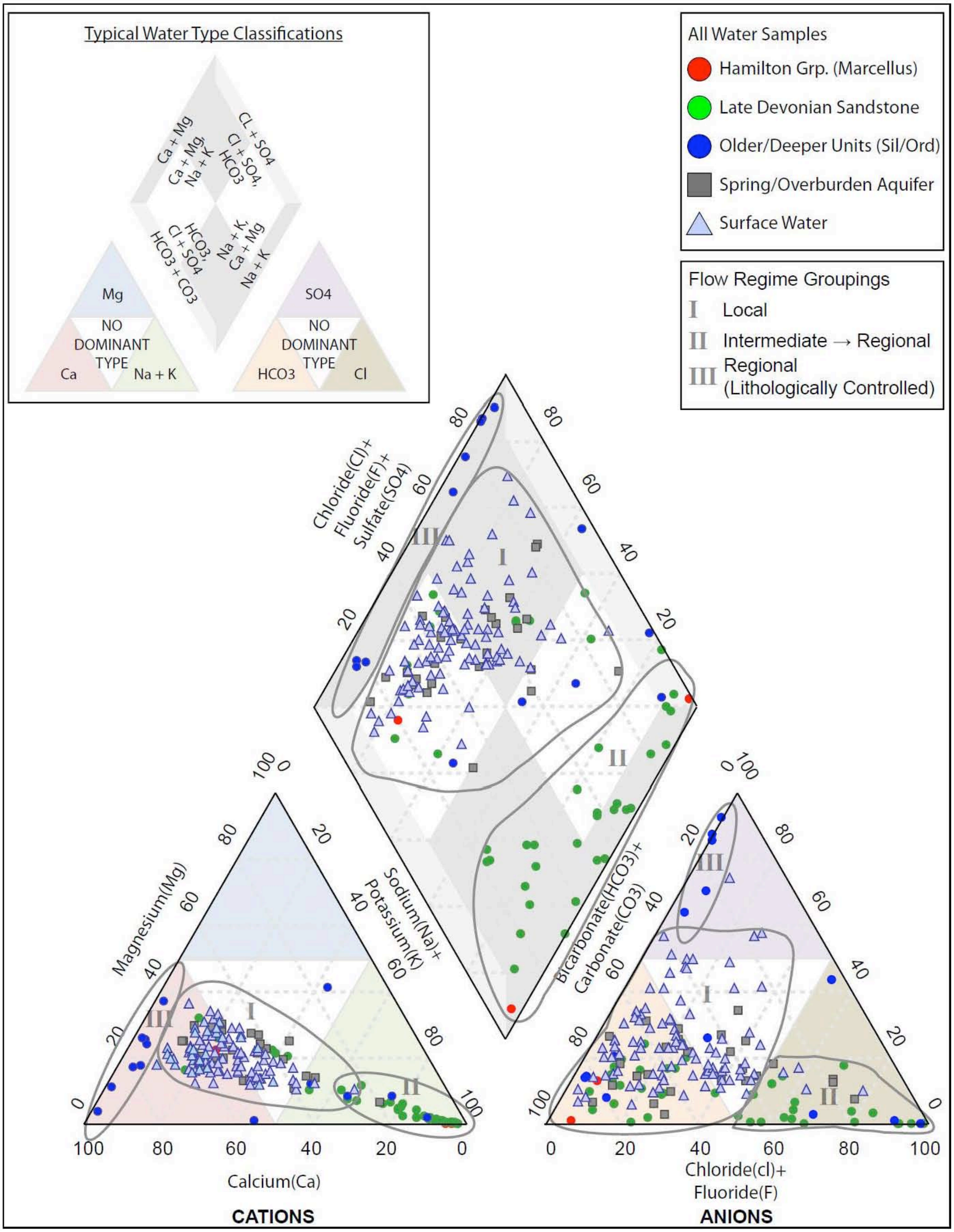

Figure 10: Trilinear diagram

2.3.4 Water Quality Signatures

By comparing the surface water and groundwater data on the trilinear diagram, water-quality signatures can be established for the corresponding water sources in the Region. Based on this graphical comparison of data, the surface water quality under baseflow conditions generally reflects that of groundwater in the overburden (glacial deposits), springs, and to some degree groundwater in the Late Devonian (upper) bedrock formations. As such, the quality of these sources is considered to be typical of the local flow regimes in the Region, and not that of the deep bedrock formations. Based on the trilinear diagram, the surface water and overburden quality signatures tend to be characterized by high calcium and bicarbonate concentrations, while groundwater in the Devonian bedrock formations tends to be characterized by high sodium and potassium with calcium and magnesium. Conversely, the samples that correlate with the deeper or older bedrock units (Silurian and Ordovician aged) tend to exhibit high sulfate and calcium concentrations with sodium and potassium as controlled by the mineralogy of the contributing units.

Based on these observations, it is anticipated that influences from deep groundwater on the surface water and shallow groundwater could result in detectable changes in water quality. Utilization of the respective signatures for comparison purposes can provide a useful method for assessing the future impacts of migrating deeper groundwater on local aquifers and water bodies.

Section 3: Natural Gas Development Activities and Potential Impacts

The purpose of this section is to describe natural gas development activities and identify potential impacts to water quality, water quantity, and water supply infrastructure. Information contained in this section is drawn from a review of available industry standard practices, state and federal regulations, academic and geologic research, gas drilling experiences in other states, and team experience. These sources were used to catalog the activities that may be involved in development of natural gas resources in New York and to identify the potential impacts of such on the NYC water supply system. Primary categories of activities described in this section include:

- Well siting
- Well drilling
- Well development/stimulation
- Well completion/gas production
- Wastewater/chemical management
- Gas transmission
- Well rehabilitation and secondary recovery
- Well closure

The subsections below provide a description of each of these activities, followed by a discussion of potential impacts.

3.1 Well Siting

Well siting refers to the series of activities involved in selecting and establishing a gas-well drill site.

Aerial Mapping

Aerial mapping is an investigative technique used by gas and oil development companies in which surface and subsurface features are recorded from aircraft for the analysis of a variety of attributes, including:

- Subsurface geologic features (e.g., gravitational and magnetic anomalies);
- Surface geologic features (e.g., fracture traces);
- Topography; and
- Hydrography.

Seismic Testing

Seismic testing is a technique used to acquire subsurface information (e.g., thicknesses of underlying geologic units, locations of geologic contacts and faults, etc.). Seismic investigations consist of introducing seismic energy into the ground and recording the migration of the generated seismic waves. Seismic energy can be introduced into the ground using explosives, manual equipment, heavy equipment or other similar methods. Oil and gas exploration relies primarily on heavy equipment (e.g., thumper trucks, Figure 11), which can cover large distances in remote areas relatively quickly. Seismic testing using explosives placed in shallow (30 – 100') shot holes may also be used in some locations. No estimate is available for the amount of testing that may be required to map the Marcellus Shale.

Figure 11: Thumper truck used for seismic testing

Leasing and Property Acquisition

A professional called a “landman” is hired by exploration companies to acquire leases of mineral rights from landowners. The leases they offer are private contracts, which grant rights and place obligations on both the lessor (i.e., the landowner) and the lessee (i.e., the oil and gas company). An oil and gas lease may include specific terms for the safety of crops, buildings, and personal property along with reclamation plans for damage from access roads, storage of equipment, and drilling sites, but does not transfer ownership of the property. Because these contracts are negotiable, it is incumbent on the lessor to ensure that any lease is carefully reviewed and negotiated by the landowner before it is signed. The DEC does not regulate private agreements between landowners and operators.

Key lease components include an up-front payment for signing the lease (i.e., signing bonus), the number of years the lease will be in effect (primary and secondary terms), and the landowner’s share of the production revenues (referred to as the royalty). A primary term lease typically lasts from one to ten or more years. The secondary term is an extension beyond the primary term if a well is drilled or if the lease is pooled with other neighboring leases to form a unit for a producing well. The lease can also be structured so that it expires when the productive life of the well ends. Royalties are generally 1/8 of the revenue from oil and/or gas produced and sold. A shut-in royalty is payment in lieu of a production royalty if the well is capable of production but is kept off-line by the operator.

The area of land assigned to a well is called a spacing unit. The spacing unit roughly correlates to the area of land from which the gas well is assumed to be extracting product. The Environmental Conservation Law (ECL) establishes criteria for spacing unit sizes and how close the well can be to the unit boundaries. The typical spacing unit allowed for a horizontal shale gas well in New York is 40 acres. For multiple wells drilled from a common pad a spacing unit of up to 640 acres (1 square mile) is allowed. DEC anticipates the current spacing unit law will result in at most 16 wells per square mile.[23] Horizontal wellbores must be separated by at least 660 feet and all wellbores must be located 330 feet from the spacing unit boundary.[24,25]

In some cases, a spacing unit assigned to a proposed gas well may encompass acreage that is not owned or leased by the well operator. ECL §23-0501(2) requires that an applicant control 60% of the acreage within a spacing unit to apply for a drilling permit. Any land not controlled by the applicant is subject to the regulations for the compulsory integration process as stated in ECL §23-0901(3). The DEC will not issue permits for wells with proposed spacing units that create stranded acreage and cannot be developed. Until a well permit is issued, there is no certainty about where a well will be drilled or what the spacing unit will look like.

State-owned lands may be leased for oil and gas development and underground gas storage under the provisions of ECL Article 23, Title 11. State lands within the Catskill Park may not be leased without a constitutional amendment. The DEC Division of Mineral Resources acts as the leasing agent for large tracts of state land and works with State surface managers to identify areas suitable for leasing and develop area-specific conditions to provide for safe and environmentally sound exploration and development.

Figure 12: Network of drill pad sites in the Haynesville Shale region of Louisiana

Site Access

Once a suitable site is selected, a network of unimproved roads must be established to provide access to drilling sites from existing roads (Figure 12).

Drill Pad Construction

The drill pad accommodates the drill rig, support trucks, waste storage, worker housing[26], fluid tanks, field office, generators, pumps and other necessary equipment. Drill pads are on the order of one to five acres in size, depending on the type of drilling method and extent of ancillary facilities. Construction of the drill pad typically requires clearing, grubbing, and grading, followed by placement of a base material (e.g., crushed stone). Drill pads typically have constructed pit(s) to handle drill cuttings, drilling

---

[23] The ECL was amended with respect to spacing units in July 2008 and horizontal wells have not been permitted while the SGEIS is being developed. Therefore DEC has no data on the potential density of shale gas wells in the region.

[24] NYSDEC. (1992). *Final generic environmental impact statement on the oil, gas and solution mining regulatory program (GEIS)*. New York State Department of Environmental Conservation Division of Mineral Resources, Albany, NY.

[25] Regulations stipulate that variances are possible from these and other rules related to well density, spacing, and setback limits.

[26] Drilling activities typically occur around the clock; therefore personnel may be housed at the drill site in temporary facilities. This requires additional area for parking, housing, dining and toilet facilities.

fluids, and fracturing fluids. Additionally, per the 1992 GEIS, erosion and sediment control plans are required for all drilling in drinking water reservoir watersheds.

3.1.1 Potential Impacts

Seismic Testing

Most seismic testing in the Catskill region is expected to be completed using thumper trucks. Thumper trucks (weighing from 3 tons to 30 tons) and/or other heavy equipment employed in seismic testing are anticipated to increase over-the-road and off-road traffic. Seismic energy released during testing can range from 2,000 to over 100,000 foot-pounds and could potentially be a threat to nearby shallow infrastructure.

For testing using explosives, improper storage, handling, or disposal could result in surface water contamination or injury or death of well drilling personnel. Possession, storage, use and transport of explosives is regulated in New York State by the Department of Labor, Division of Safety and Health, which requires various permits, licenses and certifications for personnel working with explosives. Once detonated below ground, explosive charges may leave behind toxic residues that could migrate to groundwater.

Leasing and Property Acquisition

Leasing and property acquisition could impact DEP's Land Acquisition Program in several ways. Potential natural gas discoveries could drive up land costs and make property more expensive for DEP, thus reducing the purchasing power of available land acquisition funds. Land owners may also be less willing to sell their property if there is an opportunity to lease the mineral rights and receive a bonus or royalty payment.

Site Access and Drill Pad Construction

Clearing, grubbing, and excavation/grading for access roads and drill pads may contribute to soil erosion and habitat destruction. Sites and access roads located near streams or wetlands, in hilly terrain, or close to other sensitive areas are of particular concern.

Once the drilling process is underway, substantial heavy truck traffic can be expected for the duration of drilling and stimulation operations. High volumes of heavy truck traffic may damage roads, bridges and utility lines located underneath roadbeds.[27] Site erosion and habitat destruction could affect surface water quality. Maintenance of access roads may include dust suppression; improper use of fluids or chemicals for dust suppression may pose a hazard to surface water or groundwater.

3.2 Well Drilling

Well drilling refers to the series of activities involved in drilling and establishing a gas-well, including setting, grouting and preparing casings.

---

[27] Normal trucking weights are generally limited to 80,000 lbs of gross vehicle weight for interstate and other designated highways. Routine oversized loads can weigh as much as 132,000 pounds and require an additional permit. Special oversized loads can weigh up to 200,000 pounds and require police escorts and special permits.

Drilling

This refers to the actual drilling of the borehole that serves as the gas well (Figure 13). In order to deliver and assemble the drill rig, on the order of 40 trucks may be required to haul in the equipment needed for the rig construction and support operations. Well drilling is typically conducted around the clock by a team of two to four individuals (driller and helpers) and is completed over the course of several weeks. Pre- and post-drilling related activities may take a month or more. Actual drilling duration and personnel will depend on individual drillers and the nature of the formation.

A well driller must obtain a permit from DEC and commence drilling activities within 180 days of permit issuance. Local governments and any landowner whose surface rights will be impacted during operations must be notified at least five days before drilling activities begin. DEC must also be notified immediately prior to commencing drilling operations.

Gas wells that target the Marcellus Formation will typically be advanced to a depth of approximately 3,000 to 7,000 feet and will typically include a vertical segment and a horizontal segment (i.e., lateral), which would be located in the target formation (i.e., the Marcellus). Typical well bores are on the order of 8 to 12 inches in diameter. The well bore may be larger at the surface, up to 36 inches in diameter, to accommodate multiple casings (Figure 14). Rotary rigs are the only type of drilling machinery capable of performing horizontal drilling. Rotary rigs require drilling fluids to lubricate and cool the bit while flushing cuttings to the surface and stabilizing the borehole. Drilling fluids are pumped into the borehole from orifices in the drill bit and collected upon issuance out of the hole. Given the depth of the Marcellus Shale, tens to hundreds of thousands of gallons of cuttings and formation fluids can be expected to be generated during the drilling process.

Figure 13: Well drilling operation

In order to advance the borehole from the vertical run to the lateral run, the drill string is removed and changed out with a drilling motor equipped with measurement instrumentation, which allows the 90° angle to be built. The point at which the angle begins is commonly referred to as the kickoff point. Approximately 1,200 feet of vertical distance is required to create the 90° angle. Once the horizontal borehole is achieved, advancement of the lateral continues. Lateral distances of 2,000 to 6,000 feet are not uncommon.

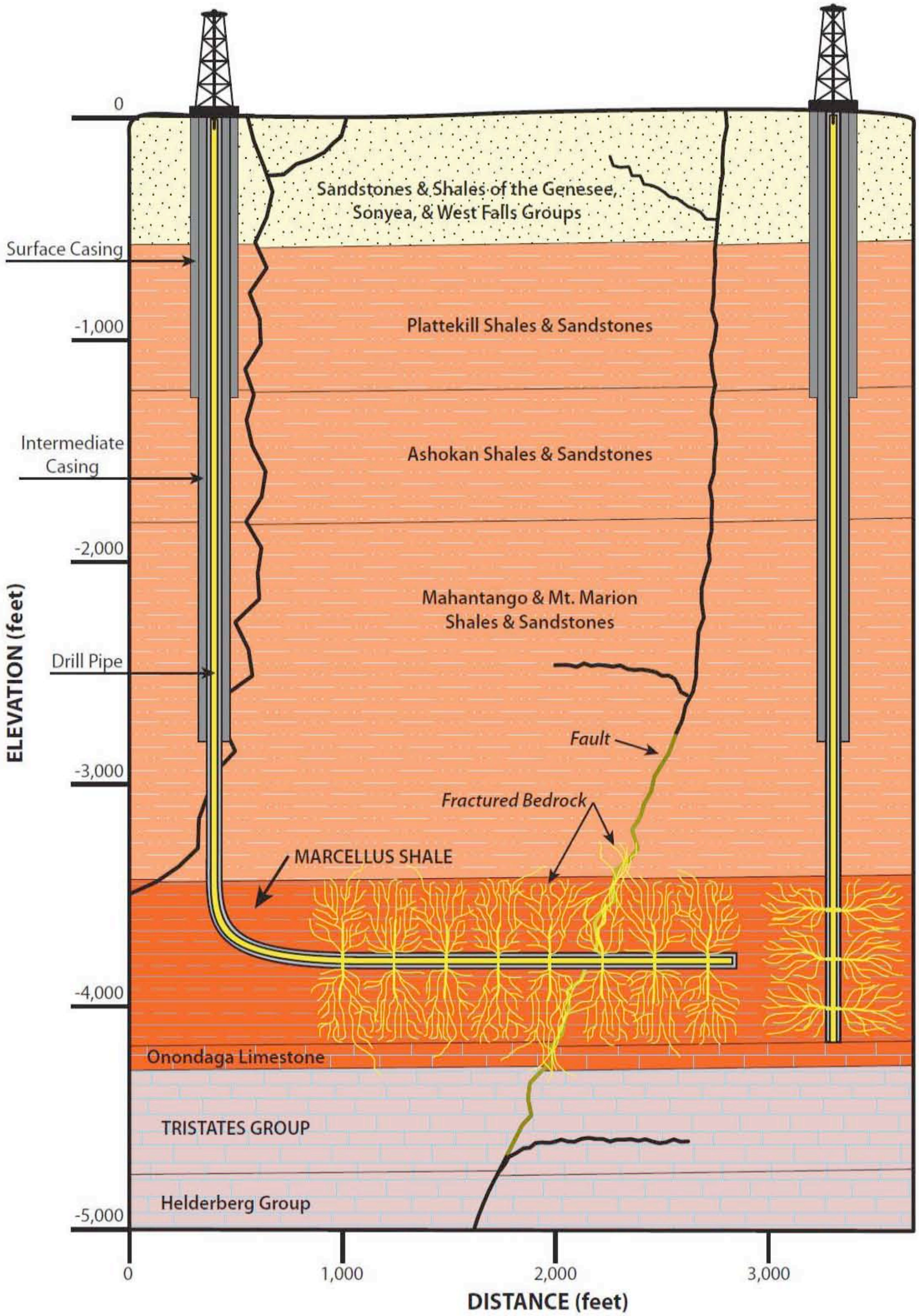

Figure 14: Generic drilling, casing, and fracturing of horizontal and vertical gas wells (thickness of Marcellus Formation exaggerated for clarity)

Multiple laterals can be constructed in different directions from a single drill pad.[28] This is typically done by moving the rig several yards and advancing a new vertical shaft and lateral run. A less common technique, multilateral drilling, allows for the advancement of two to three laterals from a single vertical shaft.

Feasible lateral lengths for horizontal well drilling technology and the current New York well spacing requirements (1 pad per 40 acres for single wells and 1 pad per 640 acres for multiple wells), will permit virtually full coverage of the below-grade formation, thereby maximizing recovery of natural gas resources.

Drilling Fluid Composition and Management

Drilling fluid (mud) is typically a mixture of bentonite clay and water, plus a variety of other chemicals (e.g., lubricants, surfactants, defoamers, detergents, polymers, emulsifiers, stabilizers, dispersants, flocculants, etc) used to control fluid properties. The types and volumes of chemicals that could be used for wells in the Marcellus are difficult to estimate. There is a lack of substantial industry experience with this formation and operators generally do not reveal specific drilling fluid formulas.

A conventional drilling fluid management system consists of open pits that collect waste drilling mud that is typically not recirculated back into the well bore. A closed loop system, on the other hand, includes treatment processes that treat the used mud during drilling to remove solids and contaminants before recirculating the mud back into the well-bore. Closed-loop systems typically use tanks, have less risk of spills, use significantly less water and require less waste hauling once drilling operations are complete. Water treatment using closed-loop systems does not treat the water to potable standards. The drilling wastewater still contains contaminants that require the same treatment and disposal practices as other drilling wastes. Operators may use hybrid systems that have conventional and closed-loop elements depending on site conditions and state regulations.

Well Casing

Well casings provide support for the well bore and serve to maintain isolation of the formations penetrated by the well. The casing consists of steel pipe with cement or grout injected between the pipe and the well bore to prevent the movement of fluids or gases within the annular space. Three or four casings are typically installed in the well as it is drilled:

- Conductor Casing: The conductor casing is a short casing that prevents surface material from entering the well. The conductor casing is set 20 to 40 feet deep, either by placement within the drilled well bore or by driving the casing directly into the soil. The casing is then cemented to prevent surface water from entering the ground. Once the cement has set, the well can continue being drilled.
- Surface Casing: The surface casing seals off the fresh water zone. DEC regulations require drilling to advance the initial vertical run of a gas well to at least 75 to 100 feet below the base of the deepest fresh water aquifer and at least 75 to 100 feet into bedrock.[29] This drilling must use air, fresh water or fresh water mud. Additionally, surface casings cannot terminate

[28] The spacing unit increases up to 640 acres for multiple vertical wells from a single well pad.
[29] Larger depths are required in areas of primary and principal aquifers.

in zones containing shallow natural gas deposits. After drilling, the drill string is extracted and surface casing is inserted to the bottom of the boring. Once the surface casing is set, it is grouted in place with a cement mixture that is pumped down through the casing and up and out of the annulus.

- Intermediate Casing: Intermediate casing can be used to seal off saline aquifers or oil/gas bearing strata, or to stabilize particularly friable bedrock units or units with substantial voids. Intermediate casing is installed in a similar manner as the surface casing.
- Production Casing: Production casing transfers hydrocarbons from the formation to the surface. After the vertical and lateral runs have been completed, the drill string is removed for the last time and geoscientists log the open well to collect data relevant to the formations' transmissivity, hydrocarbon content, etc. When the logging is complete, production casing is inserted within the surface and intermediate casings along the full length of the boring. Once this casing is set, it is grouted in place with a cement mixture that is pumped down through the casing and up and out of the annulus. A temporary wellhead is then installed and the drill rig is dismantled and removed from the site.

Naturally Occurring Radioactive Material

The Marcellus Shale is a radioactive formation, and during drilling and stimulation operations naturally occurring radioactive material (NORM) may be brought to the surface. Additionally, as equipment comes in contact with NORM, residues can build up to potentially higher concentrations than in the original formation. Referred to as technologically enhanced NORM (TENORM), it typically occurs on drilling equipment, pipelines, waste treatment facilities, etc.

New York State has no specific laws regulating NORM/TENORM differently than any other non-radioactive drilling waste. In 1999 the DEC Division of Solid and Hazardous Material commissioned a study to evaluate the potential hazards of NORM/ TENORM from drilling operations. The study determined there were no adverse impacts to human health from NORM/ TENORM due to typical activities or disposal practices. However, the Marcellus Shale was not included in the list of formations tested. The SGEIS final scope indicates it will include analysis of NORM data from the Marcellus Shale to determine if any special precautions are required.

Proper casing and grouting are essential for maintaining the structural integrity of the well, preventing movement of water, chemicals, and hydrocarbons between formations, and preventing groundwater contamination. Operators are required to test the materials used for casing operations (cement, mix water, casing pipe strength, etc.), maintain records of the volume of cement used for casing installation, and present the records to the DEC if requested. State inspectors are to be notified prior to casing operations. However, the operator can install the casing without the inspector present, unless the well is in a primary or principal aquifer. Drilling operations must cease while the casing cures and the cement reaches the minimum required compressive strength. Casing integrity can be tested using various techniques (e.g., cement bond logs or variable density logs) but is not required in New York.[30]

The Division of Mineral Resources conducts inspections before a well is drilled, during operation, and after the well is abandoned. A monitoring program may also be implemented that

---

[30] U.S. Department of Energy, Office of Fossil Energy. (2009). *Modern Shale Gas Development in the United States: A Primer*, prepared by the Ground Water Protection Council and ALL Consulting, Washington, DC.

is designed to prevent pollution, prevent the wasting of resources, protect groundwater, etc. The Division of Mineral Resources also stipulates that the well must be plugged and the site reclaimed at the end of operations.

3.2.1 Potential Impacts

The depths of gas wells in the Marcellus Shale are expected to require drilling through the fresh water aquifer, and may result in contact with saline aquifers or formations that contain hydrocarbons, heavy metals, radionuclides or other potential contaminants.[31,32] Casing or grouting failures from inadequate grouting, pipe corrosion, poor quality cement, or improper curing could create pathways for contaminants and cause groundwater or surface water contamination. Additionally, drilling fluids and contaminated formation material require proper storage and disposal to prevent accidental releases that may lead to surface water or groundwater contamination. Drilling impacts also include the slight but real potential for inadvertent penetration of a NYCDEP tunnel or aqueduct during vertical or horizontal drilling operations.

3.3 Well Development/Stimulation

Well development and stimulation refers to the series of activities required to prepare a completed well for gas production.

Production Casing Perforation

Once the production casing is set and the drill rig has been removed, service crews begin the process of perforating the lateral well casing. Perforation is designed to create a series of small holes in the casing (approximately 0.5 inches in diameter) that penetrate into the formation (approximately six to fifteen inches) and allow fracturing fluid to enter the formation from the well bore.

The goal of the perforation process is to create as deep an opening as possible into the formation without leaving behind debris that may inhibit the flow of gas into the well bore. Jet perforation using various high-grade explosives is the most common perforation method. Explosive charges are designed based on formation pressures, formation material and well bore pressures.

Hydraulic Fracturing

Hydraulic fracturing (Figure 14, Figure 15) is a method by which the gas-bearing formation is stimulated to increase its permeability/gas production rate. Typical lateral lengths of 2,000 to 6,000 feet are expected for the development of gas wells in the Marcellus. Laterals may be fractured in multiple stages using temporary plugs to isolate individual sections. The fracturing operation requires on the order of four to ten days depending on the length of the lateral.

---

[31] Hill, D.G., T.E. Lombardi, and J.P. Martin. (2004). "Fractured shale gas potential in New York." *Northeastern Geology and Environmental Sciences*. Vol. 26 (1/2) pp. 57-78.

[32] NYSDEC. (1999). *An investigation of naturally occurring radioactive materials (NORM) in oil and gas wells in New York State*. New York State Department of Environmental Conservation Division of Solid & Hazardous Materials Albany, NY.

The first step in the process is injection of an acid solution to remove residue from drilling and perforation. Fracturing fluid (described in more detail in Section 3.4) is then pumped into the wellbore and pore space at very high pressures that are designed to be larger than the fracture gradient of the formation rock to induce fracturing.[33] As the formation cracks, fluid is forced further into the formation, thereby extending the fractures until equilibrium is reached between the fracturing pressure and the sum of internal stresses. The orientation of fracture propagation is typically perpendicular to the minimum principal stress because it is the weakest path; this generally results in vertically oriented fractures for deep formations.

Figure 15: Horizontal gas well hydraulic fracturing operation

Once the formation has been opened, a series of proppants are injected into the formation to widen fractures and hold them open during production.[34] Proppants typically consist of sand or other inert minerals (e.g., coated sands, sintered bauxite, zirconium oxide, or ceramic materials). Resins, glass or other fibers are employed to hold the proppants in place so they will not flow back into the bore. After the proppant sequence the well is flushed with clean water to remove excess proppants and chemicals. Flowback of fracturing fluids may account for 30 to 70% of the original fracturing fluid volume, and may occur over the course of several weeks.[35]

The large volumes of fracturing fluid (on the order of millions of gallons) and proppant (tens to hundreds of cubic yards) required for the hydraulic fracturing process are typically stored at the wellhead. In New York State lined open pits or lagoons are required to store fluids. Closed tanks can be used but are not required. DEC is evaluating in the SGEIS the potential benefits of closed tanks.

3.3.1 Potential Impacts

Improper storage, handling, or disposal of perforation explosives could result in surface water contamination and injury or death of well drilling personnel. Possession, storage, use and transport of explosives is regulated in New York State by the Department of Labor, Division of Safety and Health, which requires various permits, licenses and certifications for personnel

---

[33] The fracturing fluid pressure gradient is typically on the order of 0.6 to 0.8 psi/ft of depth, which requires between 5,000 and 20,000 psi of pumping pressure at the surface.

[34] Arthur, J.D., Bohm, B., Layne, M. (2008). *Hydraulic fracturing considerations for natural gas wells of the Marcellus Shale*. Presented at the Groundwater Protection Council - 2008 Annual Forum, Cincinnati, Ohio September 21-24, 2008.

[35] Arthur, J.D., B. Langhus, and D. Alleman (2008). *An overview of modern shale gas development in the United States*. ALL Consulting, Tulsa OK. Retrieved from http://www.all-llc.com/shale/ALLShaleOverviewFINAL.pdf.

working with explosives. Once detonated below ground, the explosive charges may leave behind toxic residues that could migrate to groundwater or be brought to the surface with extracted gas.

Fractures created during stimulation could potentially propagate beyond the target formation or enhance the permeability of an existing feature (such as a fault), resulting in communication between the target formation and other formations and subsequent contamination of groundwater and surface water. Changes in subsurface geologic characteristics may also impact the structural integrity of water supply infrastructure (e.g., dams, tunnels, and aqueducts) and could potentially allow contamination of tunnels or aqueducts. The SGEIS scope indicates that DEC will review methodologies for containment of fractures within a target formation.

3.4 Fracturing Fluid – Chemical Composition

Fracturing fluids are a mixture of water, proppant (sand), and chemical additives. Fresh water is generally required for fracturing fluids because of the need to control fluid properties; high TDS water such as brine is not typically used.[36] Water and sand have been reported to comprise over 98 – 99.5% of the fracturing fluid mixture, with the remaining ~0.5 – 2.0% consisting of an array of chemicals used to control fluid properties during the various stages of the fracing process.[37,38,39] Though the proportion of chemicals in fracturing fluid is low, it is nonetheless significant due to the potential toxicity of the constituents it may contain. As a point of reference, raw wastewater entering a wastewater treatment plant is also approximately 99% water.

3.4.1 Potential Impacts

Fracturing fluid chemicals introduced into the subsurface environment during the hydraulic fracturing process are not fully recovered; recovery rates are reported to be on the order of 30 – 70%.[40] During or after fracturing, chemicals in fracturing fluid may contaminate groundwater supplies by migrating beyond the fracture zone via a number of pathways (e.g. naturally occurring existing fractures, propagation of induced fractures beyond the target formation, casing failures). Chemicals that reach shallow groundwater supplies could ultimately enter surface waters flowing into NYC reservoirs, thereby introducing toxic chemicals into the NYC water supply.

Fracturing chemicals may also be introduced to the environment via improper handling of fluids at the surface. Exposure to fracturing fluids without proper protective equipment can present a health hazard to well drilling personnel, emergency workers, and others. DEC is evaluating in the SGEIS the potential for alternative fracturing fluids that are less toxic.

---

[36] Brine water may be used in some limited circumstances depending on properties of the formation. Additionally, some companies have developed fracture fluid mixtures designed for use with high TDS produced water.

[37] Arthur, J.D., B. Bohm, B.J. Coughlin, and M. Layne. (2008). *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs*. ALL Consulting, Tulsa OK.

[38] Fortuna Energy (2009). *Marcellus Natural Gas Development*. Presented at NYWEA 2009 Spring Technical Conference, West Point, NY, June 2, 2009.

[39] U.S. Department of Energy, Office of Fossil Energy. (2009). *Modern Shale Gas Development in the United States: A Primer*, prepared by the Ground Water Protection Council and ALL Consulting, Washington, DC.

[40] U.S. Department of Energy, Office of Fossil Energy. (2009). *Modern Shale Gas Development in the United States: A Primer*, prepared by the Ground Water Protection Council and ALL Consulting, Washington, DC.

Fracturing Chemicals

Fracturing fluids contain chemical additives used in a wide array of specially formulated products selected to control various fluid properties during the drilling and fracturing process. Major types of products that may be used include:

- Biocides: Inhibit the growth of microbes and bacteria
- Stabilizers: Act to retain the formation particles in position
- Corrosion Inhibitors: Adsorbs on metal surfaces and stops the electrochemical process of corrosion
- Defoamers: Useful in any application where foam is undesirable
- Demulsifier: Accelerate the separation of water and oil
- Emulsifier or Gellant: Used to stabilize solutions and prevent separation
- Foaming Agent: Used in preparation of foam used as a drilling fluid
- Friction Reducers: Used to reduce the friction forces on drilling equipment in the wellbore
- Iron Control: Stabilize or prevent the precipitation of damaging compounds by keeping ions in soluble form
- Non-Emulsifiers: Used to prevent emulsions from forming (i.e., maintain separation of mixture constituents)
- pH Control: a buffer mixture to maintain constant or almost constant pH of the system
- Scale Inhibitor: dissolves and removes acid insoluble mineral scales (e.g. barium and calcium sulfate
- Solvents: used to dissolve other materials
- Surfactants: Reduces surface tension and is amphiphilic (both hydrophobic and hydrophilic)

A database of fracturing products and chemicals developed by The Endocrine Disruption Exchange (TEDX, Paonia, Colo.) was reviewed to develop a preliminary understanding of the chemicals that could potentially be introduced into the watershed during drilling and fracturing operations. Product and chemical information in the TEDX database was derived primarily from the following sources:

- Material Safety Data Sheets (MSDS);
- Emergency Planning and Community Right-to-Know Act (EPCRA) Tier II reports;
- Environmental Impact Statement and Environmental Assessment Statement disclosures;
- Regulatory documents; and
- Accident and spill reports.

The database identifies 435 products composed of over 340 individual chemical constituents. Very little is known about most products: the exact chemical composition of over 90% of the products in the database is unknown. Of the known constituents, many are recognized as hazardous to water quality and health (e.g., benzene, xylene, ethylene glycol, diesel fuel, etc.), and many are associated with a wide array of negative health effects (e.g. impairment to endocrine, respiratory, gastrointestinal, liver, kidney, brain, cardiovascular, or nervous systems).

The database does not provide a comprehensive list of all products and chemicals that are used in natural gas development or could potentially be used in the Marcellus Shale. Development of a comprehensive database is not possible due to the proprietary nature of products used, trade secret laws, and the lack of regulations requiring disclosure of products and their composition. Therefore, the information in the database is indicative of the types of chemicals that could potentially be introduced into the NYC watershed during natural gas development activities.

These data limitations highlight the need for full disclosure of the products used during hydraulic fracturing (e.g. product name, manufacturer, exact chemical composition) to enable DEP to develop appropriate monitoring programs, maintain water quality, protect the safety of first responders, and plan for emergencies.

3.5 Fracturing Fluid – Water Withdrawals

In order to produce the hydraulic fracturing fluid needed for gas well stimulation, substantial volumes of water are required. The volume ranges from three to nine[41] million gallons per well and varies based on well construction methods, fracturing techniques, and lateral length, among other factors. This water may be obtained from surface or groundwater sources.

DEC currently only requires permits for water withdrawals for public community supplies, and would not require a permit for withdrawals for drilling or fracturing operations. Withdrawals not regulated by the DEC may potentially be limited as part of the SEQRA process, based on the reported potential to impact local water resources and local land use concerns. Such limitations, if any, would depend on interpretation of common law in New York.[42]

DRBC requires approval for surface or groundwater withdrawals within the Delaware Basin.[43] However, there is no regulatory agency with the authority to limit withdrawals in the Hudson Basin, which includes Schoharie, Ashokan, and Rondout watersheds.

3.5.1 Potential Impacts

Excessive surface withdrawals could reduce inflow to NYC reservoirs, reduce storage available for diversion, and decrease the probability of refilling reservoirs prior to drawdown. Excessive groundwater withdrawals could deplete aquifers, resulting in reduced baseflow in watershed streams or wetlands. The severity of such impacts would depend heavily on the total amount of withdrawals from the West of Hudson watersheds, as well as the timing of such withdrawals. Withdrawals during periods when reservoirs are spilling would have little or no impact on supply reliability. In contrast, sustained withdrawals during periods of drought or extended drawdown could decrease the probability of refilling reservoirs and increase the probability of entering into a drought condition (i.e., watch, warning, or emergency).

Excessive withdrawals could also impact system operations by requiring increased releases to meet regulated flows in streams. For example, water withdrawals downstream of Pepacton, Cannonsville, or Neversink Reservoirs could necessitate additional releases to satisfy Delaware Basin release requirements. Similarly, withdrawals from the Upper Esopus Creek could require increased releases from Schoharie Reservoir to meet Part 670 Esopus Creek minimum flow requirements.

The final scope for the SGEIS indicates that DEC will evaluate cumulative impacts to aquifers, drinking water supplies and streams from withdrawals for natural gas development. DEC will also review existing regulatory protocols for limiting cumulative impacts of water withdrawals.

---

[41] New York State Water Resources Institute. (2009). *Water withdrawals for hydrofracing*. (http://wri.eas.cornell.edu/gas_wells_water_use.html, accessed on February 12, 2009).
[42] Weston, R.T. (2008). *Development of the Marcellus Shale – water resource challenges*. Kirkpatrick & Lockhart Preston Gates Ellis, LLP. (http://www.klgates.com/practices/ServiceDetail.aspx?service=92&view=5, accessed 2/18/09).
[43] The Susquehanna River Basin Commission establishes similar requirements in the Susquehanna Basin.

3.6 Well Completion/Gas Production

Once the well has been fractured, it is outfitted with the necessary equipment to begin extracting and producing gas.

Well-Pad Completion

When the drilling and stimulation procedures are complete, equipment is removed, and the well pad is converted to accommodate production operations. This includes set up of treatment equipment, piping, and pressure and flow monitoring equipment. The well may be equipped with a concrete collar to prevent downward migration of surface water; the remainder of the site may be allowed to return to a vegetated state, with access via gravel or unpaved road.

Wellhead Construction

Production operations commence if a completed well produces gas. Prior to actual production, a wellhead is affixed to the production casing (Figure 16). The wellhead consists of a manifold of valves and fittings welded to the top of the casing. The wellhead seals the well and annulus, while controlling flow of natural gas from the well to transmission lines.

Figure 16: Natural gas wellhead

Gas Collection

Collection of natural gas is typically accomplished using a length of tubing that extends from the wellhead, through the production casing, to the gas producing zone. This tubing provides a conduit for fluid flow to the surface and protects the production casing. The wellhead provides flow control between the tubing and the pipelines which convey the product to wellhead treatment facilities.

Produced Water

The target gas-bearing formation typically contains fluids that come to the surface with the extracted gas; this fluid is referred to as produced water. Produced water is often high in naturally occurring total dissolved solids (TDS), chloride, sulfate and metals (e.g., iron) related to the marine depositional environment responsible for the geologic formation's development. Produced water may also contain naturally occurring formation-related radioactive material or petroleum compounds (e.g., benzene, toluene, and xylene). In addition, remnants of the fracturing fluids used during stimulation may also be present in the produced water. The volume of produced water from an individual well in the Marcellus Shale has been estimated to be on the order of 15,000 gallons per year.[44]

---

[44] New York State Water Resources Institute. (2009) *Waste management of cuttings, drilling fluids, hydrofrac water and produced water*. (http://wri.eas.cornell.edu/gas_wells_waste.html, accessed on February 12, 2009).

Product Treatment

On-site treatment facilities (Figure 17) consist of gas/liquid separators where free gas is isolated via gravity. These separators are typically large vessels that contain the free gas in the upper portion, while oil, brine and condensate (if present) collect in the lower portion. If the oil content of this liquid is sufficiently high, further separation of oil from other fluids takes place in a subsequent separation process. Free gas from the upper portion of the gas/liquid separator may require further treatment (e.g., dehydration) before continuing to the transmission pipelines.

Figure 17: Natural gas treatment unit

3.6.1 Potential Impacts

Improper site restoration could result in erosion impacts. Failure of the wellhead, on-site piping, or treatment tanks could result in leakage of produced water leading to groundwater or surface water contamination. Gas leaks could create an explosion hazard leading to fires and injury or death of personnel.

3.7 Wastewater/Chemical Management

Wastewater/chemical management consists of storing, transporting, treating, and disposing of the various chemicals used and resulting wastewater produced during drilling, fracturing, and production operations.

On-Site Storage of Chemicals, Drilling Wastes and Wastewater

On-site chemical storage depends on chemicals used, scale of the fracturing operation, applicable regulations, and other factors. Chemicals may be stored on-site in drums, totes, or tanks. In some cases chemicals may not be stored on site, but delivered during fracturing operations by a chemical supplier.

During all phases of well development and extraction some form of liquid waste is generated (e.g., cuttings and mud during drilling, fracture fluid and flowback during stimulation, and produced water during extraction). In New York wastes must be stored in a lined pit (Figure 18) but can also be stored in an enclosed tank (Figure 19). Chemicals and wastes are circulated around the site by temporary above-grade piping between the well, storage tank/pit, treatment vessels, etc. Design specifications for waste pits in New York State include:

- Plastic liner (unspecified thickness or strength);
- Pits in floodplains must be constructed at grade;
- Pits are not allowed to spill or overtop due to excess precipitation; and
- Pits are not allowed for produced water storage in areas of primary or principal aquifers.[45]

[45] Enclosed tanks are required to contain produced water in areas of primary or principal aquifers; the tank must be enclosed by a dike capable of holding 1.5 times the tank volume.


Figure 18: Lined waste storage pit


Figure 19: On-site waste storage tanks

On-Site Treatment and Reuse

Flowback water and/or produced water may in some cases be treated on-site for subsequent reuse in drilling and fracturing operations. This is a topic of active research by both industry and the government.[46] In Texas on-site filtration/distillation processes for reducing TDS levels have been piloted. According to the final scope, the SGEIS will include an evaluation of the feasibility of recycling flowback water and reusing produced water.

Transportation of Chemicals and Waste

It is expected that the majority of chemical and waste transport will occur via truck. New York oil and gas facilities are required to use waste transporters with an approved 6 NYCRR Part 364 permit. Tanker trucks are generally between 5,000 and 9,000 gallons, with 9,000 gallons being the largest capacity that complies with New York's 80,000 pound gross vehicle weight standard.

Based on these limits, every one million gallons of waste from a drilling and fracturing operation will require approximately 110 trips with a 9,000 gallon tanker truck. Water deliveries will require a similar number of truck trips to deliver water to the site. A three million gallon fracture operation, for example, could require over 600 truck trips to deliver water to the site and haul waste away from the site, depending on recovery of used fracturing fluid. The exact number of total truck trips for a given well is difficult to estimate and varies based on the specifics of the well operation. In Denton County Texas, which has over 1,300 wells drilled in the Barnett Shale, county commissioners estimate each well required approximately 800 trips to the site by heavy truck to transport water, proppant, chemicals, equipment, drill rig, waste, etc., with each truck weighing 80,000 to 100,000 pounds.[47]

In some high density production areas (e.g., Texas) temporary waste pipelines have been constructed to transport large volumes of waste to underground injection facilities. According to the SGEIS scoping document, DEC will evaluate the use of temporary pipelines and rail as waste transportation options. Such facilities could also require pumping and/or transfer stations.

Off-Site Treatment

Fluid wastes could potentially be treated at municipal wastewater treatment plants (WWTPs). WWTPs in New York require a DEC-approved industrial pretreatment program and an approved headworks analysis prior to accepting fracturing waste. Fluid wastes may also be treated at commercial treatment facilities. Five plants designed for treatment of up to 200,000 gpd of brine from natural gas drilling operations are planned for Pennsylvania.[48] Another such facility is expected to open in West Virginia in 2009.[49]

---

[46] See e.g., Department of Energy National Energy Technology Laboratory RFP DE-FOA-0000038, which seeks to fund projects that focus on "water resources and water management for shale gas development as well as the science to support regulatory streamlining and permitting associated with shale gas development."

[47] Robbins, E. (2004, Aug/Sep) "The Backyard Drill." *Planning*.

[48] RETTEW Associates, Inc. Press Release (12/5/08).

[49] AOP Clearwater/Clearfield Energy, Inc. Press Release (2/10/09).

Land application of waste[50] is common in other states, but is generally limited to road spreading of brine for deicing or dust control in New York. The practice requires a petition of Beneficial Use Determination to be submitted to and approved by DEC prior to hauling brine water from well sites. Flowback from hydraulic fracturing has been expressly prohibited for road-spreading.

Evaporation pits are reported to be a common waste disposal method in other states, but is not expected to occur in New York due to lower evaporation and higher precipitation rates.

Underground Injection

Injecting wastes into isolated porous formations is a widely used method for disposing of oil and gas wastes. A recent summary of the water management technologies currently employed in seven active shale gas basins indicates that Class II injection wells and recycling for reuse in subsequent fracture jobs are the most widely employed techniques.[51,52] The use of underground injection wells in New York is currently low (the final SGEIS scoping document indicates there are currently three active private Class II[53] injection wells in New York, and no commercial injection facilities), however their use is expected to increase substantially: as of 2008, a single company reportedly had over 60 UIC permit applications being drafted in New York.[54]

Private injection wells are permitted to accept waste from a single source, while commercial injection wells may accept waste from any approved source. In some cases dry gas wells can be reused as waste injection wells, a practice which occurs frequently in some oil and gas producing states (e.g., Texas). This requires additional permitting and evaluation as for any injection well. It is unclear whether this would become a viable practice in New York.

Monitoring and Enforcement

There is no management or monitoring system in New York to track oil and gas E&P wastes or chemicals, including reporting recovery rates of injected chemicals from the formation.

3.7.1 Potential Impacts

On-Site Storage of Chemicals, Drilling Wastes and Wastewater

Improper storage and subsequent leakage of chemicals may lead to surface or groundwater contamination. Open pits are the industry standard for storing large volumes of fluids and waste. In New York open pits are not subject to stringent design specifications and are therefore potentially susceptible to a number of failure modes, including embankment failure, punctured or

---

50 Arthur, J.D., B. Bohm, B.J. Coughlin, and M. Layne. (2008). *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs*. ALL Consulting, Tulsa OK. Retrieved from http://www.all-llc.com/shale/ArthurHydrFracPaperFINAL.pdf.

51 U.S. Department of Energy, Office of Fossil Energy. (2009). *Modern Shale Gas Development in the United States: A Primer*, prepared by the Ground Water Protection Council and ALL Consulting, Washington, DC.

52 U.S. Department of Energy, Office of Fossil Energy. (2009). *State Oil and Natural Gas Regulations Designed to Protect Water Resources*, prepared by the Ground Water Protection Council, Washington, DC.

53 Waste injection wells are classified by the EPA under the Safe Drinking Water Act Underground Injection Control program as Class II wells if they are permitted for underground injection associated with oil and gas development for either enhanced recovery of hydrocarbons or waste disposal.

54 Arthur, J.D., B. Bohm, B.J. Coughlin, and M. Layne. (2008). *Evaluating the Environmental Implications of Hydraulic Fracturing in Shale Gas Reservoirs*. ALL Consulting, Tulsa OK. Retrieved from http://www.all-llc.com/shale/ArthurHydrFracPaperFINAL.pdf.

torn liners, insufficient/improper maintenance, overtopping due to rainfall or surface runoff, etc. Any of these failures could release potentially hazardous chemicals into surface or ground waters that feed the NYC West of Hudson reservoirs. Closed tanks are less susceptible to leakage, though sufficient storage capacity and proper maintenance and inspection are still required to prevent accidental releases.

The 1992 GEIS made a series of recommendations regarding pit and liner design specifications. However, it was decided that proper maintenance was more effective at preventing leaks and spills than additional pit and liner specifications. The SGEIS scope has indicated DEC will evaluate whether pit liner or design specifications should be required, or whether enclosed tanks should be required for flowback during hydraulic fracturing operations

On-Site Treatment and Reuse

Impacts associated with on-site treatment and reuse will depend on the specific processes and methods employed. Adequate procedures are required during treatment to prevent leaks and spills.

Transportation of Chemicals and Waste

Truck traffic may lead to accidents and spills of chemicals or wastes, particularly in remote, hilly areas or over poorly maintained roads. Such spills could flow into NYC reservoirs and trigger emergency spill response measures, and potentially requiring one or more reservoirs to be taken offline until the contamination is mitigated. Depending on the location, magnitude, and severity of the contamination event, such reservoir or subsystem outages could affect source water quality and overall system reliability.

Off-Site Treatment

Off-site treatment impacts depend on the capacity and processes at the receiving WWTP. Common drilling and fracturing waste constituents (hydrocarbons, metals, TDS, etc.) may stress treatment processes and/or receiving waters at municipal WWTPs if not properly managed. Even with a pretreatment program as required by DEC, conventional municipal wastewater treatment plants do not remove constituents such as TDS, but rather dilute with other wastewater and the receiving waters.

High TDS brine water may contain significant quantities of bromide, which if released into the NYCDEP watershed, could lead to increased concentrations of brominated disinfection byproducts and impact DEP's compliance with the Stage 2 Disinfection Byproduct Rule.

Underground Injection

Poorly designed injection wells can result in movement of wastes into the groundwater or to the surface. Additionally, underground injection can trigger increased seismic activity due to hydroactivation of faults.[55]

Monitoring and Enforcement

Absent a comprehensive chemical and waste monitoring system there is no mechanism for tracking the ultimate disposal of chemicals or wastes. Limited options and/or high costs for

[55] Ake, J., K. Mahrer, D. O'Connell, and L. Block. (2005). "Deep-injection and closely monitored induced seismicity at Paradox Valley, Colorado." *Bulletin of the Seismological Society of America*, 95(2):664-683.

proper waste disposal could result in illicit dumping in rural areas and lead to contamination of surface water and groundwater resources. The final scope of the SGEIS indicates that DEC will evaluate a special manifest system for tracking drilling wastes, as well as whether a contract with a waste treatment facility is required prior to receiving a drilling permit.

3.8 Gas Transmission

This activity refers to the processes required to distribute natural gas beyond the wellhead.

Transmission to Routing Network

Pipelines are necessary to transport and distribute natural gas for consumption. Pipelines must first be installed either above-grade or below-grade; below-grade piping is typically installed via trenching or boring approximately six feet below grade. Gas is typically conveyed from the wellhead in low-pressure pipe and eventually to high-pressure pipelines via compressor stations.

Pressure Booster Stations

Pressure booster or compressor stations allow natural gas to be moved through a pipeline network at the higher pressures required for consumption. At these stations, the gas is first removed of any water vapor and then further pressurized to allow efficient transport through the pipeline network.

Natural Gas Refineries

Before the gas leaves the local delivery systems and enters the distribution network, it may in some cases require treatment to remove polycyclic aromatic hydrocarbons, sulfur, nitrogen, metals, etc. Exact treatment requirements for natural gas from the Marcellus Formation are not known but are expected to be minimal.

3.8.1 Potential Impacts

Pipeline and facility construction requires surface disturbance which could result in erosion and stream impacts. Pipeline failures could result in gas leaks causing explosions or fires. Pipeline maintenance may include herbicide treatment at the surface to prevent vegetation growth along the pipeline right-of-way. Improper herbicide use could result in surface water or groundwater contamination. Gas treatment at compressor stations and/or refineries may require chemicals and create liquid wastes that if handled improperly could lead to surface water or groundwater contamination.

3.9 Well Rehabilitation and Secondary Recovery

Although it is not known to what extent these activities will be necessary for wells in the Marcellus Shale Formation, gas wells typically undergo some degree of rehabilitation or secondary stimulation to maintain productivity throughout the life of the well.

Well Rehabilitation

Rehabilitation generally refers to a second phase of hydraulic fracturing that intended to increase declining production rates. A well may receive fracturing treatments on the order of every five to ten years. The processes used for rehabilitation are comparable to those used in initial fracturing operations.

Secondary Recovery

Secondary recovery refers to a number of methods that may be employed to help boost internal formation pressures and increase recovery rates towards the end of a gas well's life. One common form of secondary stimulation is water flooding, in which large volumes of water (on the order of hundreds of thousands to millions of gallons per well) are pumped into the target formation via a number of nearby vertical wells open to the same formation. The water pumped into the formation displaces remnants of the gas and moves it toward the production well. Water used for this process could be surface water, groundwater or produced water from initial gas extraction, depending on quality and availability.

3.9.1 Potential Impacts

Impacts associated with additional hydraulic fracturing would be the same as those for initial hydraulic fracturing operations. In addition, water flooding techniques may disrupt natural subsurface flow regimes. By artificially introducing water into the target formation, naturally-occurring vertical and horizontal groundwater flow directions may be modified, resulting in subsurface changes to local groundwater quality and pressures. Water flooding may also contribute to groundwater contamination if intra-formational conduits exist, or are formed as a result of improperly cased water-injection wells or drilling-enhanced fractures.

3.10 Well Closure

This section addresses the activities that are typically conducted for non-producing wells and wells at the end of their useful life.

Well Plugging and Abandonment

Abandonment of oil and gas wells may be necessitated by construction problems, a non-producing well (dry hole), or uneconomical operation. Well abandonment is typically intended to provide permanent closure, but wells may also be temporarily abandoned. Permanent abandonment/plugging of a well is intended to prevent the mixing of fluids from different geologic strata, prevent the flow of fluids from pressurized zones to the surface, and maintain existing pressures in the individual subsurface formations.

The ultimate goal in plugging an abandoned well is to restore the hydrogeologic conditions that existed prior to the drilling and completion of the well. Proper permanent abandonment of a well would consist of completely filling all zones with cement so that vertical movement of fluid within the well bore is prevented. However, the geological formation would remain fractured at a distance from the vertical well bore for hydraulically fractured horizontal wells.

In very deep wells it is difficult and costly to fill the entire well bore with concrete. Therefore alternative methods of plugging are used to isolate individual formations at various depths. DEC allows alternative plugging methods, such as the dump bailer, balance and bridge methods.

Plugging Inspection and Testing

Operators are required to test the materials used for plugging operations and maintain a log of plugging operations. Operators are required to submit a Plugging Report to DEC within 30 days of plugging operations. State inspectors are to be notified prior to plugging operations; the operator can install the plug(s) without the inspector present.

Site Restoration

Site restoration consists of the removal of unnecessary equipment and infrastructure, repairs to work areas and access roads, and regrading and reseeding of devegetated areas.

3.10.1 Potential Impacts

Wells that are not properly plugged and abandoned could become a conduit for the introduction of formation fluids into the fresh water aquifer leading to groundwater contamination. An effective record-keeping system is also required to ensure wells are properly plugged and to prevent problems with future well installations. No information is available on the efficacy of different plugging methods, and they are not slated to be further evaluated in the SGEIS. Additionally, poor site restoration could result in erosion problems and stream impacts.

3.11 Summary of Potential Impacts

The most significant potential risks are to water quality from a broad range of activities that could occur throughout the watershed. Erosion caused by site clearing, road construction, and heavy truck traffic; chemical or wastewater spills; subsurface migration of contaminants into aquifers; and insufficient wastewater treatment and disposal capacity in the region could all impair the quality of the NYC water supply. The likelihood of water quality impairment can be reduced by properly designed and enforced regulations and monitoring at all stages of the process, however it cannot be eliminated. While the probability of contamination from any given well and fracture operation may be quite low, the likelihood increases as more wells are drilled in the region. Further, even a relatively minor contamination incident could negatively impact the public confidence in the overall quality of NYC's unfiltered water supply.

Water quantity impacts from excessive withdrawals may also be a serious concern. The DRBC may be able to limit impacts in the Delaware Basin, but the potential risk in the Hudson Basin is higher due to the lack of a similar authority.

Impacts to water supply infrastructure (see also Section 5) could result in catastrophic consequences if a tunnel failure occurred; however risks are reduced with increased distance from tunnels, dams, and pipelines.

Table 1 presents a summary of the estimated quantities of materials (e.g., water, casings, waste, etc.) required or produced for a given activity during a typical well drilling and fracturing operation. The estimates and ranges included in the table are speculative due to the highly variable nature of the process of gas development in unconventional reservoirs such as the Marcellus Shale Formation. Some of the factors that may affect actual well drilling operations include site topography and location, formation depth, overlying material, saline aquifers, subsurface fractures, fresh water availability, operator preferences and experience, etc. Regardless, the scale of the resources required and the resulting waste generated has the potential to result in impacts to water supply, water quality, and infrastructure, posing numerous risks to the New York City water supply system.

Table 1: Estimated Quantities of Materials for Activities Associated with Natural Gas Development

Activity	Material/Waste	Quantities	Associated Truck Trips[1]
Assumes a single-well pad with total well length of 5,000 to 13,000 feet, consisting of 3,000 to 7,000 feet of depth and 2,000 to 6,000 feet of lateral length with a 6" diameter production casing and 8" diameter borehole. Lateral is cased but not grouted.			
Site Access and Drill Pad Construction	Cleared vegetation and earthwork	2 to 5 acre site, plus access roads as needed	20 to 40
Drill Rig Setup	Equipment		40
Drilling Chemicals	Various chemicals	No estimate available	
Drilling Water	Water	10,000's to 100,000's of gallons	5 to 50
Casing	Pipe	7,000 to 15,000 linear feet (60 to 130 tons) of casing. Each truck can carry 15 20' segments of casing. Assumes an additional 2,000 ft of surface and intermediate casing. Casing is 17 lb/ft.	25 to 50
	Cement (grout)	500 to 1,000 cu ft of cement needed.	5 to 10
Drill cuttings	Rock/earth/formation material	2,500 to 5,500 cu. ft of cuttings	Depends on fate of cuttings
Drilling wastewater	Waste drilling fluids	10,000's to 100,000's of gallons	5 to 50
Stimulation Setup	Equipment		40
Casing Perforation	Explosives	Single charge ~25 g, no estimate on number of charges per length of lateral	
Fracturing Fluid - Water	Water	3 to 9 million gallons	350 to 1,000
Fracturing Fluid - Chemicals	Various chemicals	Assuming 1% to 2% of fracture fluid volume is comprised of chemicals yields 30,000 to 180,000 gallons	5 to 20
Fracture Fluid Wastewater	Waste fracturing fluids	3 to 9 million gallons	350 to 1,000
Well-Pad Completion	Equipment		10
Gas Collection	Produced water	15,000 gallons per year per well average	2 to 3
		Total estimated truck trips per well	**800 to over 2,000**
1 - Truck trips are rough estimates and are assumed to be either standard 18 wheeler semi trucks or 9,000 gallon tanker trucks.			

In general, most activities for an individual well that can result in impacts occur during an approximately two to four month period as the well is developed. Once the well is completed, the risk of serious impacts is reduced. However, some impacts that could occur (e.g. groundwater contamination) may persist long after the well is completed.

Induced growth and the accompanying surface disturbance and changes in land use were not estimated for this report; however it is acknowledged that such changes would alter watershed characteristics, potentially to a larger extent than direct disturbances. Given the importance of watershed protection for unfiltered water supply systems, major changes in land use or the level of industrial activity in the watershed could be considered as a potential adverse impact for the NYC system.

Section 4: Natural Gas Development Incidents and Case Studies

This section describes the types of failures that have occurred during natural gas exploration, well development, and production based on examples of incidents that have occurred in other natural gas basins in the U.S. The objective of this section is to characterize the types of failures or incidents that have occurred elsewhere, and that could potentially occur in the NYC watershed in the event of substantial natural gas development. This section also provides context for the occurrence of failures by providing data on gas drilling activities where available (e.g., number of active wells, well permits, waste injection wells, etc.). This section does not aim to provide a comprehensive inventory of all incidents, but rather to identify the types of incidents and impacts that have occurred elsewhere.

Information contained in this section is drawn from a review of available state regulatory enforcement data and reports, news media, state and federal regulations, industry and geologically focused academic research, gas drilling experience from other states, and team experience.[56] These sources were used to catalog the failures from other regions that may occur during the development of natural gas resources in New York. For the purpose of this report a failure is broadly defined as any incident that results in a report of any of the following:

- Injury, damage, or harm to others;
- Accidental release of chemical, sediment, or waste;
- Uncontrolled subsurface movement of drilling constituents or waste; or
- Enforcement action by a regulatory agency.

Drilling techniques to be used in New York (e.g., horizontal drilling and high-volume hydraulic fracturing) have only recently been implemented on a large scale. The Barnett Shale in Texas, the formation where these techniques were initially developed for large-scale commercial gas production, has only been under intensive development for about five years. Therefore data on long term impacts from horizontal drilling and high-volume hydraulic fracturing is not available.

The following sections of this report summarize information related to documented impacts associated with gas well exploration, drilling, and production at locations throughout the U.S. (Figure 20). Although natural gas can be developed from several different types of geologic formations such as sedimentary bedrock basins, tight sandstone formations, coalbeds, and gas shales, this summary focuses primarily on those gas-bearing formations considered to be similar to the Marcellus Shale with respect to the types of drilling and production activities. However, each shale gas play (in some cases each individual well) presents a unique set of exploration and operational challenges, which in turn affects the frequency, magnitude and type of potential failures.

---

[56] Data for failures and case studies was generally limited to the past five to ten years in an effort to review incidents that occurred under current regulations and technological capabilities.

Source: Energy Information Administration based on data from various published studies
Updated: May 28, 2009

Figure 20: Major shale gas plays in the U.S.

The following formations and related sedimentary basins were targeted for review and, where possible, expanded upon through case studies:[57]

▪ Marcellus Shale	Devonian/Appalachian Basin (New York and Pennsylvania)
▪ Barnett Shale	Fort Worth Basin (Texas)
▪ Haynesville Shale	East Texas Basin (Louisiana)
▪ Fayetteville Shale	Arkoma Basin (Arkansas)
▪ Williams Fork Formation	Uinta Piceance Basin (Colorado)
▪ Jonas Formation	Greater Green River Basin (Wyoming)
▪ Fruitland Formation	San Juan Basin (New Mexico)

Data is not available for every specific activity associated with gas well drilling in each basin, nor is available data always conclusive. This is particularly evident with subsurface failures, in which the suspected cause(s) of groundwater contamination and fugitive gas impacts are masked by geologic and hydrogeologic interference that may preclude definitive identification of a mechanism for the impact. Therefore the gas well activities described in Section 3 are consolidated into the following larger categories:

---

[57] Research on other natural gas producing formations (Alabama, Kansas, Montana, Oklahoma, and West Virginia) yielded no significant additional information applicable to potential natural gas development in the Marcellus Shale; accordingly these formations are not included in this report.

- Well siting: This group consists of typical land disturbing activities associated with the well pad and consists of seismic testing, site access, drill pad construction and site restoration. This section does not focus on site-disturbance activities with impacts analogous to other activities currently encountered in the NYC watershed (e.g., forestry, construction, agriculture). Instead the focus is on siting failures unique to gas well development.
- Well development: This group consists of all subsurface activities associated with gas well development, including drilling, casing, fracturing, completion, maintenance, rehabilitation, and secondary stimulation.
- Gas production: This group consists of all activities associated with transporting gas from wellhead to regional pipeline, including gas collection, product treatment, and construction of pipelines, booster stations or refineries. As with well siting, the focus is on activities and impacts unique to natural gas development.
- Water consumption: Includes all activities associated with procurement of surface or groundwater for drilling and hydraulic fracturing.
- Wastewater/chemical management: This group consists of all activities associated with chemical and waste materials including transportation, on-site storage, off-site treatment, surface disposal, and spill contamination/management.
- Underground injection: Includes activities related to subsurface disposal of gas well development wastes in Class II injection wells. This activity is part of wastewater/chemical management but is treated separately due to the frequent use of Class II wells as the primary disposal method for oil and gas wastes in many states, and the potential for substantial new injection well development in New York.
- Monitoring and enforcement: Includes activities associated with ensuring compliance with applicable regulations and permits.

4.1 Marcellus Shale (New York)

New York allows hydraulic fracturing of vertical gas wells, which has historically occurred on a limited basis predominantly in the western portion of the state (e.g., Steuben County). Horizontal drilling and hydraulic fracturing stimulation techniques are currently being pursued in order to extract commercially viable quantities of natural gas from the Marcellus Shale, which has proven successful elsewhere in the country where similar geologic conditions exist (e.g., Barnett Shale of Texas). New York Department of Environmental Conservation (DEC) has not approved any horizontal hydraulic fracturing operations pending completion of the Supplemental Generic Environmental Impact Statement. Therefore, there is currently very little applicable data on incidents in New York.

4.2 Marcellus Shale (Pennsylvania)

4.2.1 Overview of Geologic Setting and Natural Gas Development Activities

The Marcellus Shale Formation in Pennsylvania differs little from that found in New York, with the exception of variations in depth and thickness. Natural gas development of the Marcellus Shale and use of horizontal drilling and high-volume hydraulic fracturing is still relatively recent in Pennsylvania. There are currently between 50 and 150 active wells drilled into the formation. Pennsylvania has a relatively large network of Class II injection wells associated with its existing oil and gas industry. According to EPA Region III, there are 1,855 active Class II injection wells in the state.

4.2.2 Regulatory Context

The Pennsylvania Department of Environmental Protection (PADEP) is the state agency responsible for regulating all oil and gas development activities through its Bureau of Oil and Gas Management. However, Class II injection wells are regulated by EPA Region III. Regulations governing oil and gas development are established in PADEP's *Pennsylvania Oil and Gas Operators Manual*. PADEP is also tasked with administering other state environmental and energy programs in addition to those associated with oil and gas development.

Water resources in the eastern and central parts of the state are covered by jurisdictions of two interstate agencies, the Delaware River Basin Commission (DRBC) and the Susquehanna River Basin Commission (SRBC). Any withdrawal from surface or groundwater within either jurisdiction requires approval by the governing commission. Withdrawals in other parts of the state are not governed by state regulations, except when the withdrawals are for public water supply.[58] The Pennsylvania Water Resources Planning Act requires PADEP to implement a water withdrawal and use registration system to aid the development of the state water plan. All users whose withdrawals meet certain conditions[59] are required to register and submit records of their withdrawals from both surface and groundwater sources. The act appears to only require tracking of water withdrawals and not grant authority to impose rules.

In October 2008, PADEP adopted supplemental rules for permits to drill natural gas wells in the Marcellus Shale Formation. The rules consist of additional information to be submitted to PADEP prior to permit issuance, examples of which are described below.[60]

- The Preparedness, Prevention and Contingency Plan, includes a description of the operation, pollution prevention measures, chemicals or additives used, waste generated, waste disposal methods, incident response plans, corrective action plans, and an implementation schedule.
- The Water Management Plan includes a description of source and withdrawal volumes, identification of impacted wetlands and streams, low flow analysis (e.g., Q7-10), natural diversity inventory, fracing fluid composition, and identification of treatment or disposal facility.

---

[58] Weston, R.T. (2008). *Development of the Marcellus Shale – water resource challenges*. Kirkpatrick & Lockhart Preston Gates Ellis, LLP. (http://www.klgates.com/practices/ServiceDetail.aspx?service=92&view=5, accessed 2/18/09).

[59] All public water supplies and hydropower facilities are required to register along with all other users whose average withdrawals exceed 10,000 gallons per day over a 30-day period or who obtain water through interconnections that exceeds 100,000 gallons per day over a 30-day period.

[60] Because the new permit rules are relatively recent, it is not clear if permits can be declined based on water withdrawals, chemicals used or other data submitted in the applications. Drillers have likewise indicated confusion regarding new permit requirements and have ceased some drilling operations in response.

A preliminary review of the Pennsylvania regulations governing natural gas development indicate similar requirements as compared to current New York regulations for most activities except permit applications (described previously) and pit construction. The state of Pennsylvania adopted a set of pit design standards, which are summarized in the state's *Design, Construction and Maintenance Standards for Pits and Dam Embankments Associated with Impoundments for Oil and Gas Wells*. The document primarily addresses construction of embankments to prevent failure.

Case Study: Methane Migration Dimock, PA

In early 2009 there were multiple reports of methane migration to the surface around Cabot Oil & Gas Corp. drilling sites in northeastern Pennsylvania near Dimock Township. Based on chemical analyses, PADEP determined the gas originated in the target formation and was not produced by bacteria, nor did it originate in a shallower gas bearing formation. At this time there are no details as to the conduit (e.g., natural fractures, induced fractures, gas wells, other wells, etc.), which allowed the gas to travel from the target formation to the surface. The incident remains under investigation. Currently, there is no implication of operator error, a failed well casing, or other problem causing the gas migration.

The primary risks from gas migration are explosions and fires if gas is allowed to collect in confined spaces, which has happened once already in a water well vault in the area. PADEP has required additional ventilation, installed gas detectors, and taken water wells with high methane levels offline at impacted homes to reduce explosion hazards. Additionally, PADEP requested the gas company conduct a broad range of chemical analyses on local groundwater to test for chemicals used in the fracturing process.

4.2.3 Failures and Impacts

PADEP does not release summary reports of enforcement actions, nor does it provide access to a database of enforcement actions. PADEP does archive press releases of enforcement actions, and the region is under substantial media scrutiny of gas well operations due to concerns about impacts associated with shale gas production. Reports of failures in Pennsylvania identified during this review are described in the following sections. No cases of failures associated with well siting or gas production in Pennsylvania were identified during the preparation of this report.

Well Development

The Pennsylvania portion of the Marcellus Shale has experienced numerous problems related to natural gas migration into drinking water wells or to the surface. This can be caused by failed well casings, natural subsurface fractures, or man-made fractures. Often it is difficult to pinpoint the exact pathway for the gas. The example of Dimock (inset) highlights the potential for unknown subsurface conditions to result in impacts, despite there being no apparent problems during well drilling or fracturing.

Two homeowners in a nearby area of the state have had their drinking water springs contaminated with water apparently linked to gas well drilling and fracing of the Marcellus uphill of the homes by Seneca Resources, Inc. PADEP has tested the water, deemed it unsafe, and is investigating the causes. PADEP has not released the results of the tests. The residents describe the contamination as having a briny taste and irritating to the mouth and lungs.

Damascus Citizens for Sustainability (DCS) has reported on three landowners in western Pennsylvania who have reported natural gas and other chemicals migrating to the surface, contaminating nearby streams and ponds. No water test data was presented in support of these claims nor was any indication of PADEP action presented. Photos, video, and copies of complaints sent to the state were provided to support the claims.

Water Consumption

Local television station WTAE in Pittsburgh has reported that PADEP has investigated two incidents of streams being nearly drained or pumped dry by water withdrawals. No information was available from PADEP regarding these investigations.

Wastewater/Chemical Management

In October, 2008 excessive gas well brine disposal at wastewater treatment plants (WWTPs) in the Monongahela Basin resulted in high TDS in the river and its tributaries. The high TDS led to problems for those using river water for domestic and industrial purposes. The case study (inset) emphasizes that the lack of sufficient regional drilling waste treatment capacity can result in a range of widespread impacts.

In the past six months there have been two reports of diesel fuel leaking from tanks at drilling operations run by Cabot Oil & Gas Corp near the Dimock Township in northeastern Pennsylvania. The first event was due to a loose fitting on a tank and resulted in approximately 800 gallons of diesel entering a wetland located approximately 350 feet from the tank. The spill was reported to be contained before entering a nearby stream. The second event involved approximately 100 gallons of diesel resulting in soil contamination. PADEP required the soil be removed and indicated there was no suspected groundwater contamination. No cause was cited for the spill.

Case Study: Regional Waste Treatment

In the fall of 2008 PADEP determined the TDS levels in the Monongahela River exceeded allowable standards in the segment north of the West Virginia border. The TDS were causing taste and odor problems in drinking water, high levels of brominated DBPs at water treatment plants, excessive scale on industrial boilers, and high particulates in power plant emissions. PADEP traced the problem to delivery of highly mineralized wastewater to municipal wastewater treatment plants from natural gas drilling operations. The situation was exacerbated by below-average flow in the river and abandoned mine drainage. Water samples analyzed downstream of several wastewater treatment plant discharges in the Monongahela indicated TDS levels nearly twice the allowable limit and nearly five times average levels.

Dissolved solids disposed of at conventional municipal WWTPs are not removed, but simply diluted with domestic wastewater and river flows. Therefore, PADEP ordered nine municipal plants on the Monongahela River to curtail gas well wastewater volume to a maximum of 1% of daily inflow. The Morgantown, West Virginia Utility Board followed suit and ceased all deliveries of wastewater from gas drilling operations at their municipal wastewater treatment facility.

A regional waste management plan can limit further problems by coordinating waste discharges with stream flow levels across a number of states to prevent impairment of water resources.

Underground Injection

Since the state does not administer the underground injection control program in Pennsylvania, the EPA is the only source for enforcement data associated with underground injection wells. In December of 2007 EPA launched a national database program to compile underground injection well information, compliance reports, and enforcement data. The database is not fully populated nor is it available to the public. EPA estimates the program will be fully functional by 2012. Therefore compliance and enforcement data for injection wells is not readily available for states whose injection well program is administered by EPA.

The EPA Region III website did list one undated instance of a failed Class II injection well impacting surface water quality. A failed casing and an improperly abandoned production well resulted in injected waste returning to the surface and contaminating a local stream with high TDS. EPA along with PADEP required both wells be properly abandoned; subsequent stream monitoring indicated a gradual reduction in TDS over time.

Monitoring and Enforcement

Problem Operators

The owners of Synd Enterprises, Inc. and Vertical Resources were ordered by PADEP in December 2006 to sell their oil and gas assets, and were barred from operating in the state for persistent non-compliance with regulations and obstructing PADEP's access to sites for inspection. Additionally PADEP is seeking civil penalties for over $600,000 to perform cleanup activities and plug wells. Among the violations cited in the order were:

- Over-pressurized wells, which contaminated groundwater and caused gas migration;
- Failure to implement erosion and sedimentation controls at well sites, leading to accelerated erosion;
- Unpermitted discharge of brine to the ground; and
- Encroachments into floodways and streams without permits.

In May of 2008 PADEP ordered Range Resources – Appalachia, LLC and Chief Oil and Gas, LLC to shut down surface water withdrawals from local streams, citing violations of the state Clean Streams Law. The drillers were also within the jurisdiction of the SRBC, which filed concurrent orders to cease operations. The two companies are required to submit water resource management plans for approval and obtain permits for the withdrawals prior to resuming operations.

Other Monitoring and Enforcement Issues

DCS has collected a series of photographs from various drilling operations in western Pennsylvania showing unlined waste pits and other violations at drilling sites indicating a lack of regulatory oversight. DCS did not indicate if complaints were filed with PADEP regarding these violations.

4.3 Appalachian Basin (Kentucky)

4.3.1 Overview of Geologic Setting and Natural Gas Development Activities

The sedimentary bedrock formation developed for gas elsewhere in the Appalachian Basin (south of the Catskills) includes significantly thick sequences of shale and sandstone, with frequent interbeds of coal, mostly of Mississippian and Pennsylvanian age (geologically younger than the Marcellus Shale). Besides gas, many of these formations also contain petroleum. Because of the geologic structures comprising the Appalachian basin, these bedrock formations typically occur at depths of thousands of feet and thicknesses on the order of tens to hundreds of feet. This basin has been extensively developed for natural gas over the last 50 or more years throughout Pennsylvania, Ohio, West Virginia and Kentucky. As such, there are hundreds of active wells producing gas from the respective units.

4.3.2 Well Development Failures and Impacts

Over-pressurized Wells

A common failure associated with gas production is over-pressurization of the well's annular space, resulting in periodic overflow (pressurized jets) of formation fluids (mineralized and saline formation water, oil, or gas). This occurs when pressure in the target formation or a shallower formation is high enough to force formation material above the production casing.[61] The investigation associated with one Eastern Kentucky well which exhibited evidence of this problem is described below.

An initial evaluation was made of the hydrogeologic setting to determine whether overflow onto the ground surface from the gas well could impact nearby domestic wells and/or discharge to nearby streams. The radii of influence of nearby domestic wells were evaluated to determine if they could be impacted by subsurface overflow from the gas well. General water quality was characterized using water quality diagrams and compared with published water quality regimes.

Continuous water level monitoring of the annular space of the gas well was performed to determine potential frequency of overflows. Water samples were collected from nearby domestic wells and gas-well casing annular spaces. Samples were analyzed for standard analytes (e.g., hydrogen sulfide), "secondary" analytical parameters (e.g., bacteria speciation), dissolved gases (e.g., methane), petroleum signatures, and stable isotopes. Water levels were also monitored in the gas well-casing annular spaces. The investigation led to the conclusion that the periodic discharges were affecting water quality in a nearby stream. The casing annulus was sealed with grout to prevent further movement of formation fluids.[62]

4.4 Barnett Shale (Texas)

4.4.1 Overview of Geologic Setting and Natural Gas Development Activities

The Barnett Shale (technically described as a sandstone) is a tight gas formation of Mississippian age (roughly 330 to 360 million years old), roughly 5,000 square miles in extent, that extends throughout the north central portion of Texas at depths on the order of about 5,000 feet below grade. Many of the drilling and development techniques currently being adapted for use in the Marcellus Shale were initially developed for the Barnett Shale.

As of January 2009, the Railroad Commission (RRC) had recorded 10,146 gas wells in the Barnett Shale Formation with over 5,000 additional permitted locations yet to be drilled. Over 85% of the permits for drilling the Barnett Shale were issued after 2004. As of the end of 2007, RRC also reported 31,923 active Class II injection wells out of 50,988 currently permitted wells.

---

[61] In NY production casings are required to extend 500 feet above the bottom of the well, 100 feet above any intermediate gas or water producing formations, or to the bottom of the next higher casing.

[62] Grouting of annular spaces is typically not required in most states including in New York.

These figures include waste disposal wells (24%), secondary recovery wells (75%), and subsurface hydrocarbon storage wells (1%).

4.4.2 Regulatory Context

State

The RRC is the state agency in charge of regulating all activities associated with oil and gas development in Texas, including Class II underground injection. The Texas Commission on Environmental Quality (TCEQ) is responsible for environmental protection. However, the TCEQ and the RRC have entered into a Memorandum of Understanding clarifying that the RRC has jurisdiction over all wastes generated in connection with oil and gas exploration, development, and production.

The RRC publishes a series of manuals covering standard practices and regulations governing oil and gas development. A preliminary review indicates similar requirements as compared to current New York regulations, with the exception of waste pits. Texas has adopted extensive regulations governing waste pits, which include standards for leak detection, liners, embankment design, siting and construction.

Texas, unlike New York, generally has a well-developed system of water withdrawal regulations covering both surface and groundwater. The system governing surface waters consists of a hierarchical structure that grants older water rights priority over any junior rights on a stream.[63] Conversely, groundwater is owned in absolute terms by the surface owner, who can withdraw unlimited water.[64] Although, the state has empowered nearly 100 groundwater conservation districts with the authority to promulgate rules limiting excessive withdrawals.

In order to manage its water resources, the state develops a comprehensive water plan every five years and commissions supplemental studies to regularly evaluate its water supplies. In 2007, the TCEQ study encompassing the Barnett Shale region estimated approximately six to ten billion gallons per year (~15 – 25 mgd) is needed from the Priority Groundwater Management Area for natural gas extraction.[65] The level of demand is consistent with that allocated for oil and gas extraction in the state water plan.[66]

Local

Unlike New York, Texas does not prohibit local municipalities from regulating oil and gas development activities to protect the public and their property rights. The City of Forth Worth has had a municipal drilling ordinance in effect since 2001. Beginning in 2006, as drilling increased in the Barnett Shale, the city commissioned multiple task forces to review the ordinance, solicit public comments, and make recommendations to the city council. In December

---

[63] The State of Texas owns all surface waters and grants individuals the right to use the water, which can be transferred to other owners.

[64] Rights to groundwater cannot be transferred except with the transfer of surface ownership.

[65] Texas Commission on Environmental Quality. (2007). *Updated Evaluation for the North-Central Texas – Trinity and Woodbine Aquifers – Priority Groundwater Management Study Area*, Austin, TX.

[66] Conversely, the agency expects the area to have a persistent shortfall for municipal needs by mid-century due to continued population growth.

2008 the city council adopted new language for its drilling ordinance, which includes many new constraints including:

- Increased permitting requirements;
- Noise restrictions;
- Larger setback requirements;
- Additional limitations on open pits;
- Air quality standards; and
- Screening and fencing standards.

4.4.3 Failures and Impacts

The RRC does not make available a database of enforcement actions, nor does it release summary reports. Although, the state does release a comprehensive annual report on groundwater contamination organized by responsible agency. All reports of failures identified in Texas along with those from the summary report are described in the following sections. No cases of failures associated with well siting or water consumption[67] in Texas were identified during the preparation of this report.

Well Siting

Siting cases included below do not constitute failures *per se*, but instead identify examples of gas well siting in drinking water watersheds or near reservoirs.

In 2007 the Tarrant Regional Water District, which supplies water to 1.7 million people in the Fort Worth area, leased some of its property for natural gas development of the Barnett Shale. It is not clear from the documents available if the property is located in a drinking water reservoir watershed. No reports of problems associated with drilling or hydraulic fracturing on this property were identified.

The Brazos River Authority (BRA), a state agency with jurisdiction over the Brazos River watershed, has limited drilling at its Possum Kingdom Lake, a drinking water reservoir west of Fort Worth. Operators utilized horizontal drilling from the banks of the reservoir to access natural gas beneath the lake bed. Drilling began in July 2007 and no reports of problems associated with this drilling operation were identified. The BRA did not own mineral rights beneath the lake and was compelled to allow drilling by Texas state law.[68] Available data did not indicate whether hydraulic fracturing was utilized on wells beneath the lake bed or which formation was targeted.

In 2004, the City of Tyler (population ~100,000) leased the mineral rights beneath two drinking water reservoirs that provide most of the city's water and allowed for 130 wells to be drilled on the surrounding property. No subsequent reports were found indicating any problems or contamination from the drilling activity. Available data did not indicate whether hydraulic fracturing was used in the watershed or which formation was targeted.

[67] Most reports from the Barnett Shale region indicate gas well drillers purchased water from municipalities, private suppliers, or private well owners.
[68] Texas law requires reasonable accommodation by surface rights owners to access mineral rights. Failure to do so can result in property condemnation filings or lawsuits seeking compensation for damages.

Well Development

In 2008, multiple homeowners' wells were contaminated with sulphates, hydrocarbons, and toluene after well development of the Barnett Shale began within several hundred yards of their properties in a rural area of Hill County, Texas. The Texas RRC has taken water samples and is apparently investigating the issue.

As development of the Barnett Shale play began, some drillers reported fractures propagating into adjacent formations, particularly the Ellenberger Formation. The Ellenberger Formation lies below the Barnett Shale and is not used for potable water supplies. As the Barnett Shale play developed, operators were able to adjust their fracturing techniques to limit fracturing into adjacent formations. No information was available indicating the frequency or extent of fractures into adjacent formations or whether propagation of fractures resulted in migration of fracing fluid into groundwater aquifers

Case Study: Enforcement

Beginning in 1997 local residents alleged groundwater contamination and complained of spills at a nearby oil and gas waste injection well site in Panola County, Texas. Contaminants in local resident's wells included benzene, arsenic, lead and mercury to the extent that the wells were unusable. Texas RRC did not confirm contamination until 2003 and the facility remained operational until 2004. Even after the facility was shut down, the operator did not adequately address the contamination, which led the EPA to take responsibility for remediation in 2006. The EPA investigation indicated the shallow groundwater contamination was caused by illegal dumping, surface spills, and spillover from the injection well. The EPA's solution was to remediate the groundwater and install a new water service connection to a nearby utility.

This case not only represents a failure of waste management practices, but also a significant failure of monitoring and enforcement. A quicker response to the problem could have substantially reduced the level of contamination. Additionally, because oil and gas field wastes are exempt from RCRA and CERCLA regulation, the site operators were similarly exempt from the liability requirements of those regulations, resulting in the federal government covering the costs of the investigation and remediation.

Gas Production

Natural gas pipeline explosions and fires appear to occur several times per year in Texas and are generally not reported on by the media unless they cause injury or death. Reports reviewed for this section indicate damage is generally limited to nearby gas infrastructure, which may limit production while pipelines are down, but does not appear to cause more widespread impacts. Fires in Texas appear to generally occur in open prairie. New York is more forested and has a risk of forest fires, especially during periods of dry weather or extended drought.

Wastewater/Chemical Management

A tanker truck carrying produced water contaminated with naturally occurring radioactive material (NORM) from gas production in the Barnett Shale spilled in a community near Aledo, Texas. The RRC indicated the NORM does not pose a health risk to local residents, though the spill did occur near a local school. After the spill was cleaned up, local residents remained concerned because the site continued to emit detectable levels of residual radiation. The story was not covered in any traditional news media but was reported by local community organizations.

In Parker County Texas a three-year-old produced water pipeline transporting brine water from production wells to injection well sites leaked at multiple locations killing 300 to 500 trees at a nursery. The RRC reported there were several leaks in the 6-inch steel pipe, which contaminated an area approximately 800 by 400 feet. The contaminated soil was excavated. There was no information on impacts to groundwater.

In a case dating back to 1997 (inset), a rural community's drinking water was contaminated by waste from a nearby injection well site in Panola, Texas. In an investigation spanning more than ten years, involving both the RRC and the EPA, it was determined that excessive on-site waste spills and leaking pipelines led to the contaminated groundwater. There was no indication from the investigation that there was any failure in the integrity of the injection well itself. In addition to clean-up of the site and groundwater remediation, the residents were connected to a nearby municipal drinking water supply as a permanent solution.

Underground Injection

In 2008 RRC shut down a leaking Class II injection well in Aledo, TX. The well was originally drilled in 2007 and the problem was discovered by an RRC inspection in response to a complaint. The report did not indicate the cause of the problem but indicated there was no evidence of groundwater contamination. The well owner will be allowed to repair the well, and if successful, be allowed to bring the facility back online.

In 2008, a sinkhole approximately 900 feet wide and 250 feet deep formed next to a Class II injection well used for waste disposal near Houston, TX. The RRC is investigating the incident, but it is not known at this time whether the waste injection well is the cause of the sinkhole. The director of the petroleum geosciences program at the University of Houston believes the sinkhole was caused by the erosion of a salt dome by the injected waste, causing formation collapse.

In 2007 an underground injection well was shut down at a Wise County, TX site due to increased casing pressures on gas production wells within a half mile radius. The RRC indicated the operator did not violate its permit, but would need to investigate further to determine why the injection well caused the pressure increase at neighboring production wells. Members of the local community cited this as evidence that the well has the potential to contaminate groundwater and are petitioning the RRC to permanently shut down the well.

In recent years as natural gas drilling and subsequent waste injection has increased in the Fort Worth region there has been a similar increase in the level of seismic activity. There has yet to be any definitive proof of causation, but waste injection has been known to cause hydroactivation of faults. Most of the earthquakes are small, less than 3.0 on the Richter scale, and have not caused any damage.

Three other reports were identified dating back to 2004 indicating various failures associated with injection wells including:

- Operators injecting unpermitted wastes;
- Wastewater leaks; and
- Wastewater surfacing from nearby abandoned wells.

Monitoring and Enforcement

According to a 2007 report, the RRC had failed to perform any site inspection in the last 5 years on approximately 46% of active oil and gas leases in the state.[69,70] Nevertheless, the report characterized compliance and enforcement as comprehensive and consistent across the state with most complaints being resolved quickly.

NORM is common to drilling in the Barnett Shale and is generally not required to be handled differently than other wastes in the state. However, as pipes and equipment are used, radioactive residue builds up and is referred to as technologically enhanced NORM (TENORM). TENORM is required to be decontaminated prior to disposal. The Texas Department of State Health Services (DSHS), the regulatory authority for TENORM, has indicated there have been 25 decontamination sites in three counties with heavy Barnett Shale activity since 2005. Neither the RRC nor the DSHS inspects for or monitors TENORM; drilling companies are required to self-report. Many communities are concerned that there may be additional sites requiring decontamination that have not been reported.

Summary of Groundwater Contamination in Texas

The Texas Groundwater Protection Committee produces an annual report compiling monitoring, enforcement, and corrective actions from ten state agencies charged with regulating groundwater quality.[71] The report includes progress on past cases dating back to 1990 as well as detailing new cases for the current year.

Since 1990, there have been on average 6,000 cases of alleged groundwater contamination under investigation in any given year, with approximately 500 to 1,400 new cases added annually. Additionally, there are approximately 1,500 cases of confirmed contamination being remediated in any given year.

The most recent data indicate there are 5,267 cases currently being investigated for 2007. Of these investigations, 373 (~7%) are related to oil and gas development, which includes oil and gas well development, production, and waste disposal. These data do not indicate which cases are specifically related to natural gas development in the Barnett Shale Formation.

4.5 Haynesville Shale (Louisiana)

The Haynesville Shale (also known locally as the Bossier) occurs in the East Texas Basin that brackets the border between Texas and Louisiana. This formation is typically found at depths in excess of 10,000 feet below grade and is considered a tight shale. The Haynesville Shale is geologically younger than the Marcellus Shale, having been formed during the Jurassic period

[69] Texas State Auditor's Office. (2007). *Inspection and Enforcement Activities in the Field Operations Section of the Railroad Commission*, Austin, TX.
[70] As of 2007 there were 169,770 oil and gas leases in Texas. The report indicates that there could be up to 100 individual wells on any given lease and provides no data on individual well inspections. The RRC estimates there are approximately 250,000 active oil and gas wells in Texas.
[71] Texas Commission on Environmental Quality, Texas Groundwater Protection Committee, (2007). *Joint Groundwater Monitoring and Contamination Report,* Austin, TX.

(about 170 million years old). This formation underlies an area about one tenth of the Marcellus Shale and lends itself to gas development by both vertical and horizontal wells.

There are approximately 250 active wells in the Haynesville Shale Formation, most of which have been drilled since 2007. No reports of failures in the area due to gas well development were identified, which is not unexpected due to the relatively recent activity within this shale play.

The greatest concern identified in research for this report was related to groundwater supply. Certain aquifers in the region are heavily utilized for drinking water, have limited recharge, and are somewhat stressed due to demands. There are concerns that mechanisms for protection of these aquifers are insufficient. There are other aquifers in the region that have lower quality water and are not typically utilized for drinking water, but are suitable for gas well drilling. Therefore, without infrastructure for transporting water from low quality aquifers to drilling sites or improved protection of the high quality aquifers, drinking water wells may be impacted by withdrawals for natural gas development.

4.6 Fayetteville (Arkansas)

4.6.1 Overview of Geologic Setting and Natural Gas Development Activities

The Fayetteville Formation consists of shale, sandstone, and limestone units, which are considered to be characteristically tight with respect to gas yield. As such, the Fayetteville Shale is considered to be an unconventional play like the Barnett and Marcellus Shale. The formation is of Mississippian age and typically ranges from about 50 to 550 feet thick, occurring at depths of 1,500 to 6,500 feet below grade. The Fayetteville is located in the Arkoma Basin, with the corresponding gas play underlying central Arkansas.

According to the State of Arkansas Oil and Gas Commission, there have been approximately 1,400 wells drilled into the Fayetteville Shale Formation since 2004. There are also approximately 900 Class II injection wells in the state. Arkansas, like some western states, allows land application ("land farming") of drilling wastewater, which entails applying the waste to agricultural fields.[72] The state heavily regulates the practice to prevent pollution.

4.6.2 Regulatory Context

The Arkansas Oil and Gas Commission (AOGC) has the authority to regulate all aspects of oil and gas development, including the underground injection control (UIC) program for Class II wells. The Arkansas Department of Environmental Quality (ADEQ) administers the protection of natural resources (air, water and land) from the threat of pollution. The AOGC publishes a comprehensive manual covering rules and regulations for oil and gas well development. The ADEQ has numerous manuals pertaining to the various state environmental programs that apply to oil and gas development activity, which appear to be consistent with requirements in New York.

---

[72] Land farming is not allowed in New York; however, road spreading of brine wastewater is allowed with special permits from DEC, which could result in similar water quality impacts as land farming.

4.6.3 Failures and Impacts

Neither ADEQ nor AOGC provides substantial information on compliance or enforcement. All reports of failures uncovered in Arkansas are described in the following sections. No cases of failures associated with well siting, well development, gas production, water consumption or underground injection in Arkansas were identified during the preparation of this report.

Water Consumption

Available documents indicate that the state legislature, the public, and regulatory agencies have some awareness of the risks associated with water consumption and are pursuing monitoring plans to prevent negative impacts to water resources as the shale play develops.

Wastewater/Chemical Management

A leaking unlined, unpermitted storage pit resulted in a fish kill in an adjacent stream. A nearby property owner had complained to ADEQ, which subsequently tested the discharge and found high chlorides in the water. ADEQ executed an emergency order to shut down the facility and is pursuing civil penalties for the violation. ADEQ indicated there was no threat to drinking water from the wastewater; no information was provided regarding potential groundwater contamination.

In addition, there have been other reports in recent months of environmental violations associated with drilling waste land farms. Due to the violations and increased waste from drilling operations, ADEQ issued a moratorium on new or modified land farm permits to allow time to study the impacts on the state's water resources and wildlife.

Monitoring and Enforcement

There are concerns that there are not enough resources for proper inspections and oversight of gas well drilling in the state. The governor has proposed shifting some funds to be collected from leasing state land for gas development to the state Oil and Gas Commission to add staff to handle additional permitting, inspection, and enforcement associated with the Fayetteville Shale play.

4.7 Williams Fork (Colorado)

4.7.1 Overview of Geologic Setting and Natural Gas Development Activities

Colorado has historically been a large producer of natural gas from both conventional and unconventional formations. The U.S. Energy Information Agency estimates Colorado possesses nearly ten percent of the proven reserves in the U.S. The Williams Fork Formation is of Cretaceous age (about 145 to 65 million years ago) and is located in the Piceance Basin in northwest Colorado. It is a tight formation consisting of interbedded sandstones, siltstones, shale, coals, and limestones that is being developed in a manner similar to other tight formations. Much of the activity is centered on Garfield County, which currently has over 4,000 active wells drilled since 2000. Statewide, Colorado has approximately 63,000 oil and gas wells and approximately 800 Class II injection wells, of which 70% are for enhanced recovery with the remaining used for waste disposal.

4.7.2 Regulatory Context

The Colorado Oil and Gas Conservation Commission (COGCC), a division of the Department of Natural Resources, has broad statutory authority over nearly every aspect of oil and gas development, including primacy over UIC for private Class II wells.[73] COGCC's authority extends to any land, water, air or biological resource that may be impacted by oil and gas development.

Regulations governing oil and gas development in Colorado have generally favored resource extraction and were considered by many to provide inadequate protection of public health and the environment. Due to recent rapid population growth[74] and increased oil and gas well development activity,[75] the state reevaluated its oil and gas regulations in 2006. In December 2008 the state adopted extensive new regulations governing oil and gas development that are believed to more strictly regulate adverse impacts associated with oil and gas development. The regulations include new and revised rules, including provisions for:

- Chemical disclosure;
- Waste management;
- Stream buffers;
- Emissions controls; and
- Public health and wildlife agency review.

4.7.3 Failures and Impacts

The COGCC allows citizens to research oil and gas inspections and incidents through its Colorado Oil and Gas Information System (COGIS). All reports of failures identified in Colorado along with a summary of enforcement data listed in COGIS are described in the following sections. No cases of failures associated with water consumption or gas production in Colorado were identified during the preparation of this report.

Case Study: Casing Failure

In early 2004, natural gas was observed bubbling into the stream bed of West Divide Creek near the towns of Rifle and Silt in Garfield County, Colorado. In addition to natural gas, water samples indicated benzene concentrations up to 99 μg/L in the creek and as high as 240 μg/L in the groundwater.

COGCC investigated the problem and found the operator (EnCana) had continued with drilling and completion operations after there were indications of subsurface problems and had failed to properly notify COGCC of the issues. Additionally, COGCC found the operator at fault for failing to adequately seal the gas producing formation in the well. This allowed gas and contaminants to migrate through the well, into naturally occurring fractures, and ultimately to the surface. Remedial casings installed in the well resulted in an immediate and substantial reduction at the seep.

Due to the incident, Garfield County began a series of hydrogeology studies to determine the nature and extent of groundwater problems due to gas well drilling. Two of three phases have been completed to date indicating methane and other contaminants in groundwater have increased as gas drilling activity increased. The cause is believed to be a combination of both naturally occurring fractures and inadequate casing or grouting in gas wells, similar to the EnCana incident. The reports recommend a comprehensive inspection program for existing wells to determine which, if any, have failed casings, in addition to continued groundwater monitoring of contaminants.

This case study details how a series of problems during well development due to local formation conditions (along with operator response) has the potential to result in well failure and water contamination. It also demonstrates how local geological conditions can contribute to wide-spread problems of groundwater contamination.

---

[73] Commercial injection wells and environmental protection not associated with oil and gas development are under the authority of the Colorado Department of Public Health and Environment.
[74] Colorado is ranked the fifth fastest growing state in the nation.
[75] Oil and gas permitting reached record numbers in both 2007 and 2008, with a total of over 14,000 permits issued for the two-year period.

Well Siting

A number of reports were identified claiming damage to terrestrial ecosystems associated with thumper trucks in Colorado. The U.S. Bureau of Land Management (BLM) allows oil and gas exploration on public land in southwest Colorado, a sensitive desert landscape home to many rare and threatened species. Thumper truck activity results in compacted soil and crushed vegetation, which due to the nature of the landscape and climate is very slow to recover.

Well Development

Very few reports of well development failures in Colorado were identified. However, one notable case in Garfield County has been reported multiple times in the media (inset). In 2004 a seep formed in West Divide Creek, releasing natural gas, BTEX and other contaminants into the stream, which also resulted in groundwater contamination. The state determined the seep was formed by a casing failure at a well less than a mile from the creek. The state issued a moratorium on all production within two miles of the seep to allow time for remediation and to investigate the failure.

Water Consumption

A recently completed draft study of the water needs for energy development in western Colorado prepared for the Colorado Interbasin Compact Committee Energy Subcommittee indicates there are no anticipated water supply problems associated with coal, natural gas or coalbed methane extraction. Although water resources are expected to become limited as oil shale becomes more viable in the next few decades.

Wastewater/Chemical Management

There have been numerous failures associated with chemical management in Garfield County. One instance reported in 2008 was the failure of a fracture fluid pit that released 1.6 million gallons of fluid, which then seeped into the ground and resurfaced as a waterfall through cracks in a cliff. Also in 2008, four large spills were reported that contaminated a tributary of the Colorado River. The agency is investigating the spills and has not released details, except that at least one of the spills was over one million gallons.

Another example is that of a truck accident that resulted in a spill of over 300 gallons of undiluted fracturing chemicals. In October, 2007, a mixer truck crashed on a gravel road in Garfield County. The vehicle went off the road and slid 20 feet down an embankment. Some of the constituents released included glutaraldehyde, methanol, naphthalene, isopropanol, 2-butoxy ethanol (2-BE), heavy aromatic petroleum naphtha, petroleum distillate, and a variety of ethoxylated alcohols. The spill was cleaned up by a private contractor. There was no report of water contamination.

Overall, COGIS records indicate there were over 1,500 spills related to oil and gas development in the four year period ending in March 2008. Approximately 300 of those events resulted in contamination of either groundwater or surface water. COGIS includes spill data from both oil and gas development, but the query structure does not allow for efficient filtering of spill data by type of well. However, surface operations for both oil and gas development are generally analogous such that activities that result in spills are similar for both types of operations.

Underground Injection/Monitoring and Enforcement

An incident occurred in 2004 related to both a leaking injection well and enforcement problems at a commercial injection facility in Colorado. The injection well leak detection system had indicated a problem with the well. Instead of reporting the problem, the owner and employees proceeded to falsify documents and water samples to avoid compliance. Upon discovery of the problem all three were convicted of criminal charges. Shallow groundwater was impacted by the release, but no drinking water wells were contaminated.

Other

An incident that occurred in Colorado, which is related to safety of first-responders, is the case of an emergency room nurse who became ill after assisting a worker to remove his boots soaked with fracturing fluids from a spill.[76] The nurse inhaled the fumes from the boots while helping the worker and later went into respiratory, cardiovascular, and liver failure, which was nearly fatal. The product's MSDS stated it contained 15 to 40% of a proprietary phosphate ester. As the nurse's health began to fail her doctor was unable to get information about the composition of the proprietary chemical from a number of sources to help determine the appropriate treatment. The product manufacturer, Weatherford, continues to refuse to specifically identify the proprietary chemical. This case helped encourage new chemical disclosure rules for Colorado. Additionally, some local communities have modified their first responder policies in how they deal with gas field workers whose clothing may be contaminated with chemicals.

The following incident highlights the potential for unforeseen impacts to occur. In the 1960s the U.S. Army injected millions of gallons of brine and chemical waste into a formation approximately 12,000 feet below the surface at the Rocky Mountain Arsenal in Colorado. The well was implicated in inducing a series of earthquakes that lasted over ten years, the largest of which was 5.3 on the Richter scale. The injected fluid is believed to have lubricated a dormant fault line. The Army stopped injecting wastes in 1966 and the well was permanently sealed in 1985.

4.8 Jonah Formation (Wyoming)

Wyoming is one of the largest producers of natural gas in the nation, typically producing approximately ten percent of total U.S. production. Most of its production has come from conventional formations and coal bed methane. The Jonah Formation is one area that contains a tight sandstone formation somewhat analogous to the Marcellus Shale. However, it is very small and does not lend itself to horizontal drilling. The Jonah Formation is located in the northwestern Green River Basin and produces primarily from fluvial deposits (floodwaters) of Cretaceous age. This formation is composed of medium- to very fine-grained sandstone, silty-sandstone, siltstone, and mudstone. The Jonah Formation[77] in Sublette County is less than 50 square miles but contains approximately ten tcf[78] of natural gas. Additionally, 98% of the surface and mineral estate is publicly owned, 94% by U.S. Bureau of Land Management (BLM) and 4% by the state.

---

[76] Moscou, J. (2008, August 20). "A Toxic Spew? Officials worry about impact of 'fracking' of oil and gas." *Newsweek* (http://www.newsweek.com/id/154394 accessed on 1/25/09).

[77] A small area referred to as the Pinedale Anticline is included as part of this formation.

[78] For comparison the Barnett Shale contains 2 to 30 tcf but is over 5,000 square miles in area.

Gas drilling activity in the Jonah Formation is extremely dense, utilizing predominantly vertical wells with no limits on number of wells or well spacing.[79] There have been a number of reports of drilling impacts associated with gas development in Sublette County. Impacts have predominantly been related to socio-economic issues, traffic, and air resources due to rapid, dense gas well development in the area. Accordingly, the EIS prepared by the BLM focused on socio-economic impacts, wildlife, and cultural resource protection.

> **New Mexico Pit Waste**
>
> Testimony was presented on November 13, 2007 at a Santa Fe, New Mexico Oil and Gas Commission hearing on the chemical content of residuals in six drilling reserve pits that were about to be closed. Of the 51 chemicals and metals found, only one (naphthalene) matched the list of chemicals known to be used in New Mexico during drilling or fracturing. Further investigation revealed that 90% of the chemicals reported in the pits were on the list of toxic chemicals for the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), and the Emergency Planning and Community Right to Know Act (EPCRA).

The EIS did include several provisions that have potential applicability to regulation of oil and gas development in New York.

- Establishment of the Jonah Interagency Office (JIO), the objective of which is to evaluate the effectiveness of guidelines, mitigation measures, BMPs, and monitoring activities in the formation.
- Payment of funds by operators for compensatory mitigation and JIO operational costs.
- Establishment of a groundwater monitoring program for all water wells in the area, which includes water quality testing and monitoring withdrawals.

It is difficult to gauge the effectiveness of the program, since it has been in place for less than three years. However, the JIO appears to be a promising management structure to coordinate gas drilling activities between the various operators and regulatory agencies. Additionally, costs for the JIO are paid by operators through the compensatory mitigation fund, therefore reducing reliance on state funding.

4.9 Fruitland Formation (New Mexico)

4.9.1 Overview of Geologic Setting and Natural Gas Development Activities

New Mexico has long been a top producer of oil and gas; it is often ranked in the top five for onshore production. Historically natural gas has been produced from conventional formations, and more recently unconventional formations. The Cretaceous age Fruitland Formation is one such unconventional formation and is composed of sandstone, shale, and coal. It is found in the San Juan Basin underlying the border of New Mexico and Colorado. The methane generating coal beds of New Mexico do not appear to be analogous to the Marcellus Shale Formation in regards to horizontal drilling and high-volume hydraulic fracturing. However, there are lessons that can be learned from how New Mexico has administered surface operations and waste management.

---

[79] BLM released a Record of Decision for its Final EIS in 2006 allowing intensive well development but limiting cumulative land disturbance along with numerous other conditions and mitigation requirements.

According to the New Mexico Petroleum Recovery Research Center there are approximately 55,000 active oil and gas wells in the state. According to the Groundwater Protection Council there are approximately 4,900 underground injection wells in New Mexico, most of which are used for enhanced recovery of crude oil.

4.9.2 Regulatory Context

The New Mexico Oil Conservation Division (NMOCD) has authority to regulate most aspects of oil and gas development. The New Mexico Environment Department has jurisdiction over state environmental programs. The two organizations jointly administer the UIC program and publish numerous manuals regulating oil and gas operations in the state.

Pits for storing drilling wastes have generally not required a permit in New Mexico. Due to the lack of state oversight for pit construction or maintenance, pits have been responsible for hundreds of instances of groundwater contamination. In 2008 the NMOCD issued extensive new pit rules to reduce further groundwater contamination from oil and gas pits.

Revised Regulations

In 2008 Colorado, New Mexico, and Fort Worth, TX all significantly revised oil and gas drilling regulations to address many of the impacts caused by the industry. The new regulations are too recent to determine if there has been any quantifiable reduction in the occurrence of impacts. Below is a brief summary of some of the provisions enacted:

- Pre- and post-drilling water quality measurements for wells in proximity to waterways or wetlands;
- Introduction of setbacks restricting drilling or requiring closed tanks for liquid waste and other fluids;
- Coordination with local utilities and public safety officials of activities and materials stored on-site;
- Requirements to directly notify local utilities and public safety officials of spills; and
- Approval by local officials of hazard management plans and emergency response plans.

4.9.3 Failures and Impacts

Well siting, water consumptions and well development in New Mexico are not generally comparable to activities expected to occur in the Marcellus Shale, and no cases of failures associated with gas production, underground injection, or monitoring and enforcement in New Mexico were identified during the preparation of this report.

The NMOCD does provide a summary report of cases of groundwater contamination associated with oil and gas development, which indicates New Mexico has a relatively poor record of waste and chemical management at oil and gas drilling sites. In the last ten years NMOCD has reported nearly 700 confirmed cases of groundwater contamination associated with oil and gas development, most of which are related to pits.

4.10 Summary

The data compiled for this section indicate that many natural gas wells are completed without incident. Of the reported incidents, most were related to water quality impacts. Water quantity impacts were much less prevalent, typically due to insufficient water withdrawal regulations. No water supply infrastructure incidents were identified, though it is acknowledged that most gas well drilling has occurred in areas that are not analogous to the NYC watershed area in terms of prevalence of large water transmission infrastructure.

In most cases failures were isolated and caused by human error or negligence, unknown subsurface conditions contributed to a number of incidents as well. Systemic problems were less common and generally the result of inadequate regulation. Colorado, New Mexico, and Fort Worth, Texas have all enacted new regulations in an attempt to address the causes of previous failures. Other states, such as Pennsylvania, are currently pursuing new regulations.

Incidents cataloged in this section provide an indication of the types of problems that could potentially magnify under increased natural gas development activity in New York. Key areas of concern include groundwater and surface water contamination with fracing chemicals or formation materials, the availability of environmentally sound methods for treatment and disposal of frac and produced water, excessive water withdrawals in sensitive stream reaches, and cumulative impacts associated with large-scale natural gas development activity.

The rate and density of natural gas well construction is a critical factor in evaluating potential impacts to the NYC water supply. Based on available data from the Barnett and Fayetteville shale plays, well completion rates in these areas have since 2004 averaged roughly 1725 and 280 wells per year, respectively. Scaling these rates based on the relatively smaller size of the NYC watershed (~1500 square miles), a similar pace of development in the NYC watershed would translate to well completion rates on the order of 50 to 500 wells per year.

Section 5: Subsurface Risks to NYCDEP Infrastructure

This section has been redacted for security reasons

Section 6: Summary of Findings

This section summarizes the major potential risks from natural gas development activities within the NYC watershed (or near critical infrastructure) on water quality, water quantity, and water supply infrastructure that have been identified during this Rapid Impact Assessment.

6.1 Water Quality

Nearly every activity associated with natural gas development in the Marcellus Shale has the potential to impact NYC source water quality to some degree, although some impacts are more likely and have already proven to be problematic in other states. The following sections describe the potential risks to water quality based on general categories of natural gas development activities.

6.1.1 Well Siting

The majority of the impacts anticipated during well siting are expected to be those typically related to land disturbance (e.g., habitat destruction, erosion, etc.). Current State and City regulatory programs provide a structure for mitigating such impacts on a site-by-site basis. Depending on the scale and intensity of drilling operations in the NYC watershed, substantial increases in levels of staffing for permitting, monitoring, inspection, and enforcement may be required to minimize adverse impacts.

6.1.2 Well Development

As described in Section 2, disruption of existing flow regimes can result in groundwater contamination due to the migration of poor quality groundwater or contaminants into shallow fresh-quality groundwater via communication with deeper formations. Surface water quality can hence be affected by baseflow contributions to local streams by contaminated groundwater.

Numerous reports of drinking water well contamination proximal to drilling operations were identified in the course of this review.[84] The exact causes vary from site to site, and in many cases are not identified. Conditions that may lead to groundwater contamination during well development activities include existing subsurface fractures, failed casings, poor annulus seals, grouting failures, and unsealed or over-pressurized formations, among others. Strict well construction standards and rigorous outside monitoring/inspection during well development may help reduce the incidence of these problems, but cannot be expected to eliminate the potential for problems to occur.

6.1.3 Gas Production

Development of the Marcellus Shale (or any of the other gas producing units in the region) will require miles of new collector pipelines to deliver gas from individual wells to regional

---

[84] Information reviewed for this report did not differentiate between failures from vertical versus horizontal wells, or between the vertical and lateral components of horizontal wells. Additionally, no comprehensive studies have been identified that evaluate the potential for hydraulic fracturing operations to allow contaminant migration from deeper formations into fresh water aquifers.

transmission pipelines. The primary impacts associated with pipeline production are erosion and habitat destruction. Fires or explosions are also a risk associated with gas pipelines in areas of intensive gas production; under dry conditions pipeline fires or explosions could potentially lead to forest fires.

6.1.4 Wastewater/Chemical Management

Improper wastewater/chemical management appears to be the greatest risk to source water quality from gas development activities. Accidental spills, leaks, and releases have resulted in hundreds of documented groundwater and surface water contamination incidents across the country. Unlined or substandard waste pits are a common cause of contamination. Additionally, poor pit siting (i.e., proximity to streams) increases the risk of water resource impacts in the event of failure. Hauling of chemicals and drilling/fracturing wastes expands the area at risk from spills beyond the drill site itself. Chemical/waste transit routes that run adjacent to or cross streams or reservoirs in the NYC watershed would pose a heightened risk of water quality impairment. More stringent regulations for on-site storage (e.g., pit or tank requirements), in addition to tracking waste to its ultimate disposal location, could help prevent accidental releases.

6.1.5 Ultimate Disposal

Hydraulic fracturing in the region will produce large volumes of wastewater that are difficult to treat due to the presence of elevated TDS and organic chemicals. Surface disposal is limited by treatment capacity and the ability of streams to assimilate the waste. There are currently several oil and gas wastewater treatment plants planned for the region. However, until these plants come on-line, there will continue to be uncertainty as to the availability of environmentally sound methods for treatment and disposal of wastewater derived from natural gas development. Without an effective regional waste management plan to address this issue across affected states and river basins, regional contamination events such as that experienced in the Monongahela Basin may increase.

Underground injection is a common disposal method for drilling and fracturing waste disposal. Although utilization has so far been limited in New York, the number of injection wells could increase substantially as the Marcellus Shale is developed. Several cases of injection well failure resulting in surface and groundwater contamination were identified for this report from other states. Proper design, monitoring, reporting, and inspection are critical for preventing failures or detecting them early to prevent wider impacts. Induced seismicity and potentials impacts to NYC infrastructure should be considered carefully when siting underground injection wells.

A further potential risk associated with underground injection wells is the presence of improperly closed or abandoned oil or gas wells, which could act as conduits for injected waste to move beyond the target storage formation. DEC indicates that it lacks records for over 50% of the oil and gas wells that have previously been constructed in the state. Thus, the location and condition is unknown for approximately 40,000 wells that could serve as conduits for injected fluids to contaminate groundwater or surface water.

6.1.6 Monitoring and Enforcement

Effective permit review, monitoring, inspection, and enforcement by responsible agencies are critical to ensure compliance with regulations and minimize adverse impacts. Deficiencies in this arena may be linked to inadequate funding, regulatory capture, negligence, or insufficient technical training.

6.2 Water Quantity

Hydraulic fracturing requires large volumes of water which could potentially impact the water supply reliability of the NYC water system. Impacts depend on several factors, including the location, timing, source, and magnitude of withdrawals. Additionally, as indicated in Section 2, groundwater flow regimes could be altered by natural gas development, potentially impacting stream baseflow. Surface withdrawals will have a direct effect on stream flows, whereas groundwater withdrawals will typically have an indirect impact and a related lag in timing of impact, depending on the hydrogeology.

The location of withdrawals can impact DEP by either directly reducing inflows to NYC reservoirs or by requiring additional reservoir releases to meet downstream flow targets (e.g., Delaware Basin Montague Flow Target, Shandaken Tunnel and Esopus Creek flow and water quality requirements). The timing of withdrawals, both with respect to season (e.g., winter/spring vs. summer/fall) and year (wet year vs. dry year) is an important factor in determining impacts on NYC reservoir storage levels and other goals (e.g., refill by June 1, maximum drawdown maintaining sufficient volume for cold water fisheries, etc.). The magnitude of withdrawals will heavily influence the overall impact on NYC water supply reliability.

Successful water resources management in other areas of the country experiencing rapid gas well development appear to depend on effective regulatory/water rights structures and sound long-term planning efforts. Without these two components, water demands related to extensive gas well development may impair existing uses. This is of particular concern in the Catskill watershed, which lacks the withdrawal permitting authority and basin-level planning framework provided in the Delaware watershed by the DRBC.

6.3 Water Supply Infrastructure

Drilling and hydraulic fracturing operations in close proximity to critical NYC infrastructure (e.g., tunnels/aqueducts and dams) could potentially lead to leaks or structural failures with subsequent severe and/or catastrophic impacts on the NYC water system. There is also a risk of influxes of poor quality groundwater and/or natural gas under certain conditions. Portions of NYCDEP infrastructure are at high risk due to close proximity to the Marcellus Shale Formation. Additionally, issues encountered during construction of certain sections of pipelines and tunnels (e.g., rock fractures or methane gas) could be indicative of existing communication pathways with natural gas producing bedrock units such as the Marcellus Shale Formation.

No incidents of impacts to water supply infrastructure were found during the preparation of this report. However, there appears to be no other gas-producing region in the U.S. that has a density of large, critical water supply infrastructure comparable to that of the NYC watershed.

6.4 Conclusion

There is a broad range of activities during natural gas development that have the potential to contaminate groundwater or surface water supplies, cause reliability problems from water withdrawals, or damage critical DEP infrastructure. Effective regulation, inspection programs, inter-agency coordination, and regional planning can minimize these potential impacts, but they cannot be expected to eliminate risks to the water supply.

Though the majority of natural gas development activities may occur without causing such impacts, even a small number of water contamination incidents could have a substantial negative impact on public confidence in the NYC water supply. In addition, were natural gas development to occur at a density and rate observed in other major shale plays, the cumulative impacts could stress the efforts of DEP and other watershed stakeholders to protect the unfiltered water supply.

Overall, the pace of gas well development in the region and the ability of regulatory agencies to manage the process will have a substantial influence on the resulting level of risk to the NYC water supply system. Managed development that occurs at a pace commensurate with available inspection and oversight resources may help reduce impacts associated with natural gas development.