Section 1: Introduction

1.1 Project Background

In recognition of increased natural gas development activity in New York State and its potential to impact New York City's water supply, the NYCDEP 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.

NYCDEP retained the Joint Venture of Hazen and Sawyer, P.C., an environmental engineering firm, and Leggette, Brashears & Graham, Inc., a hydrogeologic and environmental consulting firm, to assist in performing this assessment. The first phase of the project included evaluation of regional hydrogeology and development of a conceptual hydrogeologic model of the region, characterization of activities and impacts associated with natural gas well development, review of a database of drilling and fracturing chemicals, examination of case studies from other formations, and preparation of a preliminary infrastructure assessment. Results from the first phase were summarized in a Rapid Impact Assessment Report issued in September 2009.

The current Final Impact Assessment Report incorporates the previous work into a cumulative watershed risk assessment and provides further evaluation of subsurface migration pathways and risks to NYC infrastructure.

1.2 New York City Water System and Source Protection Measures

The New York City water system is comprised of three separate supply systems – the Catskill, Delaware, and Croton systems. Approximately 90 percent of the City's water supply (more than one billion gallons per day) is drawn from the Catskill and Delaware systems located west of the Hudson River in upstate New York. As such, it is NYCDEP's mission and responsibility to protect both the NYC water supply system and public health and safety, ensuring continued reliability in serving nine million consumers within New York City and upstate communities (in Westchester, Putnam, Orange, and Ulster Counties) who depend on the New York City system as the primary source of their drinking water. The NYC watershed is a working watershed that supports multiple uses. The 1997 Watershed Memorandum of Agreement signed by New York State Department of Environmental Conservation (NYSDEC), NYCDEP, Environmental Protection Agency (EPA), environmental parties, and numerous local governments committed the parties to foster economic development within the watershed that is consistent with principles of watershed protection.

The City's decision to pursue source water protection was based in part on the existing quality of the water and in part on the belief that keeping pollutants out of the water was in the long term a more sustainable strategy than the more conventional approach used by most water suppliers – employing treatment technologies to remove pollutants after they get in the water.

The West-of-Hudson watershed is a pristine, largely undisturbed landscape, characterized by high rates of forest cover (78 percent) and predominantly rural land uses. Development has historically been confined to the river valleys and impervious surfaces cover a mere 1.2 percent of the land area. Dairy farms are a common part of the rural landscape, particularly in the far western reaches of the watershed, and there are minimal industrial activities. These natural and land use factors combine to produce a very high quality water from the Catskill/Delaware watershed.

Beginning in the early 1990s, NYCDEP initiated development and implementation of a suite of programs designed to preserve and enhance the existing quality of the Catskill/Delaware source waters. Prior to undertaking design of protection programs, NYCDEP initiated a comprehensive water quality monitoring program. Samples were taken at various locations and frequencies to accurately characterize water quality conditions throughout the watershed. Data acquired through this effort was used to identify existing and potential pollution sources and to identify pollution control strategies. Based on monitoring data, NYCDEP identified the primary threat to water quality as coliforms, pathogens, nutrients and turbidity. To this day, those pollutants – which largely derive from natural sources, limited residential development, and agriculture – remain the primary pollutants of concern for the New York City water supply.

DEP's watershed protection program is based on water quality science supported by extensive monitoring and water quality data. Various program elements seek to either remediate existing sources of pollution or to prevent future sources. The overall program has been tailored to be mindful of and support the economic vitality of the communities and the residents of the Catskills. The major elements of the watershed protection program include:

- Land Acquisition – increasing the amount of land to be preserved in its natural condition;
- Watershed Regulations – primarily targeting stormwater and wastewater pollution from development;
- The Watershed Agricultural Program – working with watershed farmers to implement pollution control practices on farms;
- The Stream Management Program – working with riparian landowners to restore degraded streams to more natural conditions;
- The Wastewater Treatment Upgrade Program – funding the upgrade of all pre-1997 WWTPs in the watershed to state-of-the-art tertiary treatment;
- The New Infrastructure and Community Wastewater Management Programs – designing and constructing new wastewater infrastructure for communities with concentrations of failing or likely-to-fail septic systems;
- The Septic Rehabilitation Program – funding the repair or replacement of failing septic systems for individual residences and small businesses;
- The Stormwater Retrofit and Future Stormwater Controls Control Programs – seeking to address pollution from stormwater runoff, either by retrofitting existing sites or funding compliance with the Watershed Regulations; and
- The Watershed Forestry Program – working with owners of forested land to promote a vigorous forest landscape and forestry practices that are protective of water quality.

Taken together, these programs effectively address the current range of human activity in the watershed that could threaten water quality. Instrumental to the success of the City's program has been the strong collaboration between a multitude of stakeholders – watershed

representatives and residents, environmental groups, regulatory agencies and NYCDEP. These partnerships are key to the success of the programs because certain elements have the potential to modify individual property rights and community growth goals. The City has worked to develop programs that strike an appropriate balance between water quality preservation and community interests.

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 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 Filtration Avoidance Determination 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.

Proof of the effectiveness of the City's approach lies in the fact that water from the Catskill/Delaware system continues to be of exceptionally high quality and is virtually free of chemical contaminants. Water supply monitoring is extensive and far exceeds regulatory requirements, both in the watershed and in the distribution system. NYCDEP operates five modern water quality laboratories throughout the watershed and distribution system, and processes approximately 50,000 samples from 1,400 sample locations for up to 240 contaminants and 600,000 analyses per year. Analyses performed include those for basic physical parameters, nutrients and metals, and tests for disease-causing organisms such as bacteria, viruses and protozoans. Additionally, the water supply is routinely scanned for synthetic organic compounds at watershed locations and throughout the distribution system. Extensive monitoring is used to ensure that NYCDEP delivers the highest quality water to the consumer and helps to instill a high degree of public confidence in the water supply system.

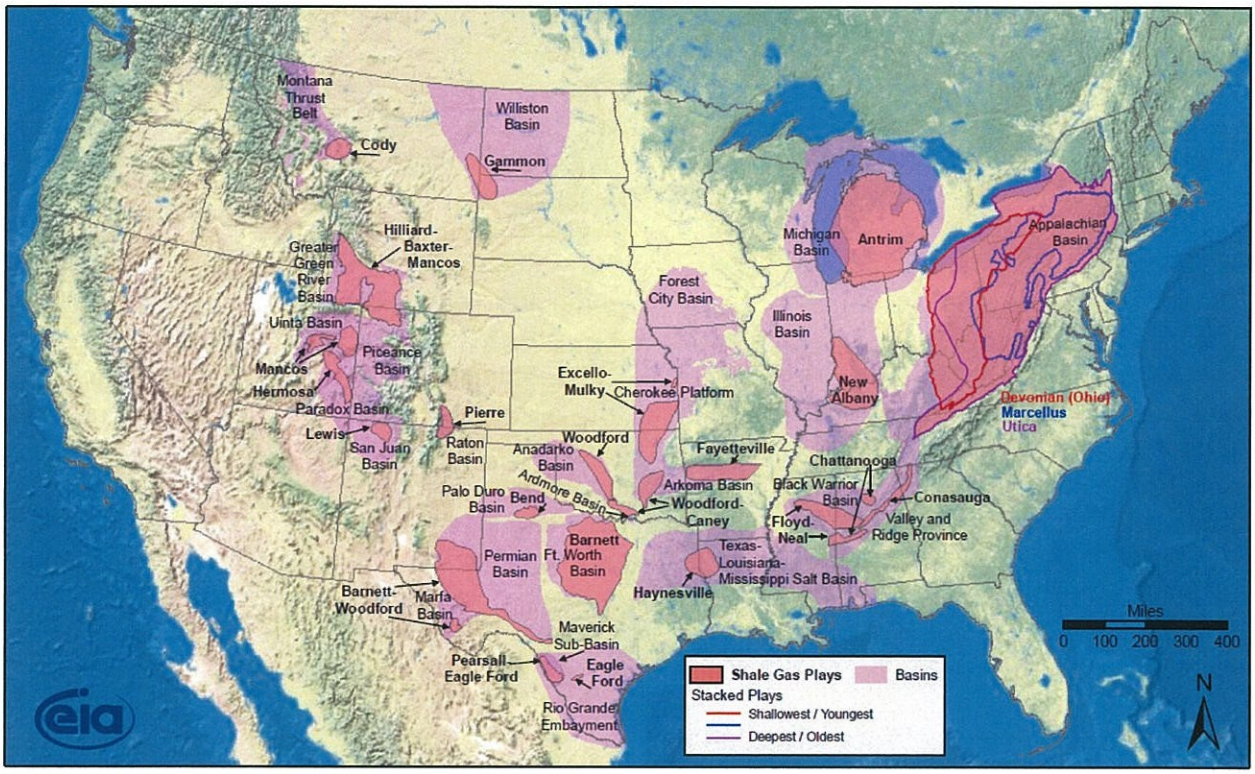
1.3 Trends in Drinking Water Regulations

Currently, the federal Safe Drinking Water Act requires the monitoring of about 90 contaminants in water supply systems. Additionally, the Unregulated Contaminant Monitoring Rule and the Candidate Contaminant Listing process require EPA to establish criteria for expanding the number of contaminants subject to monitoring requirements, and require EPA to make determinations on regulating additional contaminants. As a result of these rules and listing processes, as public health concerns associated with chemical contaminants continue to increase, and as analytical techniques improve, the trend will be toward more stringent drinking water regulations in the future. The number of regulated contaminants will expand and the maximum contaminant levels (MCLs) of contaminants are likely to decrease. The recent heightened national concern over pharmaceuticals and emerging contaminants, and most recently the Environmental Working Group's report on chemical contamination in water supply utilities in the United States,[2] gives a clear indication that the public's expectation is for contaminant-free drinking water. This expectation is consistent with NYCDEP's mission to deliver the highest quality water possible to the consumer.

[2] Available at http://www.ewg.org/tap-water/home.

1.4 Overview of Natural Gas Well Development

Shale formations with gas producing potential are distributed throughout much of the United States (Figure 1-1). Recent technological advances such as hydraulic fracturing and horizontal drilling, in combination with market forces, have made the development of shale gas resources economically viable. The most heavily developed shale gas "play" is the Barnett in Texas and dates back only to the late-1990s. The Fayetteville in Arkansas and the Haynesville in Louisiana and Texas are other major plays that have been more recently developed. There is currently substantial interest in the Marcellus formation because of its size and gas-producing potential.



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

Figure 1-1: Gas-Producing Shale Formations in the US

Shales are generally considered geologically "tight" formations with limited permeability and primary porosity.[3] Hydraulic fracturing is employed to increase permeability and porosity of the rock mass and enhance the movement of gas to the well bore. Horizontal drilling is employed to increase the areal extent from which gas can be drawn to a single well location. The Marcellus and other potential gas-producing formations underlie most of New York, and the state is currently in the process of approving horizontal drilling and high-volume hydraulic fracturing for exploiting these resources.

The natural gas development process using horizontal drilling/high-volume hydraulic fracturing is initiated in a similar manner to traditional gas exploration and includes mapping and geologic

[3] Primary porosity is the void space that remains between grains of sediment deposits after initial deposition and rock formation. Sedimentary rocks, such as the Marcellus Formation, are formed from the compaction of sediments. Secondary porosity results from fractures or other post-depositional physical changes to the formation.

analysis, seismic testing, leasing of mineral rights from landowners, and submission of well permit applications. Each well is assigned to a spacing unit, which roughly corresponds to the area of land from which the well is assumed to be extracting natural gas. For multiple horizontal wells drilled from a common well pad, as is expected for most Marcellus wells, a spacing unit of up to 640 acres (one square mile) is allowed.[4] Spacing unit requirements do not limit the number of horizontal wells that may be drilled from a multi-well pad. Instead, the total number of wells per spacing unit is governed by the number of wells needed to efficiently and economically extract the natural gas resources within a given spacing unit. Industry reports cited in the draft Supplemental Generic Environmental Impact Statement[5] indicate that six to ten wells will be developed per well pad in the Marcellus.

Initial site activities include clearing, grading, and construction of site access road, well pad, and utilities. The size of the pad is expected to be on the order of five acres. Total area requirements including well pad and related features such as roads and pipelines are estimated at seven acres per well pad based on data from the Fayetteville shale.[6] Once the site is prepared and the drill rig and ancillary equipment are set up, operators begin drilling the well. In the New York area, wells will likely consist of a 3,000- to 7,000-foot deep vertical section that extends from the surface to the target formation, plus a horizontal section that extends laterally for an additional 2,000 to 6,000 feet. The lateral section is not allowed to extend beyond a specified setback distance from the spacing unit boundary.

Construction of gas wells in the Marcellus formation requires drilling through shallow freshwater aquifers and penetrating deeper geologic formations that contain naturally-occurring contaminants such as hydrocarbons, metals, radionuclides, and high salinity. The well borehole creates a conduit for fluid to flow between these previously isolated geologic formations. To prevent such flow, the annular space between the well casing and the formation is filled with grout.

After the well is drilled, cased, and grouted, the operator proceeds with hydraulic fracturing operations to stimulate gas production. The process entails injecting a mixture of water and chemicals into the well at high pressure to create fractures in the gas-bearing formation, thus increasing its permeability and enhancing the release of gas for collection. Sand or other inert materials (i.e., proppants) are injected with the fluid mixture to prop open the fractures. A typical fracturing operation may require on the order of three to eight million gallons of water, depending on formation characteristics, lateral length, and fracture design. Water may be obtained from surface or groundwater sources; to date most fracking operations have used fresh or low salinity water.

A variety of chemical additives are added to fracking fluid to control fluid properties. Chemicals are often cited as making up 0.5 to 2.0 percent of the fracking fluid. For a four million gallon fracture operation, this translates to 80 to 330 tons (160,000 to 660,000 lbs) of chemicals per

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[4] Natural gas well spacing unit requirements are defined in ECL §23-0501.

[5] Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program – Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs.

[6] U.S. Department of the Interior. 2008. *Reasonably Foreseeable Development Scenario for Fluid Minerals: Arkansas*. Prepared for the Bureau of Land Management Eastern States Jackson Field Office. March 2008.

well. The exact chemical composition of many additives is not known. Of the known chemical components, many are toxic to the environment and human health.

The active drilling and fracturing process requires on the order of four to eight weeks per well. When support activities such as site clearing and grading, pad construction, mobilization and demobilization of drill rigs and other equipment, water delivery, and waste disposal are included, the time during which a drill site can be considered active is on the order of four to ten months for one well, depending on site-specific conditions. For a multiple well pad, site activities may be sequenced such that multiple wells are under various stages of concurrent development. All wells from a multi-well pad must be completed within the three year permit period. A high volume of heavy truck traffic (approximately 800 to 1,200 trips per well) is required during the development process to convey equipment, chemicals, water, and waste to and from the site.

Wastewater disposal is a critical feature of hydraulic fracturing operations. A sizeable fraction (approximately 10 to 50 percent or more) of the original fracturing fluid volume is returned to the surface as "flowback" over a period of several weeks. Flowback water contains chemical additives and naturally occurring formation materials, including high levels of total dissolved solids, metals and naturally occurring radioactive material (NORM). Flowback water is trucked off-site for disposal at underground injection wells, certain municipal wastewater treatment plants (WWTPs), or industrial WWTPs.

When drilling and stimulation operations are complete, the drill rig and equipment are removed and the site is partially restored. If the well produces gas, pumping and treatment equipment are installed at the site and pipelines are constructed to connect the well to the regional transmission network. Tanks are also constructed for temporary storage of the "produced" water that the gas well discharges during the course of normal operation.

As the well ages and the gas production rate declines, the well may be re-fractured to boost productivity. Limited data from the Barnett shale indicates the interval between re-fracturing operations could range from one to more than ten years. The useful life of a well may be on the order of 20 to 40 years; at the end of this time the well is plugged and abandoned. For locations overlying "stacked" shale plays, which appears to be the case in the NYC West-of-Hudson watershed, it is unclear whether multiple gas-bearing formations in the "stack" would be developed simultaneously, or if development of other formations would ultimately require the service life of the site to be extended. Once there are no longer other wells or collection facilities operating on the same well pad, the site can be fully restored.

1.5 Regulatory Context for Gas Exploration and Development

Federal Regulations

Many of the activities associated with natural gas development have the potential to pollute air or water and therefore fall under the nominal jurisdiction of a number of federal environmental regulations, including the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act and the Toxic Release Inventory reporting requirements of the Emergency Planning and Community Right to Know Act. However, each of these regulations currently contain important exemptions regarding the definition, reporting, use, and disposal of the toxic chemicals required during hydraulic fracturing and other gas development activities. At

this time there are few constraints on natural gas development at the federal level, and related activities are generally regulated at the state level.

State Regulations

Natural gas development in New York is regulated by the NYSDEC, which under the Environmental Conservation Law (ECL) is charged with conserving, improving and protecting natural resources and the environment, preventing water, land and air pollution, and authorizing the development of gas properties to increase the ultimate recovery of oil and gas resources.

In 1992, NYSDEC finalized a Generic Environmental Impact Statement (GEIS) on the Oil, Gas and Solution Mining Regulatory Program as part of the State Environmental Quality Review Act (SEQRA) process. At the time the GEIS was drafted, the use of horizontal drilling and high-volume hydraulic fracturing for oil and gas extraction in shale and tight sandstone reservoirs was not technologically feasible. Since that time extraction technologies have matured and led to commercially viable development of the Marcellus and other formations. In 2008, Governor Paterson directed NYSDEC to prepare a supplemental GEIS (SGEIS) to review potential additional impacts related to these technologies.

The draft SGEIS was released on September 30, 2009, and included analysis of potential impacts and established a number of permit conditions for drilling applications. Several salient conditions established in the dSGEIS include:

- A requirement for site-specific SEQRA reviews for wells within 1,000 feet of NYCDEP infrastructure, well pads within 300 feet of a reservoir, or well pads within 150 feet of other surface waters. Outside of these setbacks, no additional watershed-specific review is required (i.e., wells may be drilled anywhere else in the NYC watershed or adjacent to tunnels without additional review).
- Baseline and periodic ongoing groundwater water quality testing is required for private wells within 1,000 to 2,000 feet of a gas well.
- Operators are required to disclose to NYSDEC the fracturing products (i.e., additives) that will be used for a given well.
- Surface water withdrawals must allow a specified passby flow to maintain stream habitat.
- Various mitigation plans are required for visual impacts, noise impacts, invasive species, and greenhouse gases.

The dSGEIS is presently under review and is not anticipated to be finalized until 2010. Therefore the proposed permit conditions and mitigation requirements included in the final SGEIS may differ from those described herein.

NYC Watershed Regulations

With the exception of requiring NYCDEP approval of stormwater management plans for activities meeting certain impervious surface or disturbance thresholds, the NYC Watershed Rules and Regulations have little or no applicability to horizontal drilling and high-volume hydraulic fracturing activity in the watershed.

1.6 Report Organization

- Section 2 describes regional geology and hydrogeology and discusses pathways for subsurface migration of fracturing chemicals and formation water;
- Section 3 describes the rates and densities of natural gas well development in comparable formations, and estimates the number of wells that could be constructed in the NYC watershed on an annual basis and under a full build-out scenario;
- Section 4 presents an assessment of cumulative impacts of natural gas well development in the NYC watershed;
- Appendix A provides more detail on the geology and hydrogeology of the region;
- Appendix B provides more information on rates and densities of well development;
- Appendix C provides more detail on the analysis of surface spills; and
- Appendix D identifies potential mitigation measures for reducing the risk of impacts to the water supply.