
Water Use Associated with Natural Gas Shale Development: An Assessment of Activities Managed by the Susquehanna River Basin Commission

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The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland and New York, the Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with Basinwide authority, the Commission's goal is to coordinate the planning, conservation, management, utilization, development, and control of Basin water resources among the public and private sectors.

*Statutory Citations: *Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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DEFINITIONS

Report Period – Also referred to as the “report period” or “period,” the term covers the span of time from July 1, 2008 through December 31, 2013.

Basin – The term Basin is used throughout the report to identify the Susquehanna River Basin.

Commission – A name used to represent the Susquehanna River Basin Commission.

Consumptive Water Use – A term used by the Commission to identify water that has been withdrawn from either groundwater or surface water sources, or from public water supplies, and is used in such a way that it is not returned to the Basin undiminished in quantity. Water that is evaporated, transpired, incorporated into products, or injected underground is removed from the hydrologic cycle of the Basin and unavailable for future use within the Basin and is therefore considered to be consumptively used. The Commission assumes that 100 percent of all water obtained by the gas industry is consumptively used and therefore removed from the hydrologic cycle of the Basin.

Docket – The Commission approves individual projects in the form of an official document. This document is referred to as a docket. Each docket contains the name of the project sponsor, a description of the project features, the location of the project, approved withdrawal or consumptive use limits, general Commission conditions, and project-specific conditions.

Flowback – A term used by the Commission to represent the return flow of water and formation fluids recovered from the wellbore of a hydrocarbon development well (including unconventional gas wells) following the release of pressures induced as part of the hydraulic

fracture stimulation of a target geologic formation. These fluids are considered flowback until the well is placed into production.

Industry – The word industry will be used throughout this document to represent the unconventional natural gas industry.

Production Fluids – A term used by the Commission to represent the return flow of water or formation fluids recovered at the wellhead after the well is placed into production. This term is synonymous with produced water.

Unconventional Natural Gas Development – Used by the Commission to represent the drilling, casing, cementing, stimulation, and completion of wells undertaken for the purpose of extracting gaseous hydrocarbons from low permeability geologic formations utilizing enhanced drilling, stimulation, or recovery techniques.

Water Source – The original location or position within a watershed of a surface water or groundwater withdrawal.

Water Withdrawal – A term used to represent a volume or quantity of surface water or groundwater that has been physically removed from its original location or position within a watershed for use by the industry. In simplistic terms, water withdrawals can be considered in this document to be the beginning of the journey and consumptive use to be the end of the journey for water acquired and used by the industry.

I. Introduction

A. Objectives

With the early stages of the unconventional natural gas industry activities now having been completed, the Susquehanna River Basin Commission (Commission) considered it important to review and assess those activities from a water management perspective. The primary objectives of this report are to summarize the following: 1) the regulatory responses taken by the Commission to address this new, and previously unfamiliar, energy sector activity; 2) the water use characteristics of the industry operating within the Susquehanna River Basin (Basin); 3) the various water quality monitoring activities conducted by the Commission in response to industry activity; and 4) the efforts undertaken by the Commission to track the industry's compliance with its regulations.

The detailed information presented in this report includes:

- The role of the Commission in regulating water acquisition and consumptive water use by the gas industry.
- A detailed summary of the number of wells permitted, drilled, and fractured within the Basin during the assessment period of July 2008 through December 2013.
- The amounts of water acquired and consumptively used by the industry during the assessment period of July 2008 through December 2013.
- The sources of surface water and groundwater developed by the industry to meet its water needs.
- The aquatic resource surveys conducted by the Commission as part of the project review process.
- The remote water quality monitoring network established by the Commission to detect and document potential negative impacts on water quality associated with natural gas industry activities.
- The auditing program established by the Commission to document the level of compliance of the natural gas industry with applicable Commission regulations.

The information contained in this report is presented in four parts. Part I details the regulatory role of the Susquehanna River Basin Commission. Part II presents a discussion of the number of unconventional gas wells permitted, drilled, and hydraulically fractured within the Basin during the report period; the amounts and locations of water withdrawals and water consumption by the unconventional natural gas industry operating within the Basin during the report period; and the limitations of the water withdrawal approvals issued to the industry by the Commission. Part III of the document discusses the operational changes made at the Commission in response to the industry's water-related activities conducted within the Basin. Part IV of the document contains a summary of the observations made and conclusions drawn regarding water use by the industry during the report period; the ability of the Commission to

adequately address the sustainability of the water resources of the Basin; and the water-related changes expected to occur at the Commission and within the Basin as the industry matures.

B. Historic Perspective

According to Carter et al. (2011), the first commercial gas well in Pennsylvania was drilled in Oil Creek Township, Crawford County, in 1872. The earliest shale gas wells located within the Basin were reportedly drilled in 1881-1882 at a location west of Tunkhannock, Wyoming County. At least one of these wells was drilled to a depth of 2,089 feet (Ashley and Robinson, 1922).

The use of hydraulic fracturing techniques to enhance oil and gas production began in 1949 when Halliburton Oil Well Cementing Company received the first patent and exclusive license (Petroleum Transfer Technology Council, 2011). Although not part of the actual well drilling process, this technique is used to increase the productivity of individual wells by physically fracturing the bedrock in which the oil or natural gas is held and thereby facilitating the movement of the oil or gas from the bedrock into the perforated casing of the well. The first recorded use of hydraulic fracturing to stimulate deep gas wells in Pennsylvania occurred in 1953 in Elk County, Pennsylvania, on property owned by the Commonwealth of Pennsylvania (Fettke, 1954). According to Lytle (1964) and Carter et al. (2011), by 1963, more than 70 percent of deep gas wells in Pennsylvania were stimulated using hydraulic fracturing technology.

The first horizontal oil well in Pennsylvania was drilled in 1944 and located in Venango County. However, the applicability of horizontal well drilling technology to commercial gas wells nationwide did not occur until the early 1980s (U.S. Energy Information Administration (EIA), 1993)). It is unclear when the first horizontal gas well was drilled within Pennsylvania using directional drilling technology. However, in 2003, Range Resources Corporation drilled the Renz No. 1 gas well in Mount Pleasant Township, Washington County, Pennsylvania. The well was subsequently deepened and hydraulically fractured in 2004. It is commonly held that this Renz No. 1 well marked the beginning of the modern Marcellus Shale gas industry in Pennsylvania (Carter et al., 2011). The marriage of horizontal well drilling technology with hydraulic fracturing techniques defines the unconventional natural gas industry as it currently exists within the Basin.

The unconventional natural gas industry first received permits to drill wells within the Basin from the Pennsylvania Department of Environmental Protection (PADEP) in the first half of 2005 (PADEP, 2012). Initial wells included both exploratory vertical wells and relatively short horizontal wells. Both types of wells were primarily used by the industry to hold land leases and prove that natural gas contained within specific geologic formations could be physically and economically withdrawn.

It has been many years since a land use or natural resource development activity occurring within the Basin has created more public scrutiny and a greater infusion of external monetary investment than has the development of the unconventional natural gas industry. Within a few short years, the industry that had been operating within the Basin for many decades using conventional techniques and experiencing a slow but steady rise in production sprang to

life in a substantial way in 2008 (PADEP, 2012). Large multi-national energy companies and smaller, more regional exploration companies realized considerable success using the proven process of hydraulic fracturing performed in horizontal wells drilled into gas-containing shale formations. These same formations underlie approximately 85 percent of the Basin (Berg et al., 1980). Unlike the conventional gas industry that uses very little water for drilling and development purposes, the unconventional gas industry uses hydraulic fracturing technology that requires significant quantities of water. While many of the environmental issues surrounding the unconventional gas industry fall to the state regulatory agencies responsible for addressing those issues, the regulation of water acquisition and consumption by the unconventional gas industry occurring within the Basin falls under the purview of the Susquehanna River Basin Commission (SRBC, 2015).

Although there are several natural gas-containing geologic formations in the Susquehanna River Basin, the Marcellus Shale formation has been the formation most targeted by the industry within the Basin during the study period. For this reason, the name Marcellus Shale has been synonymous in the public's eye with all unconventional natural gas development occurring within the Basin and throughout the Mid-Atlantic region regardless of the specific geologic formation actually being targeted. Figure 1 identifies the portion of the Basin underlain by geologic formations known to contain recoverable amounts of natural gas, including the Marcellus Shale.

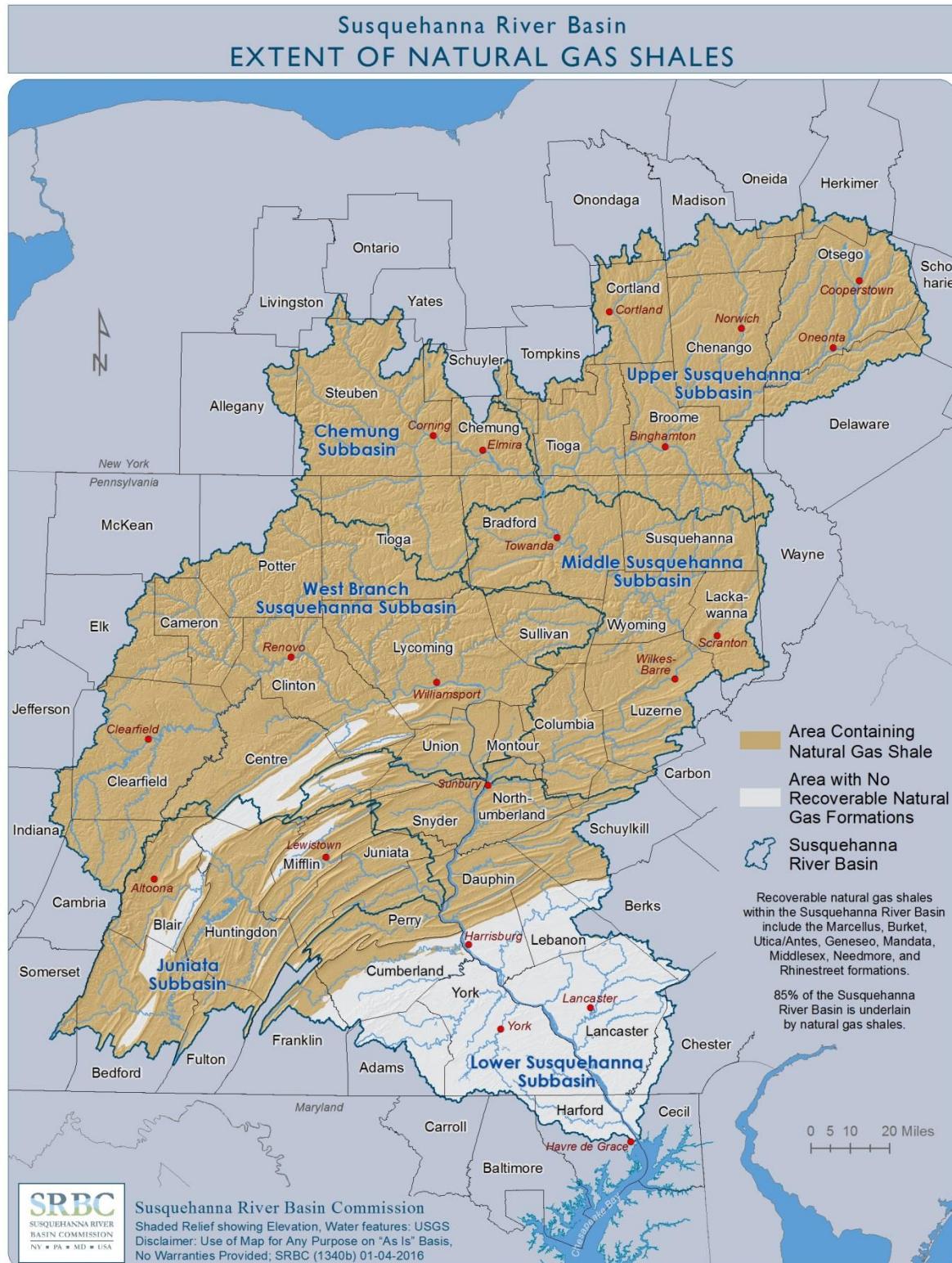


Figure 1. Extent of Natural Gas Shales (Berg et al., 1980)

II. Part I. The Regulatory Role of the Susquehanna River Basin Commission

A. Regulation of Water Withdrawals, Consumptive Use, and Diversions

The Commission, created in 1971, is a result of the enactment of the Susquehanna River Basin Compact (Compact) by the states of New York, Pennsylvania, and Maryland, and the United States, and is vested with broad statutory authority to manage the water resources of the Basin, including the authority to allocate the waters of the Basin.¹ Its member jurisdictions have delegated certain of their sovereign authorities to the Commission to act and jointly exercise that authority on behalf of the entire Basin.

The Commission has exercised its authority to develop a regulatory program that:

- manages the resource impacts of projects using the waters of the Basin;
- avoids conflicts between users; and
- provides standards to promote the equal and uniform treatment of all water users without regard to political boundaries.²

Although the Commission does not regulate water quality, it fills a critical role in monitoring water quality conditions in a consistent, watershed-based manner, across jurisdictional and political boundaries.

Fundamentally, the Commission's regulatory program requires approval of all large water withdrawals and water uses proposed in the Basin. Thresholds in regulation specify review of any project proposing to do any of the following:

- withdraw 100,000 gallons per day (gpd) or more, based on a 30-day average, from either groundwater or surface waters; or
- consumptively use of 20,000 gpd or more, also based on a 30-day average.

By definition, diversions of water out of the Basin are considered to be a consumptive use and are subject to a similar 20,000 gpd threshold. Diversions into the Basin, regardless of quantity, are likewise subject to review and approval.³

Commission review and approval is also required for any project that meets any of the following:

- located on the boundary between member states;
- will have a significant effect on the Commission's comprehensive plan; or
- could have an adverse effect individually or cumulatively on the water resources in a member state, or an interstate effect on water resources.⁴

¹ *Susquehanna River Basin Compact, P.L. 91-575; 84 Stat. 1509 et seq. (1970)*

² *18 CFR Parts 806-808*

³ *18 CFR §806.4(a)*

⁴ *18 CFR §806.4(a)5-7*

Commission approval is provided to individual projects in the form of an official document. This document is referred to as a docket. Each docket contains the name of the project sponsor, a description of the project features, the location of the project, approved withdrawal or consumptive use limits, general Commission conditions, and project-specific conditions.

For water withdrawal applications, the Commission may limit, condition, or deny an application to avoid significant adverse impacts, including cumulative adverse impacts, to the water resources of the Basin. To that end, limitations can be imposed on the quantity, rate, or timing of the approved withdrawals. Adverse impacts intended to be avoided include:

- excessive lowering of water levels;
- rendering competing water supplies unreliable;
- causing permanent loss of aquifer storage capacity;
- degradation of water quality that may be injurious to any existing or potential water use;
- adversely affecting fish, wildlife, or other living resources or their habitat; and
- substantially impacting the low flow regime of perennial streams.

In taking action on applications for groundwater and surface water withdrawals, the Commission relies on its guidelines and policies to make determinations on passby flow values to be included as conditions to approvals, as needed and appropriate. The passby guidelines were first adopted in 2003 and then revised in December 2012. The 2012 revision was based upon a Basinwide study conducted in partnership with The Nature Conservancy (TNC) to update the scientific framework used to protect aquatic resources, competing users, instream flow uses located downstream from the point of withdrawal, and to prevent water quality degradation.⁵ Water use characteristics of the unconventional natural gas industry were also important considerations in the development of the policy.

For each application seeking an approval that will impact a surface water feature, the Commission may undertake a site-specific Aquatic Resource Survey (ARS) to establish baseline conditions and determine appropriate limitations. The Commission may also use other site-specific data collected by another resource agency or by the project sponsor if those data are relevant and were collected at the project site within the past five years. The Commission then evaluates these various data to formulate conditions in the approved docket related to (1) limits on the quantity, timing, or rate of withdrawal; (2) limitations on the level of drawdown in a stream, well, pond, lake, or reservoir; and (3) streamflow protection measures.

Projects involving the consumptive use of water are required to mitigate the loss of water to the Basin, particularly during low flow conditions. Essentially, mitigation is required on a gallon-for-gallon basis by employing one of several options defined in Commission regulation. All water sources for a regulated consumptive use project are subject to review and approval, regardless of the quantity of water withdrawn. For example, a withdrawal of 40,000 gpd may not in itself trigger the regulatory threshold of 100,000 gpd, but it constitutes the source for a

⁵ *Guidelines for Using and Determining Passby Flows and Conservation Releases for Surface-Water and Ground-Water Withdrawal Approvals, Policy No. 2003-01 (November 8, 2002); Low Flow Protection Policy, Policy No. 2012-01(December 2012; Ecosystem Flow Recommendations for the Susquehanna River Basin (The Nature Conservancy, 2010))*

consumptive use that exceeds its regulatory threshold of 20,000 gpd and, therefore, requires approval.

A comprehensive revision of Commission regulations occurred in December 2006. Consumptive use regulations adopted in the December 2006 revision included a new Approval-By-Rule (ABR) provision that streamlined the approval process for any project using public water systems as their exclusive water source for consumptive use. The 2006 revision also provided the Commission with sufficient management options to address the variety of water-related projects occurring in the Basin, including with some subsequent enhancements covering the industry.

B. Regulation of the Unconventional Natural Gas Industry

In December 2007, Commission staff began investigating water use for Marcellus Shale well development after it received information from the PADEP regarding drilling permits it had issued in the northern tier counties of Pennsylvania. Once the PADEP permits were reviewed by the Commission, it was evident that the exploratory work being carried out by the industry did not meet the Commission's water withdrawal or consumptive use thresholds. Although the drilling and hydraulic fracturing of an unconventional well uses more water than is required for conventional gas wells, estimates of the amount of water required were both variable and uncertain due to factors such as final well depth and construction, the specifics of the hydraulic fracturing process, and the characteristics of the local shale formation.

Given the broad interest in the expansion of the natural gas industry in 2008, the Commission recognized the potential for the industry to create adverse impacts to the water resources of the Basin, regardless of whether individual projects met or fell below regulatory thresholds. The Commission knew that gas-containing shales presented an optimal opportunity for the development of this resource. Based on the geographic extent of the Marcellus formation and extrapolated water use data from the Barnett, Haynesville, and Fayetteville Shale formations located in other states, Commission staff estimated a potential cumulative consumptive water use of up to 30 million gallons per day at full build-out, or slightly less than 11 billion gallons per year.

While estimated consumptive water use for the gas industry was still significantly less than public water supply and electrical generation estimates at the time (~325 million gallons per day (mgd) and ~148 mgd, respectively), the Commission's concerns with natural gas activity were focused on the quantity, location, and timing of withdrawals. Most of the natural gas development is focused in very rural, headwater areas in the Appalachian Region. With the exception of the bottled water industry that tends to locate in pristine watersheds for the high quality water, the vast majority of projects regulated by the Commission have historically been located alongside the mainstem of the river, major tributaries, or in the valleys along streams with sufficient flow characteristics. Quantities of water that could otherwise be considered inconsequential on a major tributary could represent an important component of the water flow regime in headwater areas.

Additionally, the nature of the water withdrawal and use by the industry is fundamentally different than other users. The industry takes water from multiple, decentralized locations, typically on an inconsistent basis, and uses it at dozens of locations based on its continuously shifting operational needs. Although large quantities of water are critical to industry operations, the locations of where the water is used are independent of and distant from water sources capable of sustaining its demands. The prominent consumptive use, injection into the well borehole for hydraulic fracturing, may only last a few days but may occur 10 to 12 times over the life of a drilling pad as additional new wells are developed or existing wells are rehabilitated.

As a result of the overlay of headwater streams with the industry's drilling and fracturing activities, coupled with the unusual nature of water withdrawal and use by the industry, the Commission began issuing natural gas well approvals in June 2008 as dockets covering consumptive use for hydraulic fracturing. Separate dockets approving the supporting water withdrawals for transport to the drilling pads were also issued for each water source (e.g., stream, river, etc.). These dockets contained important requirements, including:

- standard metering, monitoring, and reporting requirements;
- conditions for protecting aquatic life during low stream flows;
- the requirement to submit well completion reports;
- signage to be posted that identified approved withdrawal sites and drilling pads; and
- a limited four-year term of approval.

Using the Commission's existing ABR process, the first approvals were issued in July 2008 to the unconventional natural gas industry. These approvals covered the bulk water sales from public water systems for consumptive use, and thus did not require the need for a full review of an actual stream withdrawal. Using this administrative process streamlined application review for gas companies exclusively using public water supplies since the withdrawal of water at those public facilities would have previously been approved by either the Commission or its member jurisdiction.

C. The “Gallon One” Modification

In August 2008, the Commission elected to modify its regulatory approach for the industry when it lowered the existing regulatory thresholds for the industry. The modified regulatory approach would commence the Commission's review and approval authority beginning at the first gallon for consumptive use and for withdrawals, rather than the traditional regulatory thresholds noted earlier. The “Gallon One” modification resolved any potential industry confusion about who needed to apply and minimized possible inadvertent violations. The Commission believes this modification was appropriate to protect the Basin's water resources and simultaneously allow for the utilization of water by this new industry.

As the Commission increased its understanding of the unique water use characteristics of the industry, it further modified its approach in 2009 by implementing new regulations specifically designed for the industry. Those new regulations included the following:

- A new ABR process specifically applicable to the industry was approved and a transition strategy developed to ‘convert’ existing consumptive use approvals to ABRs.
- Consumptive use docket approvals would be issued as ABRs on a drilling pad basis, regardless of the number of wells developed on the pad, and included appropriate monitoring, reporting, and consumptive use mitigation requirements.
- Unlike other ABRs that required exclusive use of water from public water systems, these required only the exclusive use of Commission-approved water sources and included a provision authorizing certain source approvals (public water supplies and wastewater sources) under the ABR process.
- A new provision for listing Commission-approved sources by company (rather than by ABR) to streamline monitoring and reporting.
- The industry was authorized to utilize any of its approved water sources at any ABR site so as to provide operational flexibility and minimize the need for redundant sources.
- The industry was encouraged to share water source approvals between companies by providing for a simple registration process to facilitate that sharing and limit multiple stream withdrawal sites.
- Incentives were provided for the use of lesser quality waters, including effluent discharge and mine drainage, for hydraulic fracturing in lieu of fresh water sources.
- New policies encouraged the reuse or recycling of flowback and production fluids for hydraulic fracturing.

Additional minor modifications relevant to the industry were made to the Commission’s regulations in 2010 and 2011. Moving forward, the Commission will continue to take a dynamic approach in the development of policies and regulations for the industry to make certain that the right set of management controls are in place to allow this activity to occur while avoiding any negative ecosystem impacts. The Commission is committed to continue to make adjustments and refinements in its regulatory program to respond to changes in the programs of member jurisdictions, the evolving water use practices and demand of the industry, and improved understanding of ecosystem impacts.

III. Part II. Water Acquisition and Well Development Activities

A. Consumptive Water Use Approvals

In the second quarter of 2008, the Commission adopted an administrative process to approve the consumptive use of water for unconventional natural gas and other hydrocarbon development. The process, mentioned in the preceding section and referred to as the approval-by-rule (ABR process), has specific requirements. To qualify for the ABR process, the industry can only use the water for specific purposes and only when involving specific geologic formations. Those specific purposes include gas well drilling, hydraulic fracturing, dust control, and site reclamation. The specific gas-containing shale formations for which the ABR process

can be used include the Marcellus, Utica, and several other gas-containing low permeability shale formations present within the Basin. Proof of PADEP well permit acquisition, public notice requirements, metering requirements, site location maps, method of consumptive use mitigation, and recording and reporting requirements are integral parts of the ABR process. All construction-related activities associated with well pad development, including access roads, sediment pits, and erosion and sedimentation controls, are regulated by the PADEP and not by the Commission.

The number of ABRs issued to the industry on a well pad basis within the Basin from 2009-2013 are presented in Table 1. A total of 92 consumptive water use approvals were issued in calendar year 2008 to the industry using a pre-existing general regulation not specific to the gas industry. In 2009, a gas-specific consumptive use regulation was created. During calendar year 2009, the 92 approvals originally issued in 2008 were superseded using the gas-specific regulation. Therefore, the data presented in Table 1 for calendar year 2009 include the 92 superseded approvals originally issued in 2008. From 2009 through 2013, all consumptive use approvals for the industry were issued under the gas-specific ABR regulation. Table 1 lists the number of approvals issued, the counties in which they were issued, and the years in which they were issued. As the data indicate, a total of 2,249 approvals were issued by the Commission to the industry for the consumptive use of water occurring between 2009 and 2013. The four counties with the greatest number of ABRs were Bradford with 699, Susquehanna with 400, Tioga with 395, and Lycoming with 289. Together, these four counties contained approximately 80 percent of the total number of ABRs issued by the Commission to the industry for consumptive water use. Figures 2 through 6 provide graphic representations of the growth in the number of ABR approvals and water withdrawal approvals occurring across the Basin between 2009 and 2013. More information regarding water withdrawals is presented in the following sections of this report.

Reviews of the ABRs issued during the study period indicate that greater than 60 percent of the well pads for which ABRs were issued resulted in pad construction and the drilling of at least one gas well. A smaller subset of ABR approvals either expired over time without pad construction or are currently active and awaiting pad construction and well drilling activities. Data collected during the study period also indicate that approximately 38 percent of the constructed pads are occupied by one or two gas wells, 39 percent of the pads are occupied by three to five gas wells, 21 percent of the pads are occupied by six to eight gas wells, and 2 percent of the pads are occupied by nine to 11 gas wells. Through the end of the report period, the maximum number of wells drilled on a single pad site was 11.

Table 1. Summary of Approval-By-Rule Issued to the Natural Gas Industry

County	ABRs Issued by Year				County Totals	
	2009	2010	2011	2012		
Bedford	0	1	1	0	2	4
Blair	2	2	0	0	0	4
Bradford	79	346	145	93	36	699
Cambria	0	0	3	1	0	4
Cameron	4	6	5	0	0	15
Centre	16	26	3	0	0	45
Clearfield	18	37	31	5	1	92
Clinton	12	16	12	3	3	46
Columbia	2	10	10	0	0	22
Elk	0	3	1	0	0	4
Huntingdon	0	1	0	0	0	1
Lackawanna	3	3	0	0	0	6
Luzerne	0	7	0	0	0	7
Lycoming	37	101	66	51	34	289
McKean	0	1	0	0	0	1
Potter	4	11	13	0	0	28
Sullivan	0	41	20	17	4	82
Susquehanna	69	93	77	90	71	400
Tioga (PA)	70	234	61	24	6	395
Wayne	1	7	0	0	0	8
Wyoming	4	34	24	9	12	83
Broome (NY)	0	3	0	0	0	3
Chenango (NY)	0	7	0	0	0	7
Madison (NY)	0	2	0	0	0	2
Otsego (NY)	1	1	0	0	0	2
Annual Totals	322	993	472	293	169	2249

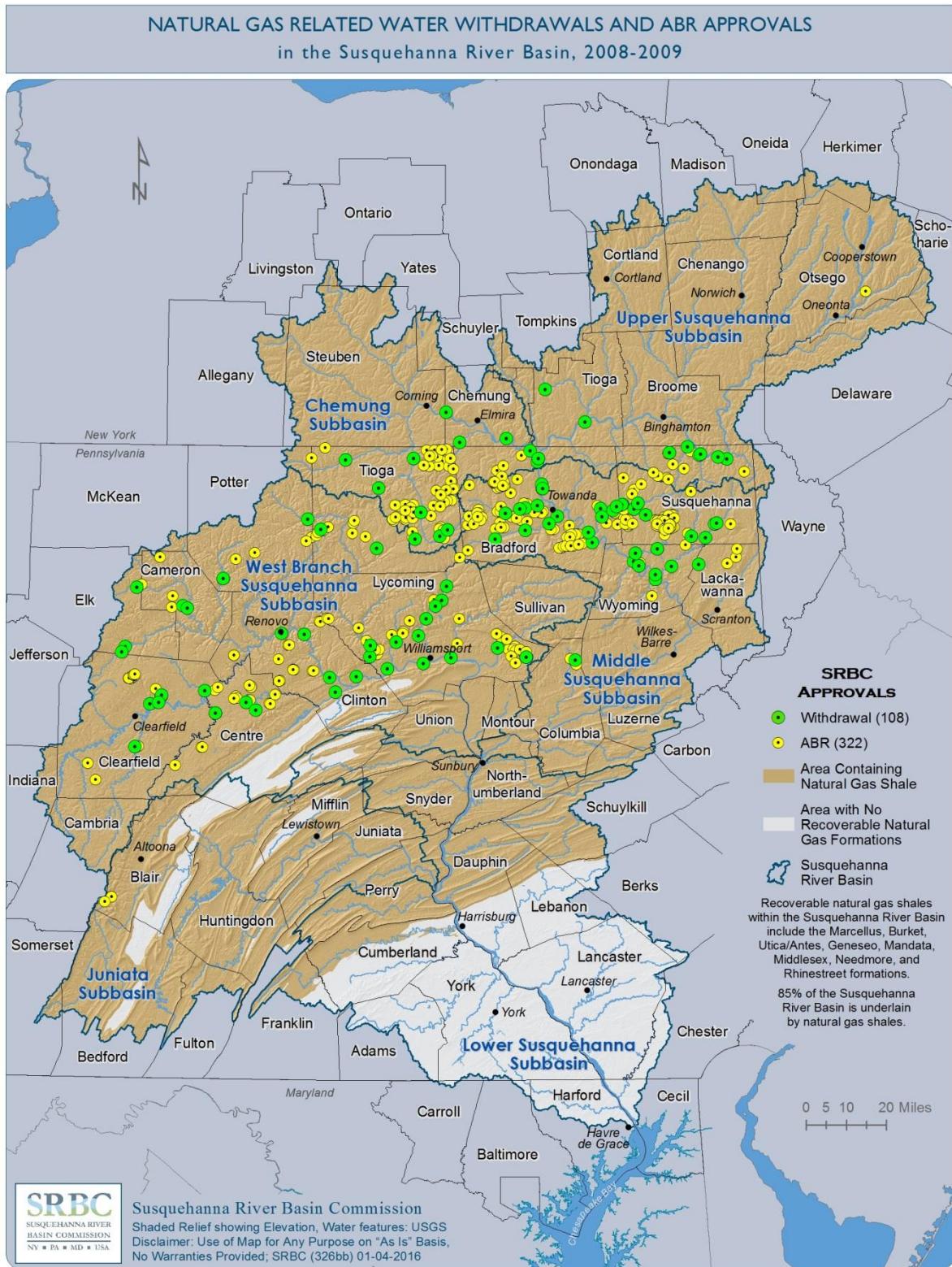


Figure 2. Natural Gas Related Water Withdrawals and ABR Approvals in the Susquehanna River Basin, 2008-2009

NATURAL GAS RELATED WATER WITHDRAWALS AND ABR APPROVALS
in the Susquehanna River Basin, 2008-2010

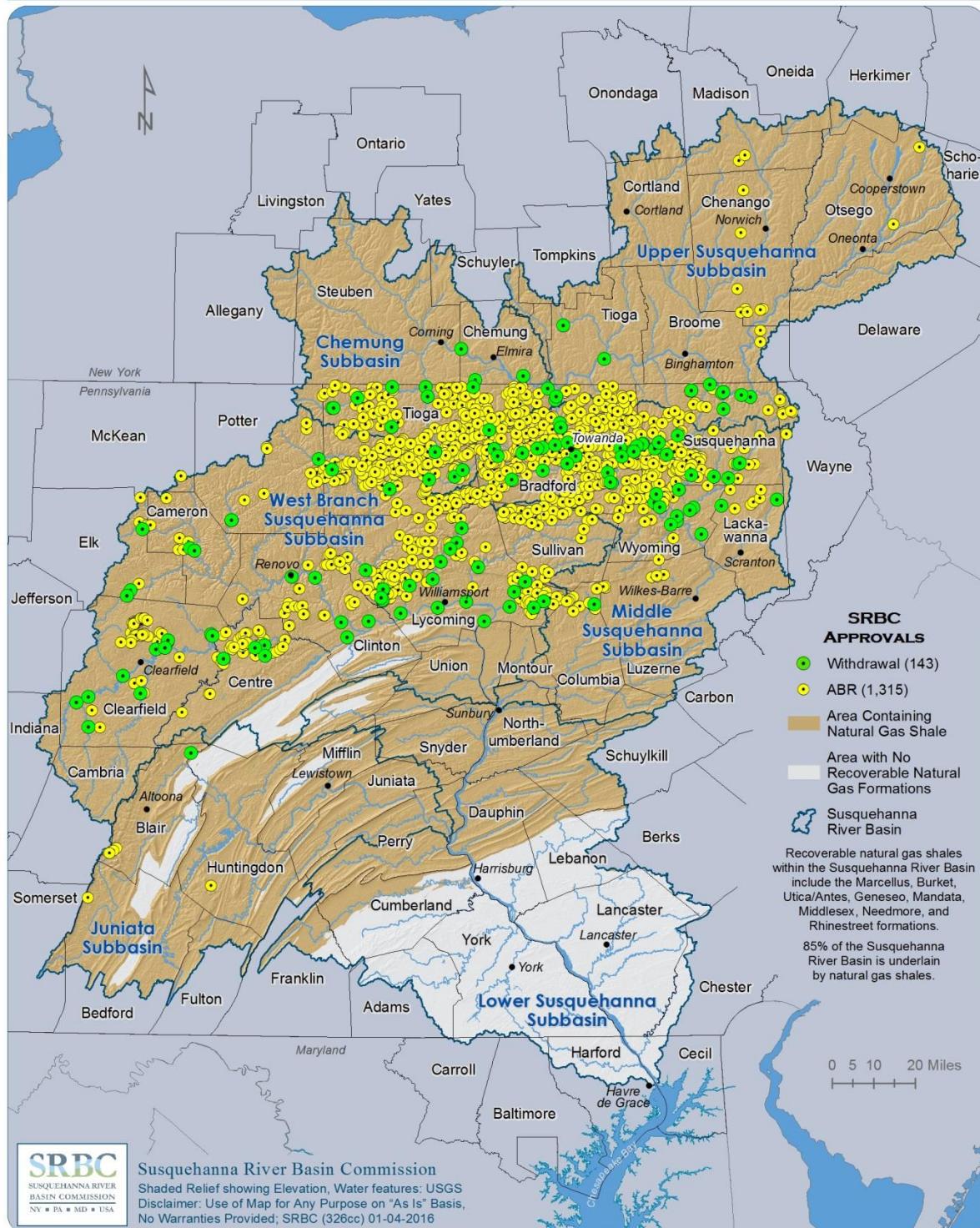


Figure 3. Natural Gas Related Water Withdrawals and ABR Approvals in the Susquehanna River Basin, 2008-2010

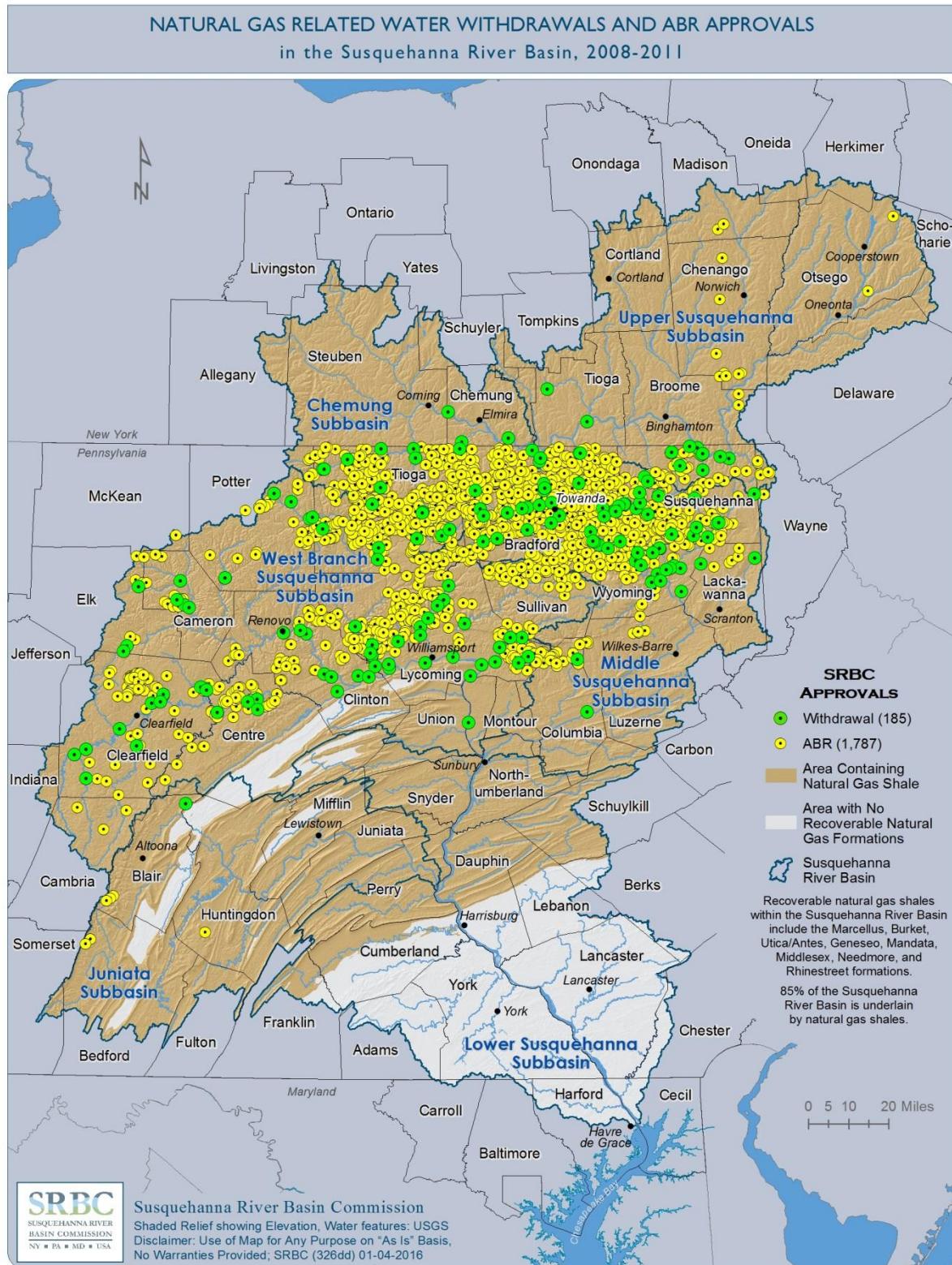


Figure 4. Natural Gas Related Water Withdrawals and ABR Approvals in the Susquehanna River Basin, 2008-2011

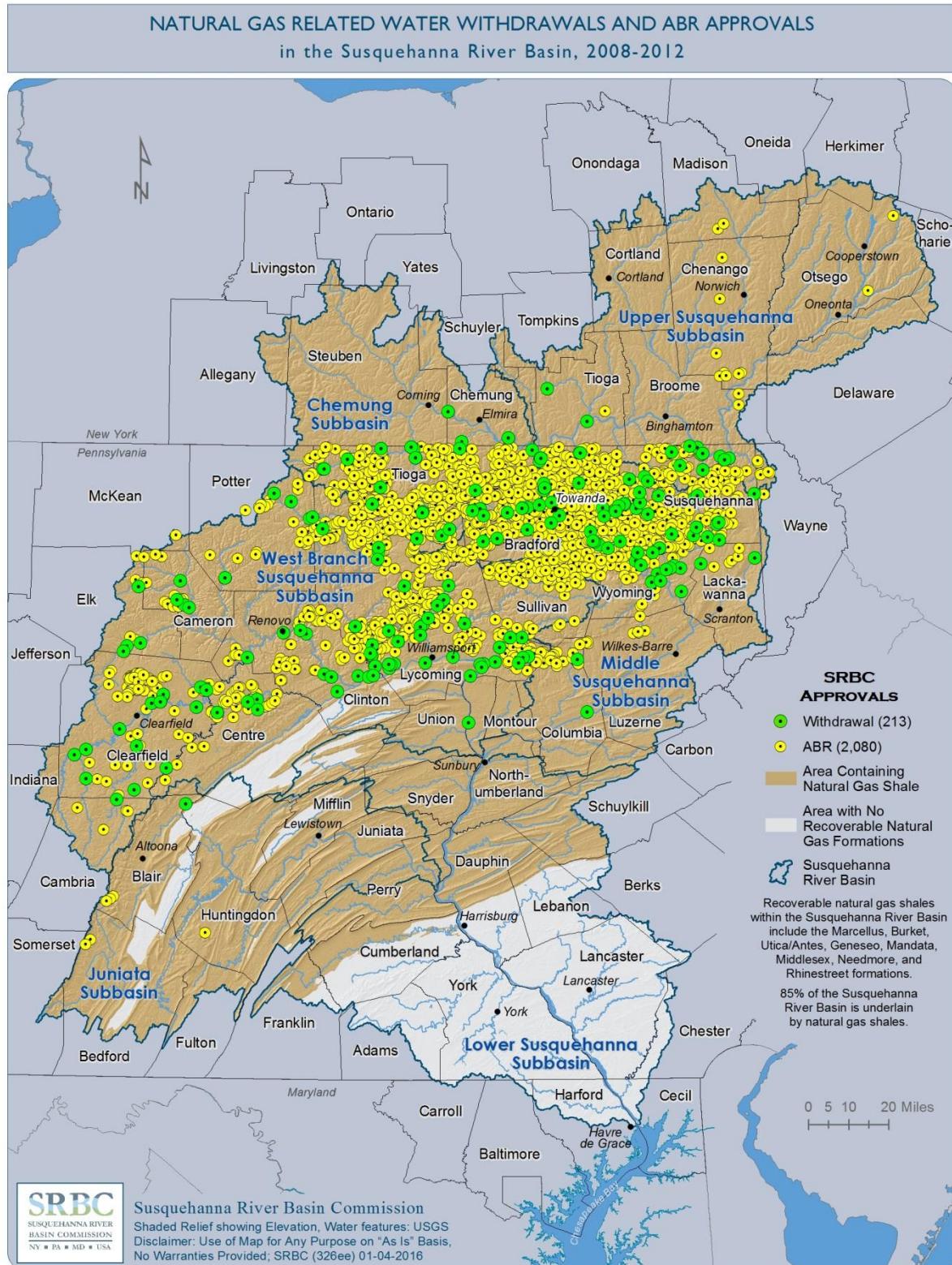


Figure 5. Natural Gas Related Water Withdrawals and ABR Approvals in the Susquehanna River Basin, 2008-2012

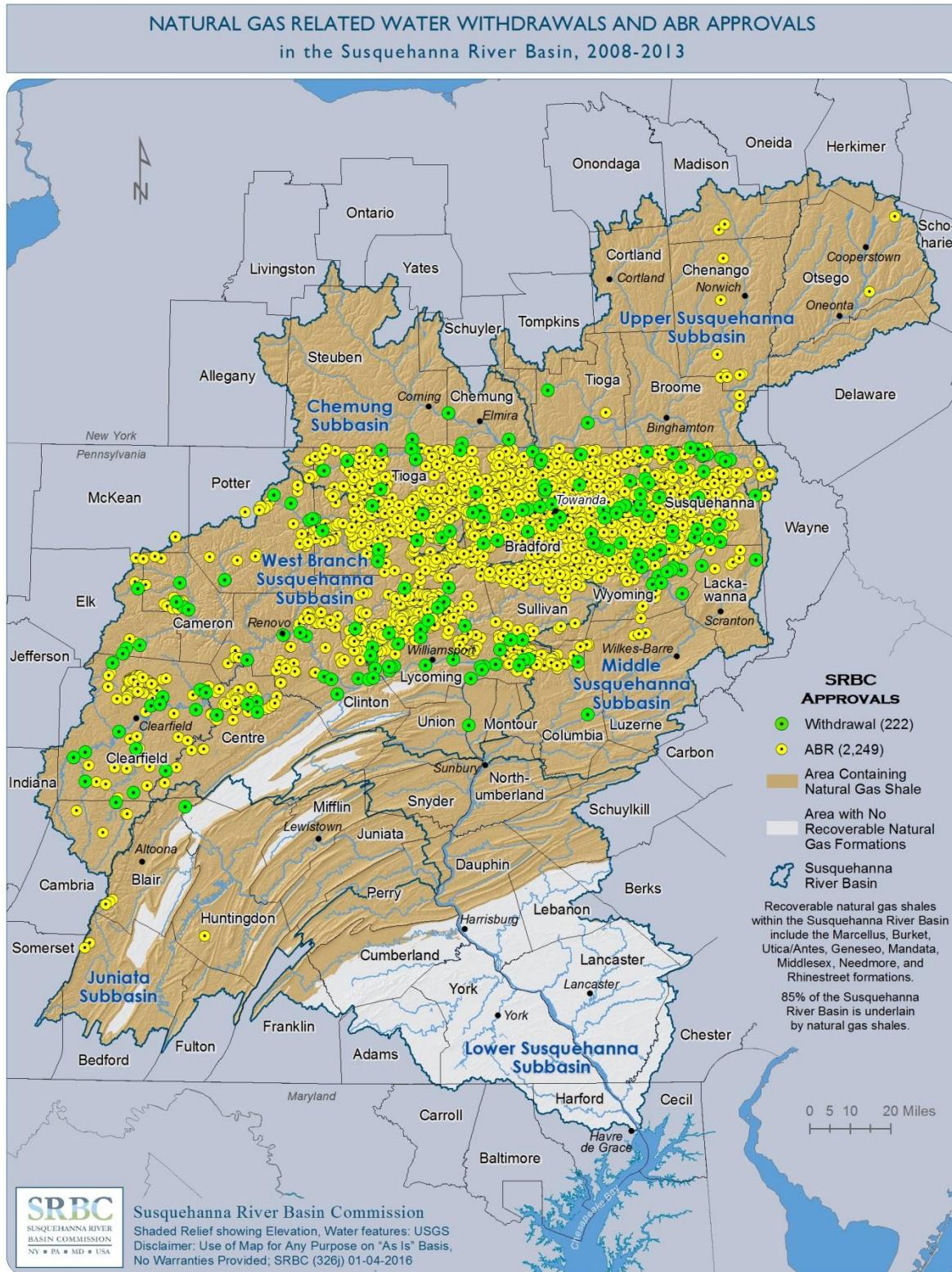


Figure 6. Natural Gas Related Water Withdrawals and ABR Approvals in the Susquehanna River Basin, 2008-2013

B. Gas Wells Permitted, Drilled, and Fractured within the Basin

The next 12 sections in this report will provide detailed information on the topics listed below based upon actual data available from PADEP's oil and gas reports (PADEP, 2012) and from information collected by the Commission as part of its reporting requirements for the industry. These topics include:

- the number of wells drilled;
- the number of wells hydraulically fractured;
- the amounts of water used by the industry to hydraulically fracture wells;
- the watersheds from where the water was withdrawn;
- the amount of flowback realized following the well fracturing process; and
- the amount of flowback reused in subsequent fracturing efforts.

During the report period, the Commonwealth of Pennsylvania was the only Basin member jurisdiction approving the use of unconventional horizontal hydraulic fracturing technology by the industry. Within the Commonwealth of Pennsylvania's portion of the Basin, unconventional well drilling and hydraulic fracturing began in 2005. PADEP regulations require the industry to obtain permits before drilling conventional or unconventional natural gas wells and to file well completion reports within 30 days after the permitted wells are drilled and hydraulically fractured (25 Pa. Code Chapter § 78.122(b)).

Commission regulations require the industry to obtain prior approval from the Commission for all consumptive water uses related to drilling and fracturing of unconventional natural gas wells on each pad site and for all water withdrawals used to support those activities. In addition, the industry is required to file a post-hydraulic fracture report to the Commission for each unconventional gas well so stimulated. These reports include well identification information, the date of the hydraulic fracturing event, the pressure release date, and the quantities and general types of fluids injected and recovered. The types of fluids include fresh water, flowback fluids, and production fluids.

During the period from July 2008 through May 2012, the gas industry was required to submit post-hydraulic fracture reports to the Commission within 30 days after each well was hydraulically fractured. During this period, some members of the industry used stimulation practices that, following fluid injection, held the formation under pressure for days, weeks, or even months before releasing pressure. This "shut-in" condition prevented flowback from occurring and thus from being included in the reports. Consequently, beginning in June 2012, the Commission required the gas industry to report flowback occurring within the first 30 days following the date on which the release of pressure was made in each well fractured (also referred to as the initial fluids recovery period). This change resulted in the collection of more meaningful data on the quantities, rates, and timing of flowback from the fractured gas wells.

The well permits issued to the industry by PADEP, the well completion reports filed by the industry with PADEP, and the post-hydraulic fracturing reports submitted by the industry to the Commission were used to compile the information presented in tabular form in Table 2 and

in graphic form in Figure 7. Table 2 provides a breakdown of wells permitted, wells drilled, and wells hydraulically fractured within the Basin by county and by calendar year. The data span the period from the first quarter of 2005 through the fourth quarter of 2013. The information summarized in Table 2 pertains only to unconventional natural gas wells located within the Pennsylvania portion of the Basin. No conventional wells located within the Basin nor conventional or unconventional gas wells located outside the Basin were included in the summary.

As indicated in Table 2, no unconventional gas wells were reportedly drilled within the Basin in 2005, with only 3 wells reportedly drilled in 2006 and 14 reportedly drilled in 2007. It was not until 2008 that more substantial numbers of gas wells were permitted and drilled in the Basin, and it was not until 2009 that significant numbers of those wells were hydraulically fractured. As of December 31, 2013, there were a total of 9,843 wells permitted within the Basin. The total number of wells drilled and fractured within the Basin by December 31, 2013, were 3,995 and 2,860, respectively. These numbers suggest that, as of that date, approximately one out of every three wells permitted by PADEP were subsequently drilled, and approximately 70 percent of the wells drilled were subsequently hydraulically fractured. It is anticipated that a greater percentage of the drilled wells will be fractured as more gathering and transmission pipelines are constructed.

Table 2. Summary of Unconventional Gas Wells Permitted-Drilled-Fractured by County within the Susquehanna River Basin between 2005 and 2013 (PADEP, 2012)

PA County	Wells Permitted-Drilled-Fractured										County Totals Number of Gas Wells Permitted-Drilled- Fractured
	Calendar Year 2005	Calendar Year 2006	Calendar Year 2007	Calendar Year 2008	Calendar Year 2009	Calendar Year 2010	Calendar Year 2011	Calendar Year 2012	Calendar Year 2013		
Bedford	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	1-0-0	1-0-0	0-0-0	0-0-0		2-0-0
Blair	0-0-0	0-0-0	0-0-0	0-0-0	2-2-0	5-2-1	2-1-4	0-0-0	0-0-0		9-5-5
Bradford	1-0-0	0-0-0	3-1-0	57-21-1	436-156-58	839-290-177	757-334-291	393-134-224	455-105-130		2941-1041-881
Cambria	0-0-0	0-0-0	0-0-0	0-0-0	6-1-0	9-0-0	7-1-0	1-1-0	2-0-0		25-3-0
Cameron	0-0-0	0-0-0	0-0-0	0-3-3	5-0-1	3-2-1	18-6-0	9-0-0	10-5-0		45-16-5
Centre	0-0-0	3-0-0	1-1-0	10-4-3	42-3-2	97-23-14	29-6-10	6-2-5	4-0-0		192-39-34
Clearfield	0-0-0	0-0-0	2-0-0	11-5-0	73-20-2	76-36-25	124-34-17	113-12-31	19-3-6		418-110-81
Clinton	0-0-0	0-0-0	0-0-0	8-1-0	42-3-4	49-17-10	58-34-30	8-10-14	8-3-1		173-68-59
Columbia	0-0-0	0-0-0	0-0-0	0-0-0	1-0-0	1-0-0	7-0-1	0-0-0	0-0-0		16-1-1
Elk	1-0-0	1-1-0	6-1-0	18-3-0	22-3-0	46-13-0	73-15-0	31-1-0	37-20-4		235-57-4
Huntington	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	1-1-0	1-0-1	0-0-0	0-0-0		2-1-1
Lackawanna	0-0-0	0-0-0	0-0-0	0-0-0	28-0-0	0-0-0	1-0-0	0-0-0	0-0-0		29-0-0
Luzerne	0-0-0	0-0-0	0-0-0	0-0-0	1-0-0	14-0-1	0-0-0	0-0-0	0-0-0		15-0-1
Lycoming	0-0-0	0-0-0	12-4-0	50-10-0	107-22-6	254-105-28	376-261-127	354-194-202	325-168-169		1478-764-532
Potter	0-0-0	5-0-0	6-5-0	9-5-0	30-8-2	81-32-9	74-10-2	25-0-0	10-0-0		240-60-13
Sullivan	0-0-0	0-0-0	0-0-0	0-0-0	1-0-0	85-17-3	48-16-22	59-14-17	57-12-19		250-59-61
Susquehanna	0-0-0	1-1-0	9-2-0	68-29-3	156-85-39	233-125-76	356-199-137	324-185-179	556-207-203		1703-833-637
Tioga	0-0-0	1-1-0	0-0-0	30-12-0	303-115-32	574-244-99	438-251-120	255-118-136	88-30-43		1689-771-430
Wyoming	0-0-0	0-0-0	0-0-0	0-0-0	4-1-1	88-23-6	121-63-32	33-14-28	135-66-48		381-167-115
Totals	2-0-0	11-3-0	39-14-0	261-93-10	1259-419-147	2463-931-450	2491-1231-794	1611-685-836	1706-619-623		9843-3995-2860

Notes:

Not all permitted wells were drilled, and not all drilled wells were hydraulically fractured.

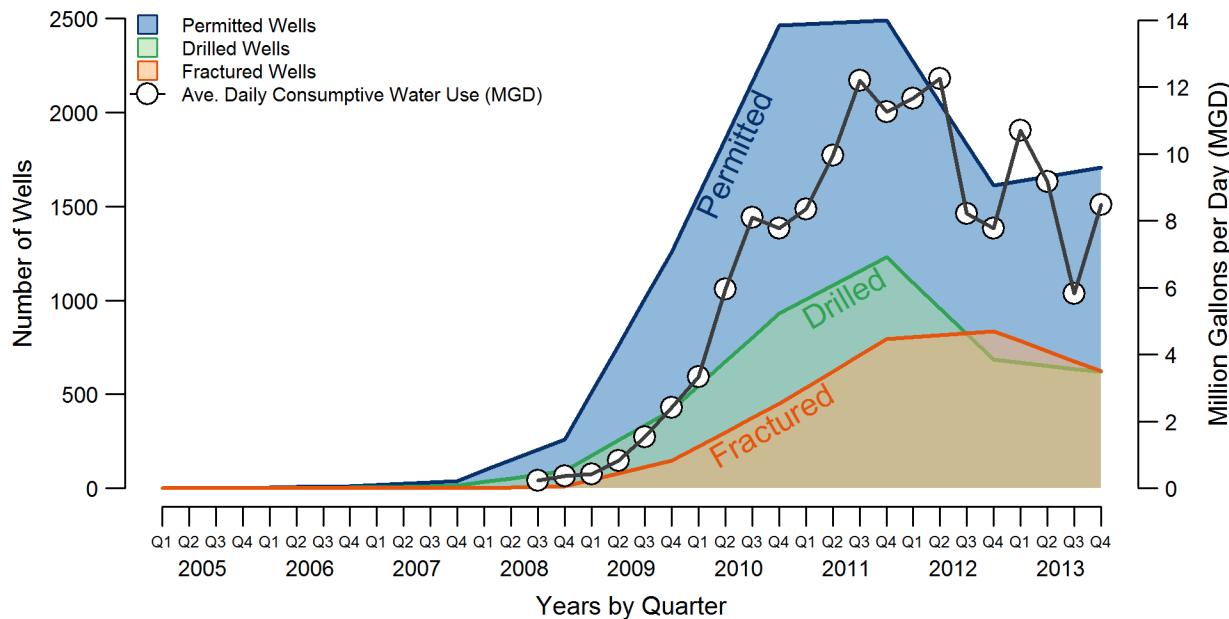


Figure 7. Wells Permitted, Drilled, and Fractured from 2005-2013 (PADEP, 2012)

C. Water Withdrawn and Consumptively Used by the Industry

Water consumptively used by the industry originates from surface water sources or groundwater sources, or a combination of the two. Surface water sources include water withdrawn from streams, creeks, rivers, lakes, ponds, and perennial springs. Groundwater sources include water withdrawn from individual water wells and from water well-fields. Water withdrawn from public water systems can be comprised of a combination of both surface water and groundwater sources. One hundred percent of all waters withdrawn from the Basin by the industry, regardless of source, are considered by the Commission to be consumptively used and therefore removed from the hydrologic cycle of the Basin.

Table 3 contains a summary of the amounts of water consumptively used by the industry, the amounts of surface water and groundwater withdrawn from approved locations, the amounts of water diverted into the Basin, and the amounts of water obtained from other Commission approved sources, primarily public water systems. As previously noted, it is easier to understand consumptive use versus water withdrawals if one simply considers water withdrawals as the beginning of the water journey and consumptive use to be the end of the journey (i.e., water injected into a well during fracturing efforts). Table 3 provides a breakdown of water consumptively used and water withdrawn within the Basin by the industry by quarter and by calendar year. The data span the study period from the third quarter of 2008 through the fourth quarter of 2013.

The values presented in Table 3 for the average daily consumptive use (CU) rate by quarter (in gallons per day) were calculated by dividing the total quantity of consumptive water use (in gallons) reported by the industry for a given quarter by the number of days in that quarter.

Likewise, the average daily docketed sources (in gallons per day) for each quarter were calculated by dividing the total quarterly quantities of water withdrawals (both surface water and groundwater) reported by the industry for a given quarter by the number of days in that quarter. The same procedure was followed for the calculation of the average daily non-docketed sources. Therefore, these average daily values represent calculated averages and not daily averages directly reported by the industry. Figure 7 provides a graphic representation of these calculated average daily consumptive water use rates for each quarter and year of the report period.

Insufficient data were collected to adequately define the consumptive use and withdrawal of water by the industry prior to the Commission's involvement and its imposition of standard metering, monitoring, and reporting requirements which occurred in the third quarter of 2008. Anecdotal information provided by the industry suggests only limited water use prior to 2008. Given the relatively low number of wells (approximately 50) permitted by PADEP, and even fewer wells drilled and subsequently stimulated using high-volume hydraulic fracturing prior to mid-2008, the amount of unreported water collectively used by the industry prior to mid-2008 is believed to be very small compared to the amount of water use reported subsequent to mid-2008.

As indicated in Table 3, from the third quarter of 2008 through the third quarter of 2009, approximately 60 to 90 percent of water consumptively used by the industry originated at public water systems. These public systems relied heavily upon both surface water and groundwater sources to meet their overall water demands. Beginning in the fourth quarter of 2009 and extending through the fourth quarter of 2012, the primary sources of water for the industry transitioned from public systems to individual surface water withdrawals approved (and docketed) by the Commission and developed and controlled by individual gas companies or by private third-party water purveyors. By the first quarter of calendar year 2013, the percent of water taken from public water systems and consumptively used by the gas industry had dropped below 5 percent of the total water used. It remained below 10 percent throughout the remainder of 2013.

Table 3. Quarterly Summary of Consumptive Water Use, Water Withdrawals, and Water Diversions by the Unconventional Gas Industry within the Susquehanna River Basin from the Third Quarter 2008 through the Fourth Quarter 2013

Quarter/Year	Total Quarterly Consumptive Use (Gallons) ¹	Average Daily CU Rate by Quarter (GPD) ²	Docketed Quarterly Groundwater Withdrawals (Gallons)	Docketed Quarterly Surface Water Withdrawals (Gallons)	Docketed Quarterly Diversions Into Basin (Gallons)	Average Daily Docketed Sources (GPD)	Non-Docketed Approved Surface Water Withdrawals (Gallons) ³	Average Daily Non-Docketed Sources (GPD)	Subtotals of Docketed and Non-Docketed Water Sources (Gallons) ⁴
Q3-2008	21,043,635	228,735	0	2,029,900	0	22,064	19,013,735	206,671	21,043,635
Q4-2008	34,546,442	375,505	0	14,255,620	0	154,952	20,290,822	220,552	34,546,442
Q1-2009	38,260,212	425,113	0	3,935,900	0	43,732	34,324,312	381,381	38,260,212
Q2-2009	75,542,837	830,141	0	36,223,528	0	398,061	39,319,309	432,080	75,542,837
Q3-2009	142,020,554	1,543,702	0	54,171,241	0	588,818	87,849,313	954,884	142,020,554
Q4-2009	221,861,054	2,411,533	0	190,925,721	0	2,075,280	30,935,333	336,254	221,861,054
Q1-2010	300,098,336	3,334,426	0	231,732,471	0	2,574,805	68,365,865	759,621	300,098,336
Q2-2010	542,943,345	5,966,410	0	460,382,624	0	5,059,150	10,855,767	119,294	471,238,391
Q3-2010	745,188,983	8,099,880	8,866,785	598,641,071	0	6,603,346	294,225,471	3,198,103	901,733,327
Q4-2010	715,797,806	7,780,411	35,691,923	705,122,887	11,193,000	8,173,998	158,407,047	1,721,816	910,414,857
Q1-2011	751,501,919	8,350,021	73,173,854	505,136,522	1,335,359	6,440,508	128,152,499	1,423,917	707,798,234
Q2-2011	905,546,785	9,951,064	81,615,842	578,166,205	31,123	7,250,694	140,780,551	1,547,039	800,593,721
Q3-2011	1,121,682,212	12,192,198	58,632,120	664,570,345	126,492	7,862,271	91,632,400	996,004	814,961,357
Q4-2011	1,035,380,050	11,254,131	123,067,345	825,308,288	13,437,118	10,454,486	245,472,039	2,668,174	1,207,284,790
Q1-2012	1,061,866,165	11,668,859	137,968,611	829,322,145	4,605,842	10,680,182	89,826,896	987,109	1,061,723,494
Q2-2012	1,114,629,592	12,248,677	120,093,248	696,941,787	4,754,339	9,030,652	49,052,219	539,035	870,841,593
Q3-2012	756,195,963	8,219,521	72,265,632	294,854,850	0	3,990,440	192,615,034	2,093,642	559,735,516
Q4-2012	714,641,714	7,767,845	58,865,915	501,383,163	0	6,089,664	96,307,517	1,046,821	656,556,595
Q1-2013	963,623,981	10,706,933	28,880,831	628,752,006	0	7,307,032	40,826,946	453,633	698,459,783
Q2-2013	833,906,784	9,163,811	34,887,036	699,203,581	0	8,066,930	43,107,368	473,707	777,197,985
Q3-2013	535,652,001	5,822,304	70,424,438	519,564,775	0	6,412,926	51,920,107	564,349	641,909,320
Q4-2013	779,765,012	8,475,707	93,969,232	725,010,113	2,582,878	8,930,024	38,822,099	421,979	860,384,322
Long-Term Totals (Gallons)	13,411,695,382		998,402,812	9,765,634,743	38,066,151		1,972,102,649		12,774,206,355
Long-Term Daily Averages (GPD)		6,673,497				5,373,183		979,367	

¹ Consumptive water use from all docketed withdrawal sources, plus other sources approved pursuant to 806.22(f).

² Abbreviations: GPD, Gallons per Day. Daily average values for each quarter were calculated by dividing quarterly totals by the number of days in each quarter.

³ The vast majority of the non-docketed approved water sources are comprised of public water systems (PWSs); however, these sources also include impaired waters such as abandoned mine discharges (AMD), industrial and municipal wastewaters, pad stormwaters, tophole waters, etc. The gray shaded numbers in Columns 8 and 9 were calculated by the Commission from PADEP data. The unshaded numbers in Columns 8 and 9 were reported by the gas industry directly to the Commission.

⁴ In any given quarter, there will be differences between the Total Consumptive Water Use (Column 2) and the combination of Docketed Water Withdrawals and Diversions (Columns 4, 5, and 6) plus Non-Docketed Approved Water Sources (Column 8) due to the plus/minus 5 percent accuracy of flow meters, and due to the dynamic changes in the amounts of water moving into or out of storage impoundments and storage tanks located on specific pads or in centralized locations.

D. Total Consumptive Water Use

The total amount of water consumptively used by the industry from July 2008 through December 2013 was 13.4 billion gallons. The highest average daily consumptive water use and highest average water withdrawal rate by the industry calculated by the Commission on a quarterly basis for the report period were 12.2 mgd and 10.7 mgd, respectively, and occurred during the first two quarters of 2012. As the data in Table 2 indicate, calendar year 2012 had the greatest annual number of wells fractured at 836, following closely behind by calendar year 2011 with 794 wells fractured. During calendar year 2013, the total number of wells hydraulically fractured dropped to 623.

While it is important to note that the total amount of water consumptively used by the industry during the report period was significant at 13.4 billion gallons, the average daily usage rate of approximately 6.7 mgd during that same period was comparable to other concurrent water users within the Basin. For example, manufacturing-related activities consumptively used an average of 8.6 mgd of water while entertainment and recreational water users (amusement parks, golf courses, and ski areas) consumed on average approximately 6.2 mgd. Electric power generators, including nuclear power plants, consumed an average of 86.2 mgd and constituted the single largest consumptive user of water within the Basin.

E. Total Surface Water Withdrawn by the Industry

A total of 9.76 billion gallons of surface water were withdrawn from waterways within the Basin and consumptively used by the industry during the report period. An additional 1.97 billion gallons of water were withdrawn within the same time period from other approved sources by the industry, primarily from public water systems. Together, these two major sources of water comprised approximately 88 percent of the total amount of water withdrawn and consumptively used by the industry.

Approximately 70 percent of the approved surface water withdrawals for the industry were conditioned with site-specific low flow thresholds below which the water withdrawal activities must cease. These restrictions are defined within Commission dockets as low flow protection or passby conditions. Every low flow threshold is unique to each project location and is based on technical evaluations and recommendations by staff at the Commission. The primary purpose of each low flow threshold is to afford adequate protection to other downstream water users and to instream aquatic ecosystems during periods of low streamflow at the points of withdrawal.

Estimates were made by the Commission of the quarterly amounts of water obtained by the industry from approved public systems prior to the advent of direct reporting in 2010. The amounts of water originating from approved but non-docketed public water systems for the third quarter of 2008 through the first quarter of 2010 were estimated by subtracting docketed withdrawal amounts from docketed consumptive use amounts for each quarter during that period of time. While these quarterly numbers should be considered estimated quantities, it is believed

that they are reasonably accurate given subsequent comparisons with reported public system usage following the second quarter of 2010.

F. Total Groundwater Withdrawn by the Industry

A total of 998 million gallons, or 7.5 percent of the water consumptively used by the industry during the five-year period, originated solely from groundwater sources. The majority of this groundwater (774 million gallons) originated at docketed public water systems or from third-party water purveyors docketed by the Commission. The balance (224 million gallons) originated at administratively-approved public water systems. Approximately 177 million gallons of water, or 18 percent of the total 998 million gallons of groundwater used by the industry, originated from groundwater sources docketed by the Commission and under the direct control or ownership of the gas industry.

G. Total Diversion of Water Into the Basin

The diversion of water into the Susquehanna River Basin from the Ohio River Basin for unconventional natural gas development during the study period was approximately 38 million gallons. This quantity constitutes approximately 0.3 percent of the total amount of water consumptively used by the industry. A portion of this diverted water was comprised of flowback and possibly some produced waters generated on well pads located within the Ohio River Basin and transported to well pads located within the Susquehanna River Basin for use in subsequent well fracturing events. As part of the Commission's into-Basin diversion approval process, all flowback and produced waters regardless of origin must remain isolated from all fresh waters of the Basin and be used solely for down-hole fracturing activities at approved drilling pad sites.

H. Total Consumptive Water Use versus Total Water Withdrawals

During the report period, the total reported consumptive water use (13.4 billion gallons) exceeds the combined total reported withdrawals and diversions (12.77 billion gallons) by approximately 637 million gallons, or 4.8 percent of the total consumptive use. This difference is likely attributable to the capture and use of top-hole water and precipitation falling on pad sites that was correctly included by the industry in consumptive use reports, and to a lesser degree, the limits of the accuracy of the meters, as well as human error during monitoring and reporting. However, it is impossible to entirely discount that some water was withdrawn from unapproved sources, although Commission staff routinely review for non-compliance and resolved several violations involving use of unapproved sources during the report period. Overall, regardless of the discrepancy, a value of 5 percent or less offers confidence that accurate and comprehensive water use tracking is occurring.

I. Details of Surface Water Withdrawals

The magnitude of the quarterly surface water withdrawal data contained in Table 3 reflects the importance of surface water sources to the industry. Approximately 93 percent of the

water consumptively used by the industry since 2008 is believed to have originated at surface water withdrawal sites. With a few exceptions, surface water and groundwater approvals issued by the Commission for the industry are valid for a period of four years and subject to additional review prior to renewal. Factors such as foreseeable water demand, availability of alternative water sources, competing water uses within the watershed, stream classification, stream water quality, and other similar factors are considered during the review process.

The Commission also created incentives for the industry to use lesser quality waters in its operations. Lesser quality waters include those waters affected by some form of pollution, such as abandoned mine drainage (AMD), municipal and industrial wastewaters, and other impaired waters. The incentive is in the form of discounted application fees associated with water withdrawals from these sources and/or relaxed passby flow restrictions consistent with SRBC Resolution Number 2012-01, Use and Reuse of Lesser Quality Water.

Table 4 presents a summary of the number of surface water and groundwater withdrawal approvals issued by the Commission during the study period to the industry and to third-party water purveyors serving the industry. Note that the first withdrawal approvals issued in calendar year 2008 expired or were renewed four years later in calendar year 2012. Likewise, the withdrawal approvals originally issued in 2009 expired or were renewed in calendar 2013. Also included in Table 4 are the cumulative number of approved withdrawal locations available for use and the number of withdrawal projects that were actually used (water actively withdrawn) during those years.

During the report period, there were a total of 222 surface water withdrawals approved by the Commission for use in natural gas development. These approvals were issued directly to the industry or to third parties serving the industry. Twenty-eight of those approvals were rescinded for various administrative reasons, 35 of the approvals expired and were subsequently renewed, and 58 approvals expired and were not renewed. Eight groundwater withdrawals were approved during that same time period, with none rescinded or expired by the end of December 2013 (Table 4).

Table 4. Summary of Water Withdrawal Approvals within the Susquehanna River Basin for Use by Unconventional Natural Gas Industry

Statistics	Calendar Year 2008	Calendar Year 2009	Calendar Year 2010	Calendar Year 2011	Calendar Year 2012	Calendar Year 2013	Totals
Surface Water (SW)Withdrawals:							
New SW Approvals Issued during Calendar Year	51	57	35	42	28	9	222
Expiring SW Approvals Renewed during Calendar Year	0	0	0	0	15	20	35
Expiring Approvals Not Renewed during Calendar Year	0	0	0	0	31	27	58
SW Approvals Actively Withdrawing Water during Calendar Year	3	19	39	57	52	46	-----
Groundwater (GW) Withdrawals:							
New GW Approvals Issued during Calendar Year	0	0	2	2	4	0	8
Expiring GW Approvals Renewed during Calendar Year	0	0	0	0	0	0	0
Expiring GW Approvals Not Renewed during Calendar Year	0	0	0	0	0	0	0
GW Approvals Actively Withdrawing Water during Calendar Year	0	0	2	3	3	4	-----

Descriptive Notes:

1. According to Commission regulations, if projects are not constructed within three years following initial approval, the projects are ruled to have expired on that third year.
2. As demonstrated in the last line of each section above, not all projects issued approvals were ultimately constructed and actively used to withdraw water.
3. There were an additional 10 surface water diversion approvals issued by the Commission in 2011 and one in 2013. All of the diversions originated from within the Ohio River Basin. Only 2 of the 11 diversions approved from the Ohio River Basin were actively used as of Dec. 31, 2013.

It is important to note in Table 4 that the number of surface water and groundwater withdrawals available for use during any given calendar year were considerably greater than the number of withdrawal sites actually used to support natural gas development activities. Of the available surface water withdrawals, 37 were from lesser quality waters, including three discharges from treatment plants and 34 mine drainage waters associated with past coal mining activities. Thirteen of the lesser quality sites were actively used by the industry during the report period, with a total of approximately 865 million gallons of impaired water withdrawn.

Data collected during the study period highlight the fact that the industry functions differently than other more traditional water users within the Basin. Unlike “brick-and-mortar” facilities such as power plants, public water systems, and manufacturing facilities where the locations of water use remain stationary over time, the gas industry’s water needs migrate considerable distances over relatively short periods of time. In addition, the industry intentionally builds in redundancy of water sources. This redundancy serves to decrease water trucking distances between various stationary water withdrawal points (sources) and active pad sites where the water is needed, to increase the availability of water regardless of the specific wells being fractured or the inactivation of certain water withdrawal locations due to prevailing low flow conditions, and to increase the overall flexibility of the water supply network upon which the companies rely. Efforts by the industry to minimize water truck travel distances and to optimize its water acquisition strategy at any given point in time initially resulted in the increased occurrence of approved water withdrawal sites that were not subsequently used, or perhaps used less frequently than originally envisioned by the individual companies and the Commission.

J. Watershed Distribution of Approved Surface Water Withdrawal Sites

A total of 222 surface water withdrawal sites were approved by the Commission during the report period, although some of these approvals were expired or were withdrawn before the end of the period. These approved sites were located within 61 individual watersheds. For the purposes of this report, an individual watershed is one in which a surface water feature (such as a run or creek) has been named by the United States Geological Survey (USGS) and appears as a named water feature on a USGS 7.5-minute topographic map. As a point of clarification, only water withdrawals pulling directly from the mainstem or West Branch of the Susquehanna River were attributed to the river. Water withdrawals from named watersheds flowing into the river were attributed to those named watersheds and not counted as withdrawals from the river itself. Likewise, withdrawals from more headwater settings were attributed to those named upper watersheds and not to the larger watersheds into which they flow.

Forty-four of the 61 individual watersheds were occupied by only one or two approved surface water withdrawal sites. Six watersheds were occupied by three to five approved surface water withdrawal sites. These six watersheds included Cowanesque River with five approved sites, and Chemung River, Moshannon Creek, and Towanda Creek each with four approved sites. Martins Creek and Little Muncy Creek (a tributary to Muncy Creek) each had three approved withdrawal sites.

Five watersheds were occupied by six to 10 approved surface water withdrawal sites. These five watersheds included Meshoppen Creek, Muncy Creek (including the Little Muncy Creek tributary with 3 sites), and Tioga River each with six approved sites, and Lycoming Creek and Sugar Creek each with nine approved sites.

Four watersheds were occupied by 11 to 20 approved surface water withdrawal sites. These four watersheds included Sinnemahoning Creek with 11 approved sites, Pine Creek and Tunkhannock Creek each with 13 approved sites, and Wyalusing Creek with 15 approved sites.

The mainstem Susquehanna River and the West Branch Susquehanna River both had 25 approved sites. No watersheds were occupied by more than 25 approved surface water withdrawal sites.

K. Number of Approved Surface Water Withdrawals Sites Used by the Gas Industry

Thirty-nine of the 61 Basin watersheds with surface water approvals had sites that were actually used by the industry as sources of water during the report period. Twenty-two of the 61 watersheds were occupied by approved surface water withdrawal sites that were never used. Twenty-seven of the 61 watersheds had only one or two actively used water withdrawal sites. Eight of the 61 watersheds had between three and five actively used water withdrawal sites. These included the Chemung River and Muncy Creek each with three actively used withdrawal sites. Cowanesque River and Tioga River each had four actively used withdrawal sites. Lycoming Creek, Meshoppen Creek, Sugar Creek, and Tunkhannock Creek each had five actively used withdrawal sites.

Three of the 61 watersheds had between six and 10 actively used surface water withdrawal sites. Pine Creek had six actively used water withdrawal sites. Wyalusing Creek had eight actively used withdrawal sites, and West Branch Susquehanna River had nine actively used withdrawal sites.

Only one of the 61 watersheds had more than 10 water withdrawal sites actively used by the industry. The mainstem Susquehanna River had 18 actively used sites.

Although withdrawals were approved from 11 watersheds located within the Ohio River Basin, the vast majority (more than 99.9 percent) of the 38 million gallons of water diverted into the Susquehanna Basin originated at one location, the Blue Valley Mine Drainage Treatment Plant. Only a very small amount (60,060 gallons) originated at the Franco Freshwater Impoundment located on Sandy Lick Creek. The other nine approved diversion sites were never used to supply water to the gas industry operating within the Susquehanna River Basin.

As previously noted, there were a total of 222 surface water withdrawal locations approved for the industry by the Commission during the study period. Of that total, 108 (or 48 percent of the total) were used by the industry during that period. The remaining 114 approved locations were never actively used. Many approvals were rescinded by the Commission or expired after a period of three years due to lack of use.

A total of 154 of the 222 original withdrawals were located within 20 individual watersheds. Eighty-five of the 108 actively used withdrawal sites were also located within the same 20 watersheds. Table 5 presents a summary of those 20 watersheds most heavily used by the industry as sources of water during the report period. These 20 watersheds accounted for over 97 percent of the 9.7 billion gallons of surface water withdrawn by the industry during that period. The balance of approximately 3 percent (282 million gallons) was withdrawn from within 19 other watersheds occupied by the remaining 23 actively used withdrawal sites. The locations of the top 20 watersheds are presented in Figure 8A. Water withdrawals from the top five watersheds (mainstem Susquehanna River, West Branch Susquehanna River, Wyalusing Creek, Tunkhannock Creek, and Pine Creek) constitute approximately two-thirds of the total surface water withdrawn by the industry during the report period (Figure 8B). The mainstem and West Branch of the Susquehanna River together account for approximately 42 percent of the total surface water withdrawn by the industry.

Table 5. Top 20 Watersheds Used as Water Sources by the Unconventional Natural Gas Industry (2008-2013)

Watershed Name	Drainage Area of Watershed ¹ (Sq. Mi.)	Number of Well Pads Approved within Watershed ²	Surface Water Withdrawals Approved by Watershed	Approved Surface Water Withdrawals Actively Used	Total Surface Water Withdrawn (2008-2013) (Gallons)	Indiv. Watershed Withdrawal as % of Total Withdrawal (%)	Cumulative Withdrawals as % of Total Withdrawal (%)
Susquehanna River, Mainstem (Above Sunbury, PA)	11,310	1,579	25	18	3,500,204,977	35.8	35.8
Wyalusing Creek	220	138	15	8	844,954,917	8.7	44.5
Tunkhannock Creek	414	144	13	5	789,601,068	8.1	52.6
Pine Creek	981	209	13	6	650,455,708	6.7	59.2
Susquehanna River, West Branch	6,979	782	25	9	577,659,886	5.9	65.2
Sugar Creek	189	162	9	5	421,738,464	4.3	69.5
Lycoming Creek	272	98	9	5	347,044,012	3.6	73.0
Arnot #5 Mine Drainage	N/A	N/A	1	1	315,905,794	3.2	76.3
Bowman Creek	120	6	2	2	284,751,336	2.9	79.2
Meshoppen Creek	114	150	6	5	254,818,962	2.6	81.8
Chemung River	2,595	321	4	3	249,858,906	2.6	84.3
Towanda Creek	277	127	4	1	234,107,068	2.4	86.7
Fishing Creek (Benton, PA)	385	24	1	1	169,763,763	1.7	88.5
Tioga River (PA)	457	209	6	4	167,648,794	1.7	90.2
Fall Brook	9	10	2	2	148,069,936	1.5	91.7
Martins Creek	52	28	3	1	130,346,068	1.3	93.1
Muncy Creek	204	58	6	3	127,613,820	1.3	94.4
Moshannon Creek	274	17	4	1	101,327,382	1.0	95.4
Fellows Creek	6	4	1	1	83,869,006	0.9	96.3
Cowanesque River	300	35	5	4	83,854,780	0.9	97.1
Subtotals for Top 20 Watersheds Listed Above	See Note 1 Below	See Note 1 Below	154	85	9,483,594,647	97.1	-----
Totals for Entire Basin	See Note 1 Below	See Note 1 Below	222	108	9,765,634,743	-----	-----
Difference	See Note 1 Below	See Note 1 Below	68	23	282,040,096	-----	2.9

Notes:

1. Some of the top 20 watersheds are contained within other top 20 watersheds. Therefore, the calculation of totals and subtotals at the bottom of Columns 2 and 3 are not appropriate.
2. Not all approved pad sites have been constructed.
3. A total of 222 surface water withdrawals were approved for gas industry use between 2008 and 2013.
4. A total of 108 surface water withdrawals, or 49 percent of the total, were actively used during that same time period.
5. The remaining 114 approved surface water withdrawals were never actively used.
6. Eighty-five of the total 108 surface water approvals actively used are represented in the top 20 watersheds listed above.
7. The balance of 23 approved surface water withdrawals actively used experienced substantially smaller withdrawal amounts than the 20 listed above.
8. To qualify as "actively used," a site need only have water withdrawn one day during the entire 2008-2013 time period.

TOP 20 WATERSHEDS USED FOR WATER SOURCES BY THE NATURAL GAS INDUSTRY
 in the Susquehanna River Basin, 2008-2013

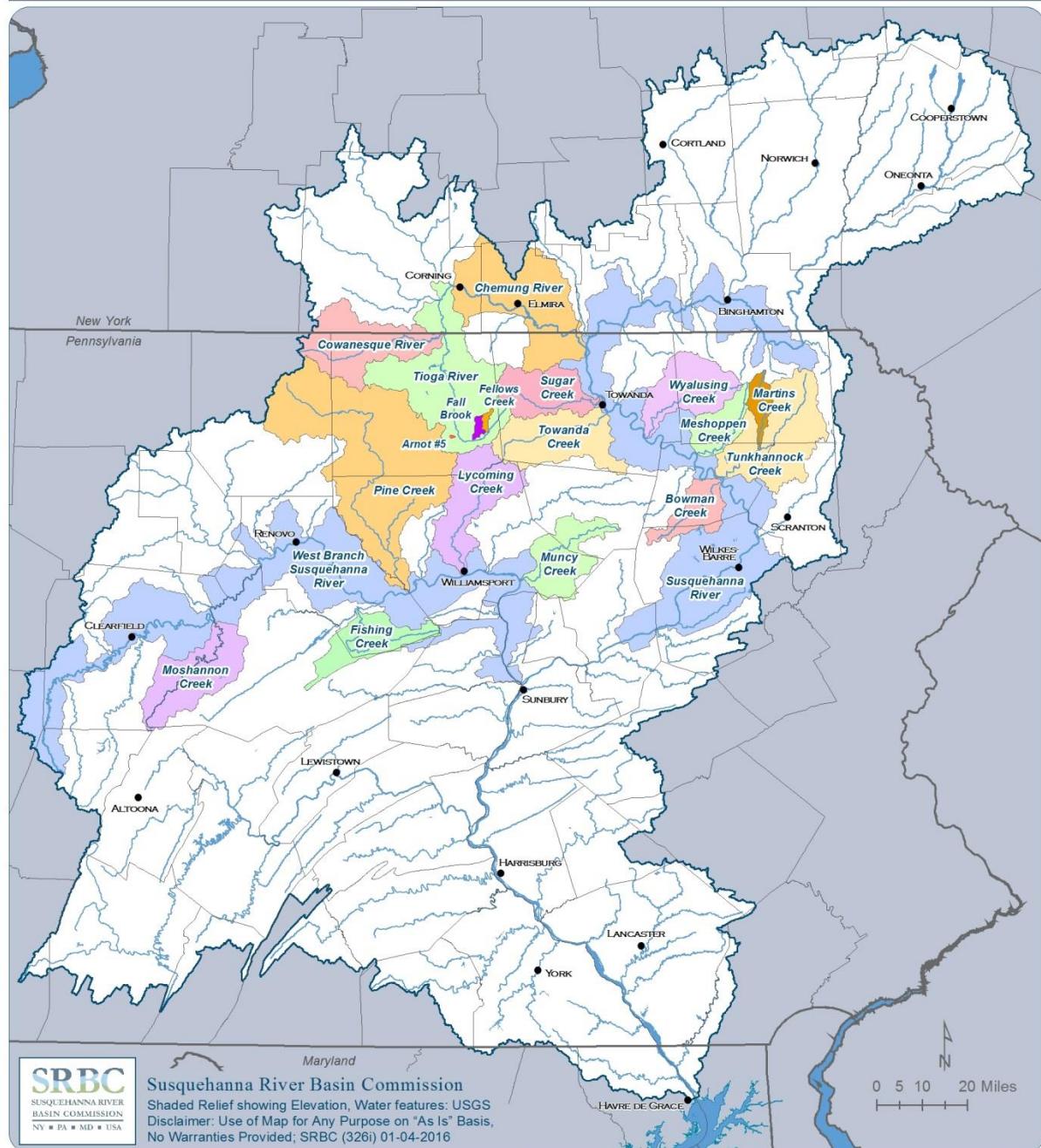


Figure 8A. Basin Locations of Top 20 Watersheds Used by the Gas Industry

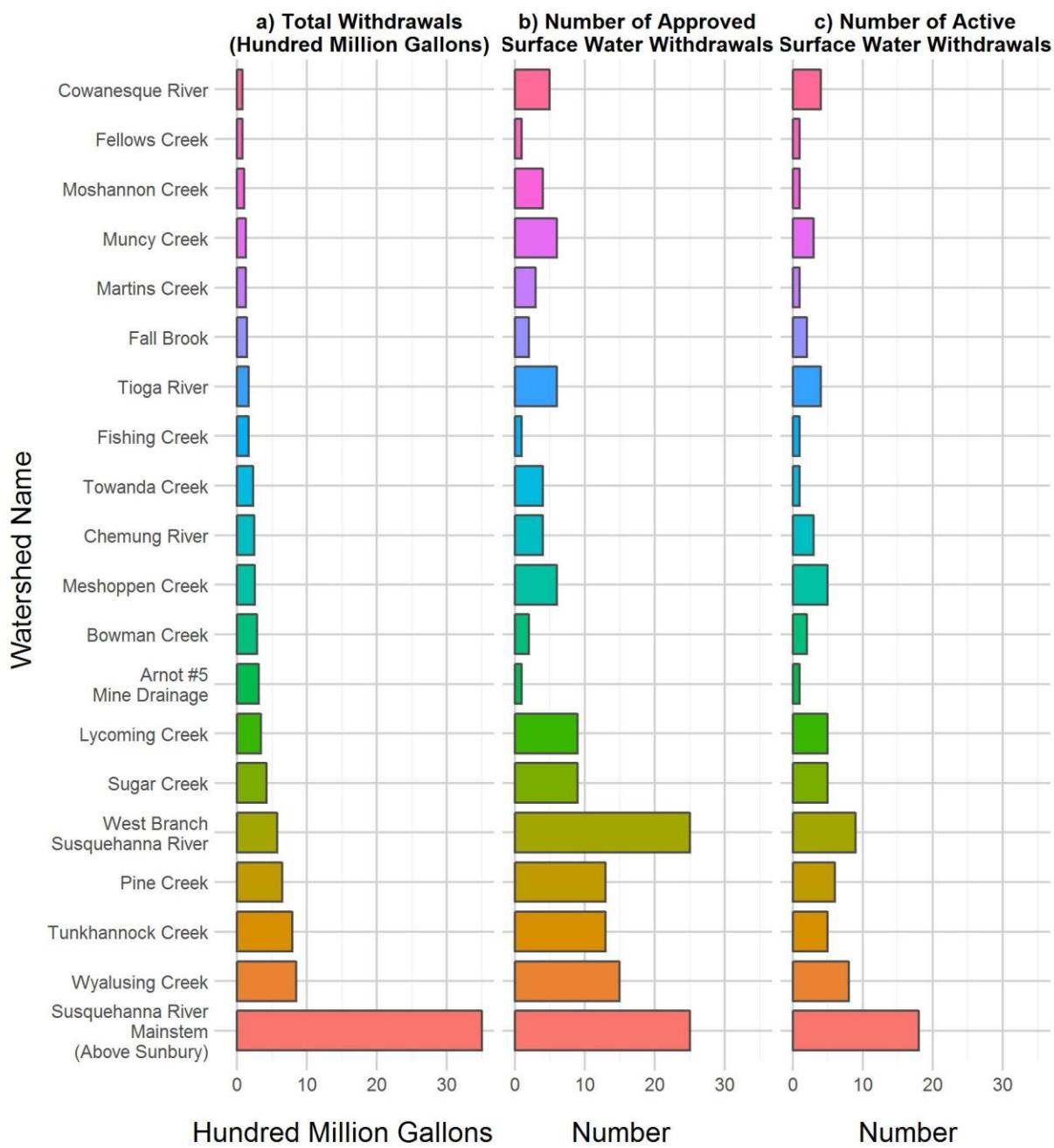


Figure 8B. Total Water Withdrawals, Number of Approved Surface Water Withdrawals, and Number of Withdrawals Actively Used During the Study Period

Frequency analyses were performed on surface water withdrawal approvals issued to the industry by the Commission during the report period to characterize the number of projects falling within any given category considering a range characteristics. The analyses addressed the range in approved maximum daily withdrawals, the range in drainage areas, and the range in ratios between the approved maximum daily withdrawals and the 10-year baseflow occurring at the points of withdrawals. The 10-year baseflow statistic (BF10YR) was chosen for the purpose of conducting a simple analysis since it represents the low flow condition in a surface water feature (stream, river, etc.) that is dominated by groundwater inflow during periods of low precipitation input (droughts) and is expected to occur on average once every 10 years. The 10-year baseflow statistic for each surface water withdrawal location included in the analyses was calculated using StreamStats, a water resources web application developed by the USGS (USGS, 2012). For a more detailed study focused on water availability and use throughout the Susquehanna River Basin, the Commission has a report and interactive web map available on its website.

Of the 222 surface water withdrawals approved by the Commission, 212 had discernable drainage areas needed for the frequency analysis. The ten excluded projects involved surface water withdrawals from quarry pits or ponds that had no clearly defined drainage areas needed for the analyses. Of the 212 surface water withdrawals analyzed, 203 had baseflow statistics needed for the ratio analysis.

Table 6A contains a summary of the frequency analysis performed on the maximum daily withdrawals approved by the Commission for the 212 surface water withdrawals mentioned above with discernable drainage areas. The approved maximum daily withdrawals for the 212 projects were divided into 13 convenient (round number) classes for the analyses. The number of approved projects falling into each class are listed in Table 6A as well as the percent of the total number of projects each class represented. As the results in Table 6A indicate, two-thirds of the approved surface water withdrawals fell within two class intervals. Thirty-three percent of the surface water withdrawals were approved at daily rates between 0.1 and 0.5 mgd and another 34.5 percent of the surface water withdrawals were approved at daily rates between 0.9 mgd and 2.0 mgd. The remaining one-third of the approved surface water withdrawals fell into other class intervals; most notably, the 0.0 to 0.1 mgd interval with 12.7 percent and the 0.5 to 0.9 mgd interval with 15.1 percent. There were no surface water locations with approved maximum daily withdrawals in excess of 3.0 mgd. The results of the maximum daily withdrawal analyses are graphically represented in Figure 9a.

Table 6A. Frequency Analysis of Approved Daily Maximum Limits for Surface Water Withdrawals

Class Intervals for Approved Surface Water Withdrawals Daily Maximum (MGD)	Number of Projects with Approved Daily Max. within Each Class Interval (Frequency, Counts)	Percent of Total (%)
Less than 0.1	27	12.7
Greater than 0.1 but equal to or less than 0.2	16	7.5
Greater than 0.2 but equal to or less than 0.3	19	9.0
Greater than 0.3 but equal to or less than 0.4	13	6.1
Greater than 0.4 but equal to or less than 0.5	22	10.4
Greater than 0.5 but equal to or less than 0.6	3	1.4
Greater than 0.6 but equal to or less than 0.7	4	1.9
Greater than 0.7 but equal to or less than 0.8	21	9.9
Greater than 0.8 but equal to or less than 0.9	4	1.9
Greater than 0.9 but equal to or less than 1.0	37	17.5
Greater than 1.0 but equal to or less than 2.0	36	17.0
Greater than 2.0 but equal to or less than 3.0	10	4.7
Greater than 3.0	0	0.0
Totals	212	100.0

Notes:

Although a total of 222 surface water approvals were granted to the industry, only 212 approvals had measurable drainage areas needed for the analyses in Table 6B.

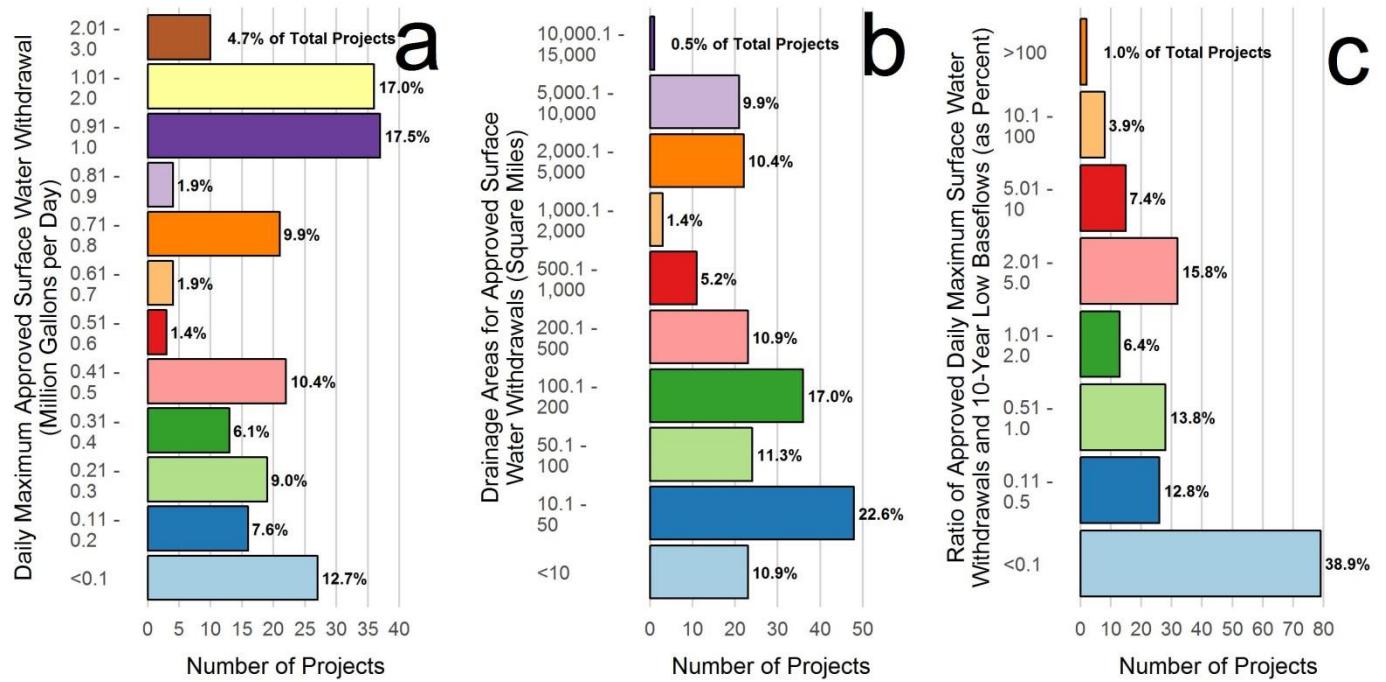


Figure 9. Graphic Summary of Frequency Analyses Performed on Daily Maximum Withdrawals, Drainage Areas, and Ratios of Daily Maximum Withdrawals to 10-Year Low Baseflows

Table 6B presents a summary of the frequency analysis performed on the drainage areas of the 212 surface water projects approved by the Commission and associated with measurable drainage areas. The drainage areas for the 212 projects were divided into 11 drainage area classes for the frequency analyses. The number of approved projects falling into each class are listed in Table 6B as well as the percent of the total number of projects each class represented. Approximately 45 percent of the surface water withdrawals were located within drainage areas measuring less than 100 square miles in size. Thirty-three percent of the surface water withdrawals were located in drainage areas greater than 100 and less than 1,000 square miles in size, and 20 percent of the surface water withdrawals were located in drainage areas between 2,000 and 10,000 square miles in size. The results of the drainage area analyses are also graphically represented in Figure 9b.

Table 6B. Frequency Analyses of Drainage Area Classes of Surface Water Withdrawal Approvals

Class Intervals of Drainage Areas for Approved Surface Water Withdrawals (Square Miles)	Number of Projects with Drainage Areas Falling within Each Class Interval (Frequency, Counts)	Percent of Total (%)
Equal to or less than 10	23	10.8
Greater than 10 but equal to or less than 50	48	22.6
Greater than 50 but equal to or less than 100	24	11.3
Greater than 100 but equal to or less than 200	36	17.0
Greater than 200 but equal to or less than 500	23	10.8
Greater than 500 but equal to or less than 1,000	11	5.2
Greater than 1,000 but equal to or less than 2,000	3	1.4
Greater than 2,000 but equal to or less than 5,000	22	10.4
Greater than 5,000 but equal to or less than 10,000	21	9.9
Greater than 10,000 but equal to or less than 15,000	1	0.5
Greater than 15,000	0	0.0
Totals	212	100.0

Notes:

1. Although a total of 222 surface water approvals were granted to the industry, only 212 approvals had measurable drainage areas needed for the above analyses.
2. Projects excluded from the above analyses include water features (quarry pits, ponds, etc.) with no clearly defined drainage areas or those with suspected groundwater components.

The relatively large number of surface water withdrawal projects (154 out of 212) located in watersheds with drainage areas of 500 square miles or less is believed to be the result of several factors. First, primarily for geological reasons, the industry is most concentrated and therefore most active in the Appalachian Plateaus Province, including the Pittsburgh Low Plateau Section, the Appalachian Mountain Section, the Allegheny Front Section, the Deep Valleys Section, and the Glaciated Low and High Plateau Sections of the Basin in north-central Pennsylvania (Sevon, 2000). The geomorphic characteristics of those areas produce relatively steep and more mountainous terrain resulting in localized watersheds (headwaters) of smaller sizes when compared to other physiographic provinces within the Basin. The relatively steep terrain creates a preference by the industry for siting well pads on the tops of hills and mountains. In addition, the industry tries to minimize the travel distances between well pads and water sources. For this reason, the industry's efforts to minimize travel distances results in its seeking water sources in nearby, smaller watersheds with limited sustainable water resources.

Table 6C contains a summary of the frequency analysis performed on the ratios of approved maximum daily withdrawals (mgd) divided by the 10-year low baseflow statistic (mgd) for the 203 surface water withdrawals approved by the Commission with available streamflow statistics. The 10-year low baseflow statistic was used to represent a one-in-ten year drought condition during which streamflows would be largely reliant upon groundwater inflow. A lower ratio (% value) indicates that the maximum daily withdrawal at an approved location comprises a smaller percent of the concurrent 10-year low flow condition at that location. In general, the

lower the ratio (% value), the greater the protection afforded to the instream ecosystem relative to a given withdrawal. As an example, a ratio of 0.1 would indicate that the maximum daily withdrawal rate would be 10 percent of the 10-year low baseflow value for that withdrawal.

The ratios (expressed as a percent) of maximum daily withdrawals to 10-year baseflows for the 203 projects were broken down into eight classes for the frequency analysis. The numbers of approved withdrawals falling into each class are listed in Table 6C as well as the percent of the total number of projects each class represented.

In general, 65.5 percent of the 203 surface water approvals included in the analysis had ratios equal to or less than 1.0 percent. This means that even if those projects were actively withdrawing water at their approved maximum daily rate during a 1-in-10 year drought baseflow condition, the withdrawn amount of water would not exceed one percent of the concurrent water flowing in that source stream or river. Another 29.6 percent of the 203 surface water approvals had ratios between 1.0 percent and 10.0 percent, indicating that the withdrawn amounts of water for those projects would not exceed 1.0 to 10.0 percent, respectively, of the concurrent water flowing in those streams or rivers during a one-in-10 year drought baseflow condition. In general, the results of the ratio analysis confirmed the protective nature of the Commission's surface water withdrawal approvals for the industry. The results of the ratio analyses of maximum daily withdrawals to the 10-year baseflows are also graphically represented in Figure 9c.

The vast majority of the surface water withdrawals with maximum daily withdrawal limits comprising 5 percent or more of the 10-year low baseflow value were those that also had low flow protection limits (i.e., passby flow restrictions) imposed by the Commission as a condition in the approval. These low flow protections would require the withdrawal be suspended before the 10-year baseflow value would be reached at each point of withdrawal. Of the 25 approved surface water withdrawals with maximum daily limits exceeding 5 percent of the 10-year baseflow value, 20 of them had low flow protection conditions that would require the suspension of all withdrawal activities at flow conditions considerably above the 10-year baseflow values for those locations. The other five projects were either rescinded or involved withdrawals from lesser quality water, specifically mine drainage.

Table 6C. Frequency Analyses of Ratios between Approved Daily Maximum Limits of Surface Water Withdrawals and 10-Year Low Baseflows at Point of Withdrawal

Class Intervals of Ratios Between Approved Surface Water Daily Max and 10-Year Low Baseflow at Point of Withdrawal (Daily Max mgd as % of 10-Yr Base Flow mgd)	Number of Projects with % Values Falling within Each Class Interval (Frequency, Counts)	Percent of Total (%)
Less than or equal to 0.1	79	38.9
Greater than 0.1 but equal to or less than 0.5	26	12.8
Greater than 0.5 but equal to or less than 1.0	28	13.8
Greater than 1.0 but equal to or less than 2.0	13	6.4
Greater than 2.0 but equal to or less than 5.0	32	15.8
Greater than 5.0 but equal to or less than 10	15	7.4
Greater than 10 but equal to or less than 100	8	3.9
Greater than 100	2	1.0
Totals	203	100.0

Notes:

1. Of the total 222 surface water approvals granted, only 203 approvals had baseflow statistics needed for the above ratio analyses.
2. The vast majority of surface water withdrawal approvals with Max mgd greater than 10% of baseflow mgd had passby restrictions included as part of their approval conditions. The few exceptions to this statement included withdrawals from lesser quality waters, such as mine drainage waters, where larger withdrawals and use were considered to be environmentally beneficial to the downstream ecosystems.

L. Profile of Water Use Associated with the Hydraulic Fracturing Process

A profile of the water used during the report period to hydraulically fracture gas wells in the Basin was developed from several Commission data sources. The industry is required to file post-hydraulic fracturing reports following the completion of a hydraulic fracturing event for every stimulated well within the Basin. In addition, the industry is required to report to the Commission on a quarterly basis the quantities of all water withdrawn from every approved withdrawal location and more recently (since 2010) all water purchased from all public water systems.

As the data in Table 2 indicate, a total of 2,860 gas wells were reported as hydraulically fractured within the Basin between July 2008 and December 2013. Each fracturing event was captured in a post-hydraulic fracturing report. The information contained in those reports enabled the Commission to calculate important statistics regarding the water use profile for the industry.

Approximately 96 percent of the water withdrawn by the industry is consumptively used in the hydraulic fracturing process. The balance of the water is consumptively used for other activities at the drilling pads such as well drilling, preparation of drilling muds and grout, dust control, maintenance operations, and site reclamation.

Data in Table 7 indicate that the long-term average water consumption for well fracturing events between July 2008 and December 2013 was 4.3 million gallons of water. Of the 4.3 million gallons of water used during an average fracturing event, 3.6 million gallons (or 84 percent) was comprised of fresh water and 0.7 million gallons (16 percent) was comprised of reused flowback fluids.

Table 7 presents a summary of the average water injected per well fracturing event and the average proportions of fresh water and flowback waters used in those events on a quarterly basis beginning in the third quarter of 2008 and extending through the fourth quarter of 2013. As the data indicate, the average amount of water used per fracturing event was relatively low in the second half of 2008 and the first quarter of 2009, ranging from 1.6 to 2.1 million gallons per event. These relatively low amounts of water used per event during this early period are believed to be primarily due to smaller exploration companies performing limited fractures on vertical wells and “toe fractures” on shorter laterals in horizontal wells to hold leases. The shorter laterals were also used by the exploration companies to test the productivity of the target formations and prove the resource.

Table 7. Summary of Average Water Injected per Well Fracturing Event and Proportions of Fresh and Flowback Waters Used in Those Events

Column 1	Column 2	Column 3	Column 4 (Column 5 / Column 2)	Column 5	Column 6	Column 7	Column 8	Column 9
Quarter/Year	Wells Fractured During Quarter	Reported Quarterly Consumptive Water Use ¹ (Gallons)	Quarterly Average Water Used Per Fractured Event (Million Gal.)	Reported Total Water Injected ² (Gallons)	Reported Fresh Water Injected (Gallons)	Reported Fresh Water Injected (% of Total) ⁴	Reported Flowback Water Injected (Gallons)	Reported Flowback Water Injected (% of Total)
Q3-2008	3	21,001,635	1.60	4,811,792	4,811,792	100	0	0
Q4-2008	7	34,513,242	1.83	12,804,608	12,804,608	100	0	0
Yearly Subtotals³	10	55,514,877	-----	17,616,400	17,616,400	-----	0	-----
Q1-2009	13	38,260,212	2.12	27,552,486	28,627,992	104	0	0
Q2-2009	31	74,688,717	2.96	91,822,229	93,418,023	102	9,227,076	10
Q3-2009	46	141,093,875	3.59	164,947,559	151,432,243	92	16,383,038	10
Q4-2009	57	220,831,918	4.06	231,571,798	209,461,272	90	28,663,533	12
Yearly Subtotals	147	474,874,722	-----	515,894,072	482,939,530	-----	54,273,647	-----
Q1-2010	44	298,903,094	3.50	154,024,689	139,156,585	90	17,174,339	11
Q2-2010	103	540,481,643	3.98	409,798,521	362,638,431	88	47,114,251	11
Q3-2010	137	740,489,787	4.38	600,706,564	544,290,696	91	56,050,865	9
Q4-2010	166	713,952,011	4.35	722,255,462	682,983,072	95	67,778,653	9
Yearly Subtotals	450	2,293,826,535	-----	1,886,785,236	1,729,068,784	-----	188,118,108	-----
Q1-2011	144	749,220,650	4.86	700,253,390	574,162,351	82	66,035,777	9
Q2-2011	157	899,691,766	4.58	719,523,743	568,614,847	79	144,610,292	20
Q3-2011	256	1,115,688,304	4.25	1,088,264,796	1,021,240,993	94	130,382,815	12
Q4-2011	237	1,032,685,548	4.67	1,106,297,747	950,127,109	86	156,859,908	14
Yearly Subtotals	794	3,797,286,268	-----	3,614,339,676	3,114,145,300	-----	497,888,792	-----
Q1-2012	261	1,060,148,713	4.38	1,143,391,449	957,626,153	84	180,159,226	16
Q2-2012	251	1,107,906,169	3.74	939,699,748	835,564,187	89	180,252,279	19
Q3-2012	166	736,667,801	3.78	627,531,835	485,536,858	77	147,052,132	23
Q4-2012	158	711,174,801	4.43	699,636,371	562,436,667	80	135,565,127	19
Yearly Subtotals	836	3,615,897,484	-----	3,410,259,403	2,841,163,865	-----	643,028,764	-----
Q1-2013	159	826,555,336	5.40	859,313,996	613,536,190	71	238,080,430	28
Q2-2013	190	833,449,522	5.31	1,009,792,764	799,563,012	79	196,781,530	19
Q3-2013	150	535,103,571	5.20	780,052,507	609,146,142	78	163,282,146	21
Q4-2013	124	924,918,220	6.55	812,086,312	653,293,942	80	149,150,528	18
Yearly Subtotals	623	3,120,026,649	-----	3,461,245,579	2,675,539,286	-----	747,294,634	-----
Column Totals	2860	13,357,426,535	-----	12,906,140,366	10,860,473,165	-----	2,130,603,945	-----
Long-Term Averages	-----	-----	4.31	-----	-----	84	-----	16

¹ The differences between Reported Quarterly Consumptive Water Use (Column 3) and the Reported Total Water Injected (Column 5) for specific quarters are primarily attributable to water used for non-fracturing (non-injection) purposes (e.g., dust control, well drilling, site reclamation, etc.) for that quarter. Some of these quarterly differences are also attributable to large quantities of water moving into or out of storage impoundments across multiple quarters.

² In any given quarter, there may be differences between the Total Water Injected (Column 5) and the combination of Total Fresh Water Injected (Column 6) plus Total Flowback Injected (Column 8). These quarterly differences are due at least in part to the allowable flow meter accuracy of plus or minus 5 percent.

³ Datasets for calendar year 2008 are incomplete; therefore, conclusions based upon those data may be unreliable.

⁴ The "104" percent value in Column 7 for Q1-2009 is believed to be an artifact of the allowable flow meter accuracy of plus or minus 5 percent.

The industry initially held that greater amounts of water used during fracturing efforts compromised the effectiveness of the fracture. Over time, this position proved to not be the case and the industry realized that greater amounts of water actually improved the effectiveness of the fracturing efforts. As the industry transitioned from the exploratory phase to the production phase, gas companies started drilling longer laterals to achieve better gas recovery from the shale formations. This led to an increase in the amounts of water used per fracturing event.

From the third quarter of 2010 through the fourth quarter of 2012, the average amount of water used per event held relatively steady at 4.3 to 4.8 million gallons per event. During 2013, the industry started lengthening the laterals and the average amount of water used per fracturing event increased from approximately 5.1 to 6.5 million gallons per fracturing event.

The difference between the total reported quarterly consumptive use (13.357 billion gallons) and the reported total water injected into gas wells for fracturing purposes (12.888 billion gallons) for the period 2008 through 2013 is primarily attributable to activities not directly related to hydraulic fracturing. These activities that consumptively used approximately 0.5 billion gallons of water included other activities at the drilling pad such as well drilling, preparation of drilling muds and grout, dust control, maintenance operations, and site reclamation.

During the second quarter of 2009, the industry began reusing flowback in subsequent fracturing events in a more concerted manner (see Column 8 in Table 7). It should be noted that the amount of flowback waters used in fracturing events increased on an annual basis from 2009 through 2013. This increased reuse of flowback waters reflects the value of these fluids in subsequent fracturing events and represents an offset or reduction in the amounts of fresh water needed for subsequent fracturing events. The reuse also resulted in a reduction in the amount of waste fluids requiring disposal or treatment.

Data taken directly from the post-hydraulic fracturing reports received by the Commission between 2008 and 2013 indicate that the average amount of flowback recovered from the wellbore of stimulated wells within the first 30 days following the release of pressures induced as part of the hydraulic fracturing effort ranged from a low of approximately 5 percent to a high of approximately 12 percent, with a long-term average of approximately 10 percent. Therefore, given the average of 4.3 million gallons of water used per fracturing event, the amount of flowback from each stimulated well ranged from approximately 0.2 million gallons (5 percent) to 0.5 million gallons (12 percent).

Using the long-term average flowback recovery rate of 10 percent per fracturing event for 2,860 wells fractured indicated that approximately 1.2 billion gallons of flowback fluids were recovered from wells during the report period. This flowback water was either: (1) reused for subsequent fracturing events without treatment on the pad from which it originated or another nearby pad; (2) was treated on the originating pad and reused for additional fracturing on the originating pad or another nearby pad; (3) was transported to an off-site facility for treatment and then trucked back to the originating pad or another pad for reuse in a subsequent fracturing event; or (4) transported off-site for treatment and/or final disposal with no reuse.

The Commission relies upon its member jurisdictions to regulate the transport, treatment, storage, and ultimate disposal of all flowback fluids and production fluids associated with unconventional natural gas development to include well drilling and fracturing activities. Information from PADEP data indicated that approximately 99 percent of flowback fluids were reused by the gas industry. The remainder (approximately 1 percent) was transported to deep injection wells, landfills, or treated and discharged into surface waters. Information taken from PADEP files also indicated that approximately 86 percent of all produced fluids from wells located within the Basin were reused by the industry, with only 14 percent of produced fluids destined for final disposal including deep injection wells (PADEP, 2012).

M. Major Findings Regarding Water Acquisition and Consumptive Use by the Industry

Great care has been exercised by the Commission in managing the locations, number, and size of the water withdrawals by the industry to minimize potential impacts on aquatic ecosystems and downstream water users within the Basin. The Commission holds as one of its highest priorities the sustainability of the valuable water resources of the Basin.

Technical information collected by the Commission on the industry operating within the Basin during the 2008-2013 report period served as the basis upon which several highlights and findings have been drawn regarding the industry's water use characteristics. These findings include the following:

1. The industry drilled its first unconventional gas well within the Basin in 2006. However, rapid expansion of its well drilling activities did not begin until the second half of 2008.
2. The largest number of wells were drilled in 2010 and 2011 (931 and 1,231 wells, respectively). Wells drilled in 2012 and 2013 were 685 and 619, respectively.
3. Well fracturing and water acquisition activities within the Basin began expanding more rapidly in 2010. The largest number of wells were hydraulically fractured in 2012 (836 wells). There were 794 wells fractured in 2011 and 623 fractured in 2013.
4. The second quarter of 2012 experienced the greatest quarterly water use with a calculated average daily rate of 12.25 million gallons per day.
5. The number of wells fractured and the amounts of water used within the Basin decreased after the second quarter of 2012, but remained relatively steady for the remainder of the study period at 120 to 160 wells fractured per quarter and approximately 500 million to 900 million gallons of water used per quarter.
6. A total of 61 different watersheds located within the Basin contained one or more surface water withdrawal approvals for use by the industry during the study period. These watersheds ranged in size from several square miles to more than 2,000 square

miles. Of those 61 watersheds, 39 watersheds (or 64 percent) were actually used as source waters by the industry.

7. The six watersheds from which approximately 70 percent of the total water withdrawn by or for the industry included the mainstem Susquehanna River above Sunbury, West Branch of the Susquehanna River, Wyalusing Creek, Tunkhannock Creek, Pine Creek, and Sugar Creek.
8. The long-term average amount of water injected per well hydraulic fracturing event was 4.3 million gallons. During 2013, the industry started lengthening the laterals and the average amount of water used per fracturing event increased to approximately 5.1 to 6.5 million gallons per fracturing event.
9. The average amount of flowback realized from each stimulated well ranged from approximately 0.2 to 0.5 million gallons, or approximately five to 12 percent of the total amount injected.
10. The amount of flowback waters used by the gas industry in subsequent fracturing events increased on an annual basis from 2009 through 2013. During calendar years 2012 and 2013, flowback comprised 19 and 22 percent, respectively, of the water used to fracture wells.

It is important to note that every docket approval issued by the Commission for water withdrawal by the industry was based upon site-specific information submitted by project sponsors or collected by Commission staff. Only water sources approved by the Commission can be used by the industry for hydraulic fracturing in the Basin. Approvals granted by the Commission for all surface water and groundwater withdrawals contain site-specific limitations including instantaneous withdrawal limits and daily limits. Approximately 70 percent of the approved surface water withdrawals also contained low flow protection conditions which required the company to suspend withdrawals when instream flows dropped below a pre-determined level during drier conditions.

IV. Part III. Commission Programs Influencing Industry Water Use

Part III of the report contains a discussion of other Commission programs that exerted influence over the unique water needs of the industry. This section includes discussion on the Commission's low flow protection policy to better protect the aquatic habitat and hydrologic characteristics of the water sources used by the industry, aquatic resource surveys that served as the technical basis upon which appropriate levels of protection were incorporated into the approvals issued to the industry, the remote water quality monitoring network developed and maintained by the Commission to track changes over time in water quality parameters reflective of the industry's activities within the northern portion of the Basin, and the expansion of the compliance program to ensure that the industry maintains compliance with the regulations of the Commission.

A. Low Flow Protection Policy

The Commission adopted a new Low Flow Protection Policy (LFPP) in December 2012, which replaced the existing Commission low flow policy (2003 adoption) to better reflect more contemporary standards regarding ecosystem flow protection science. Although the change in policies was not directly in response to industry water use, the water use characteristics of the industry were considered in development of the policy and it definitely had a major influence on industry operations considering the breadth of activity in the Basin.

The LFPP contains specifications for determining passby flows and conservation releases for approved water withdrawals. A passby flow is defined as a prescribed streamflow below which withdrawals must cease. A conservation release is defined as a prescribed quantity of flow that must be continuously maintained downstream of an impoundment. In contrast to the former policy, the LFPP specifies variable monthly low flow protection thresholds as opposed to a constant annual threshold. The scientific framework for developing the LFPP was a study conducted by The Nature Conservancy (TNC) which produced a report entitled *Ecosystem Flow Recommendations for the Susquehanna River Basin* (TNC, 2010). In the report, TNC presented a set of recommended flows to enhance protections for aquatic life communities and key ecological processes within the various stream types in the Basin. One of the key findings of the study was that seasonal water flow recommendations are preferred to year-round flow recommendations as ecosystem water needs are naturally seasonal.

The LFPP contains criteria for classifying Basin waterways into an Aquatic Resource Class (ARC) (Table 8). Figure 10 depicts Basin streams according to ARC. The approach leverages the existing Northeast Aquatic Habitat Classification System (NEAHCS) River and Stream Size Classification based on ranges of drainage area. The result is a uniform, streamlined approach to classifying Basin streams for use in determining standard low flow protection requirements for approved withdrawals.

Table 8. Aquatic Resource Class Criteria and Distribution within the Susquehanna River Basin

ARC	Description	Drainage Area (mi ²)	Total Stream Length (mi)	% Composition
1	Headwaters	<=10	40,421	81%
2	Creeks	>10 <50	4,357	10%
3	Small Rivers	>=50 <200	2,139	4%
4	Medium Tributary Rivers	>=200 <1,000	1,300	3%
5	Medium Mainstem Rivers	>=1,000 <5,000	467	1%
6	Large Rivers	>=5,000	582	1%

Acceptable methods for computing streamflow statistics, including monthly percent exceedance values, at the point of stream withdrawal or impact are referenced in the LFPP. These include both regional reference gages and regression analyses. Provision is made for conducting cumulative water use assessments to comprehensively evaluate the effect existing

upstream water use has on water availability at, and downstream of, a proposed withdrawal site. Similarly, an evaluation of the effects of a proposed withdrawal on existing downstream water uses is also described. A proposed withdrawal, evaluated both individually and cumulatively on a monthly basis, considered by the Commission to be too low in magnitude to have any appreciable effect on instream flows is not subject to low flow protection requirements. These are referred to as *de minimis* withdrawals and are determined based on the cumulative withdrawal relative to the 95th percent exceedance (P95) flow for each month. The LFPP outlines *de minimis* withdrawal thresholds by ARC (Table 9).

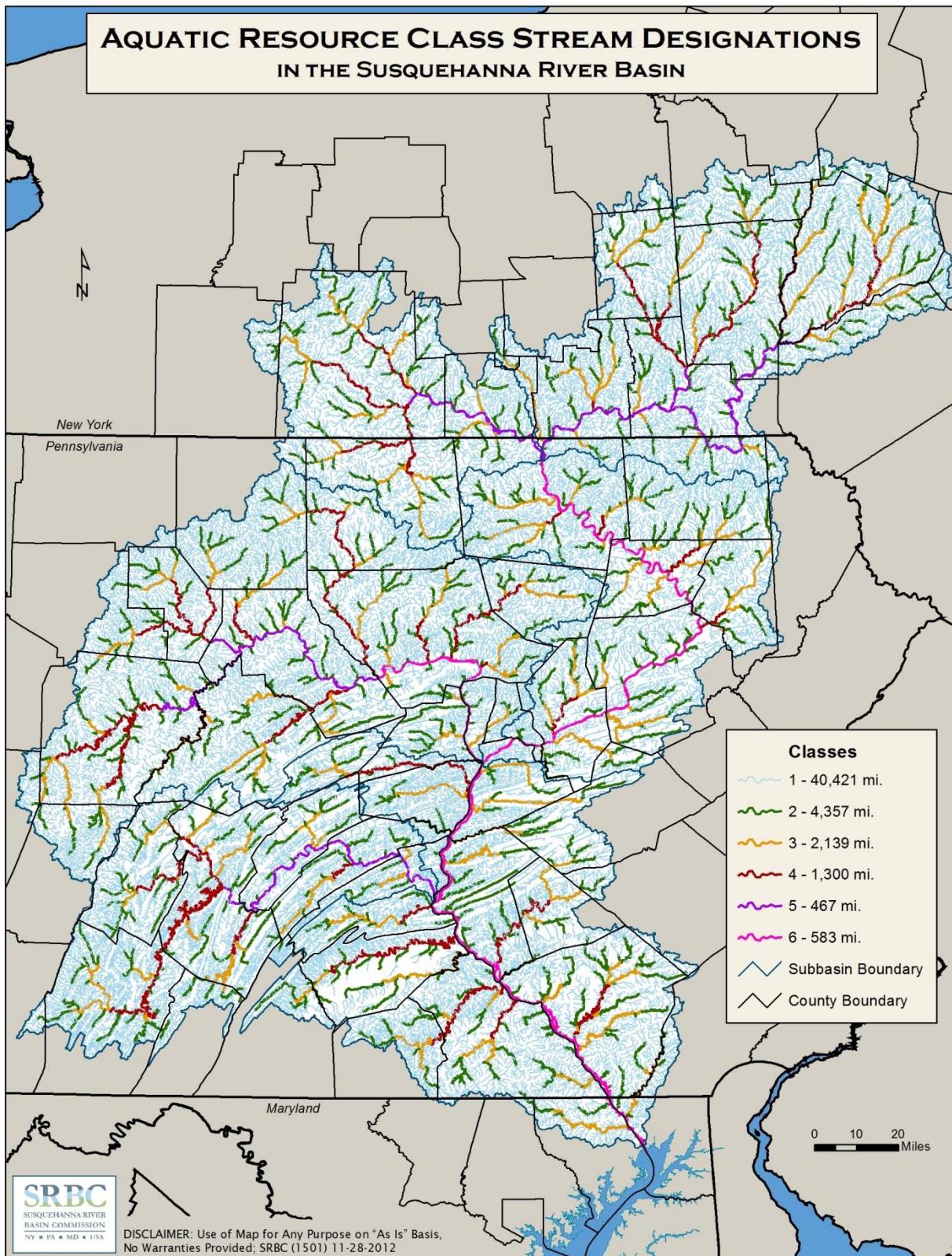


Figure 10. Aquatic Resource Class Designations for Basin Streams

Table 9. De minimis Withdrawal Thresholds by Aquatic Resource Class

ARC 1	ARC 2	ARC 3	ARC 4	ARC 5	ARC 6
None	5% monthly P95	5% monthly P95	5% monthly P95	10% monthly P95	10% monthly P95

The LFPP cites two primary methods for determining passby flow and conservation release thresholds. These include the percent exceedance value method and Pennsylvania-Maryland Instream Flow Study (PA-MD IFS) method. The former is broadly applicable to all stream types in the Basin and derived from the TNC ecosystem flow recommendations for the low flow component of the annual hydrograph. The standard passby flow/conservation release thresholds applicable when employing this method are outlined in Table 10. The latter is applicable to coldwater trout streams with drainage areas less than 100 square miles in the PA-MD IFS area and leverages flow/habitat loss relationships assessed based on Instream Flow Incremental Methodology (IFIM) modeling. Flexibility is afforded for determination of low flow protection requirements for withdrawals from exceptional quality and impaired waters. Generally, more stringent thresholds may be established for exceptional quality waters (e.g., native trout streams) and less stringent thresholds may be established for impaired waters (e.g., mine discharges). This acts to incentivize development of water sources from lesser quality waters.

Table 10. Passby Flow/Conservation Release Schedule

ARC 1	ARC 2	ARC 3	ARC 4	ARC 5	ARC 6
monthly P70	monthly P75	monthly P80	monthly P85	monthly P90	monthly P95

In order to preserve natural flow variability and meet seasonal flow protection objectives, the Commission may also limit a proposed withdrawal rate. This condition may be imposed when the proposed withdrawal has the potential to affect seasonal flow variability or lead to overall unacceptable change to the stream's characteristics. In establishing such conditions, the Commission considers TNC's ecosystem flow recommendations and other related environmental flow science. The LFPP also outlines a suite of special cases and conditions which can influence the determination of appropriate low flow protection requirements including seasonal versus monthly thresholds, project specific instream flow studies, water conservation measures, drought emergencies, and adaptive management considerations.

From the time of adoption of the LFPP to the end of the study period in December 2013, the Commission approved 83 water withdrawals. Of those, 29 are associated with unconventional natural gas extraction, and 22 of those have been conditioned with passby flow or conservation release requirements. Figure 11 depicts the location of these approved water withdrawals, by type.



APPROVED WATER WITHDRAWALS AND PASSBY CONDITIONS FOR NATURAL GAS EXTRACTION IN THE SUSQUEHANNA RIVER BASIN, 2009-2013

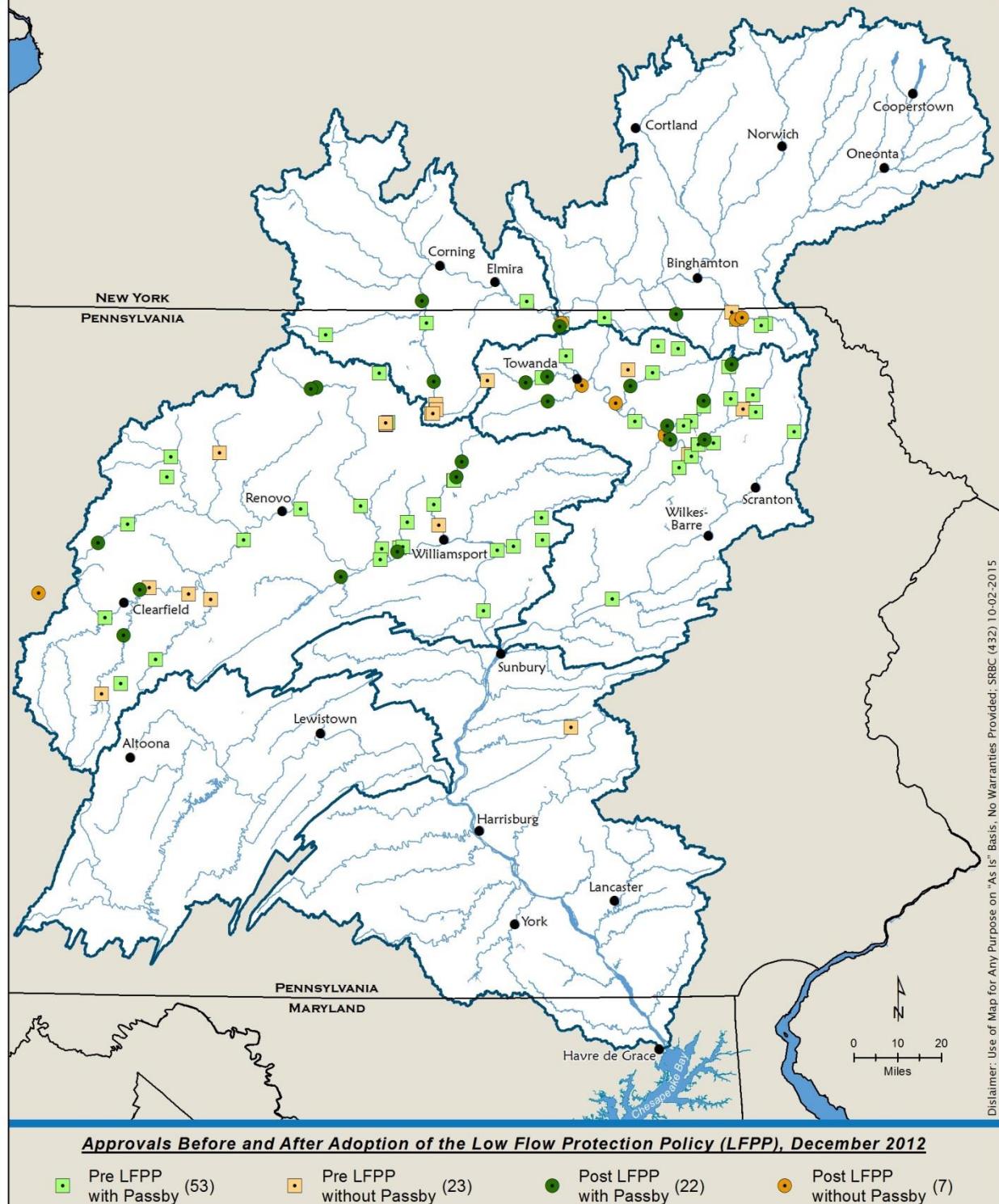


Figure 11. Approved Water Withdrawals and Passby Flow Conditions for Natural Gas Extraction

V. Monitoring and Protection

A. Aquatic Resource Surveys

In 2008, when the Commission first began receiving applications for surface water withdrawals for natural gas development, the decision was made to enhance the Commission's existing program for collecting physical, chemical, and biological data from streams where withdrawals were proposed and watersheds where pads were permitted. This data collection process, referred to as an Aquatic Resource Survey (ARS), is performed where a stream meets specific criteria (as described below). Understanding the aquatic resources and supporting habitat present in streams is an essential component of the Commission's mission, and is built into its technical review of proposed water withdrawals. Site-specific data collected during an ARS allow Commission staff to assess the current baseline stream condition at a proposed water withdrawal location. These data are used in conjunction with information about water availability, stream hydrology, and existing water uses in the Commission's evaluation of potential impacts to the stream. Additionally, ARS information may serve to identify potential impacts attributable to other influences such as land uses, wastewater discharges, and riparian cover.

The Commission screens all proposed water withdrawal sites for environmental concerns and conducts an ARS within a targeted stream when one or more of the following criteria are met:

- Recent or comprehensive stream assessment data are not available;
- A state agency has designated the stream as exceptional quality;
- Wild trout populations and/or rare, threatened, or endangered species are likely to be present;
- The stream is in a headwater setting.

The physical habitat of each ARS site is evaluated using a slightly modified version of the habitat assessment procedure outlined by Barbour and others (1999). Twelve habitat parameters (e.g., instream cover, riparian vegetative width) are field-evaluated at each site and used to calculate a site-specific habitat assessment score. The dominant substrate and weather conditions are noted, along with a discharge measurement using standard USGS procedures (Buchanan and Somers, 1969).

During the outset of the ARS program, the only chemical measurements recorded at a site were standard field chemistry parameters which include water temperature, pH, dissolved oxygen, and specific conductance. In 2011, this suite of parameters was expanded to include many of the potential water quality constituents associated with the industry. This expansion was important because ARSs are often conducted in areas of gas development activity.

In 2013, water samples collected during the surveys were analyzed by a laboratory for the following parameters:

- acidity
- alkalinity
- aluminum
- barium
- bromide
- calcium
- carbon dioxide
- chloride
- iron
- lithium
- magnesium
- manganese
- nitrate/nitrite
- total kjeldahl nitrogen
- total nitrogen
- total phosphorus
- potassium
- sodium
- strontium
- sulfate
- total dissolved solids
- total organic carbon

The biological component of an ARS includes fish and macroinvertebrate assemblage data. These data have been collected using standardized methods throughout the duration of the ARS program. Field personnel use three-pass electrofishing to collect fishes from a length of stream that is dependent on wetted width. All fishes are identified to species and enumerated in the field or laboratory. Benthic macroinvertebrates are collected using a D-frame net with 500-micron mesh in six representative riffle/run areas within the stream reach. Two hundred organisms from this composite sample are randomly extracted in the laboratory and identified to genus or the lowest possible taxonomic level (PADEP, 2009). Fish and macroinvertebrate assemblage data provide insight into the health of the aquatic ecosystem on a site-specific scale.

Between 2008 and the end of 2013, the Commission conducted a total of 152 ARSs at approximately 80 percent of the proposed surface water withdrawal sites located on wadeable streams (Figure 12). The majority of the ARSs have been associated with water withdrawal applications for natural gas development; however, surveys have also been conducted for proposed withdrawals for golf course irrigation and water bottling facilities. The majority of ARSs (131) were conducted in response to a water withdrawal application for a new project. However, water withdrawals specific to the natural gas industry are approved for a term of four years. If the project sponsor wishes to continue operating beyond that term or to modify their withdrawal operation (e.g., increase the maximum daily withdrawal quantity or pumping rate), the project will be subject to another technical review and may involve another ARS. In response to projects requesting renewals or modifications, an additional 21 ARSs were performed through 2013 (Figure 12).

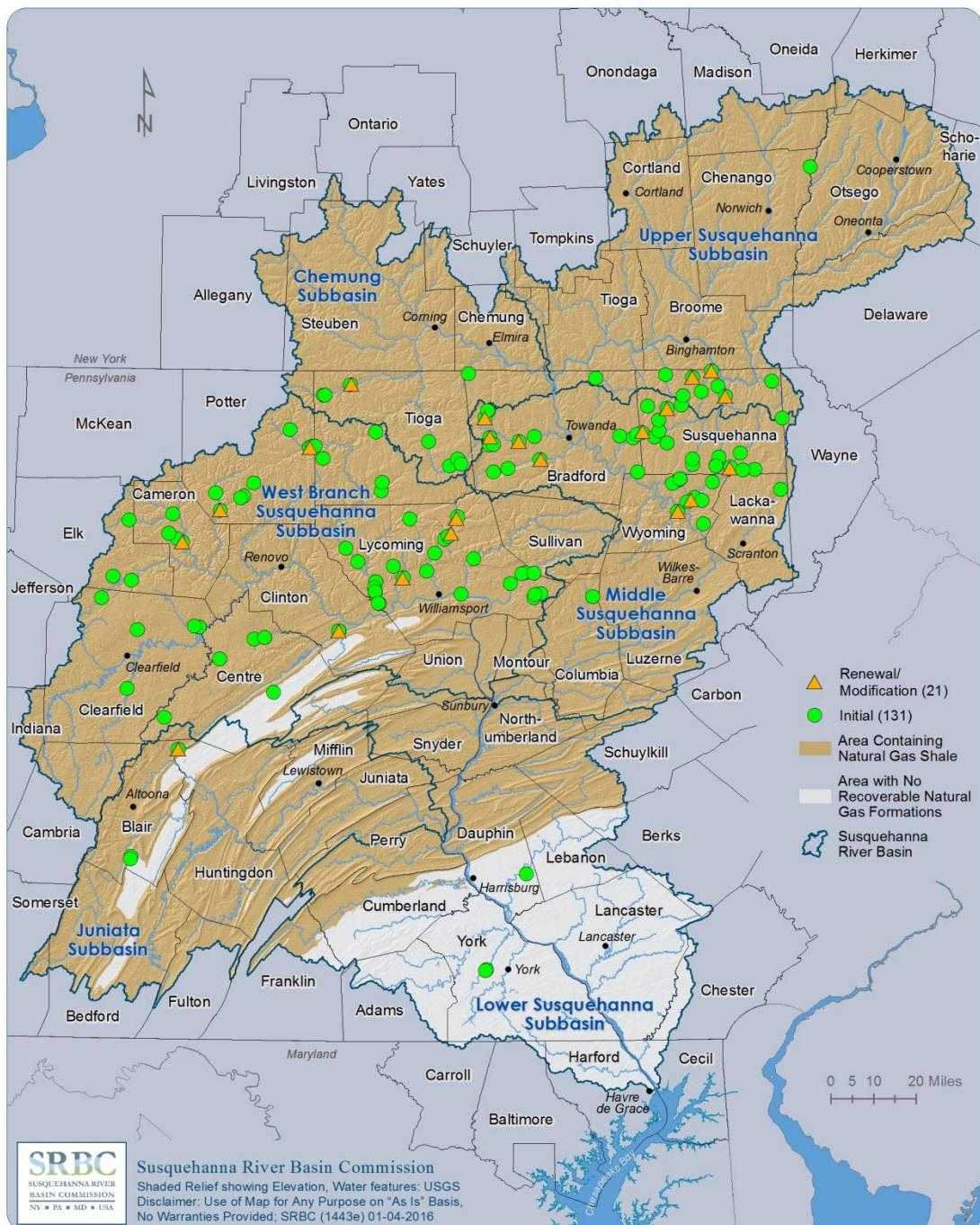


Figure 12. Aquatic Resource Survey (ARS) Locations through 2013 in the Susquehanna River Basin

The largest number of ARSs were conducted during the earlier years of natural gas development in the Basin due to the lack of existing data. The number of ARSs conducted annually has decreased from 38 in 2008 to 11 in 2013 as a result of increased overall data collection activities by both the Commission and its member agencies (Figure 13a). Most ARSs

have been conducted in areas with the highest amount of drilling activity (i.e., northern tier of Pennsylvania), which comprises large portions of the West Branch and Middle subbasins (Figures 12 and 13b). Counties along the northern tier of Pennsylvania have experienced the most withdrawal requests and associated drilling activity within the Basin and subsequently have also had the largest number of ARSs performed (Figures 12 and 14).

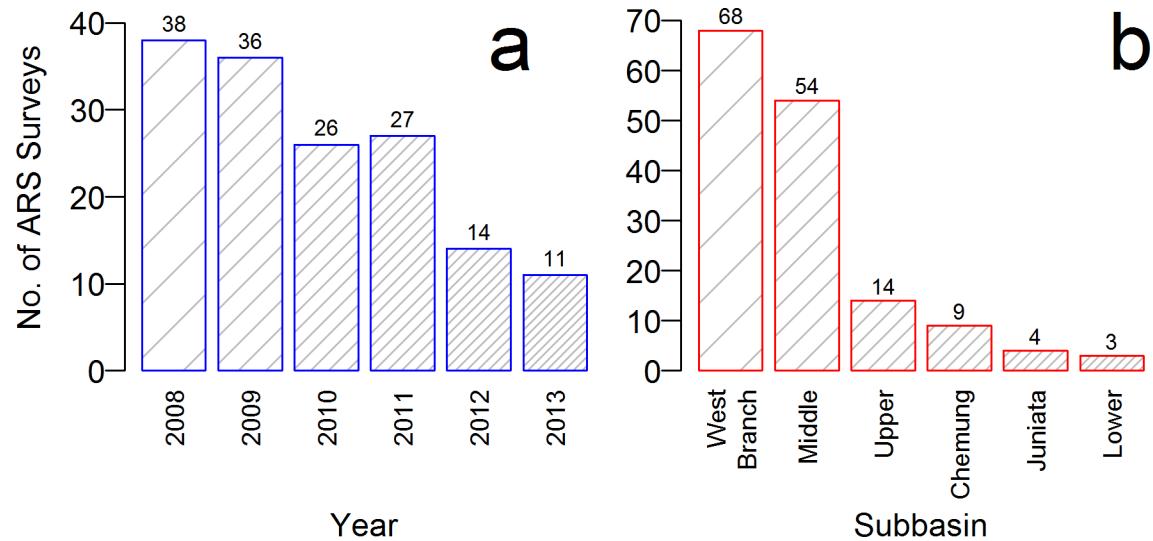


Figure 13. Number of Aquatic Resource Surveys (ARS) by Year (a) and Subbasin (b) (Labels of actual values placed atop each bar.)

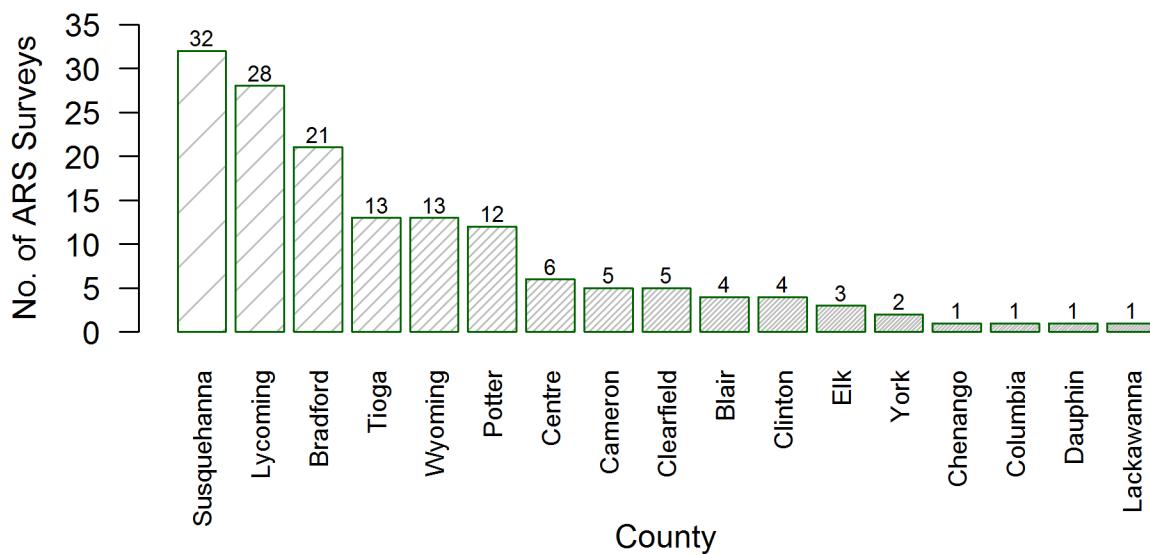


Figure 14. Number of Aquatic Resource Surveys (ARS) by County (Labels of actual values placed atop each bar.)

After careful review and analysis of all the data collected as part of an ARS, Commission staff recommends appropriate protective measures, as needed, to avoid or minimize significant impacts to the waterway. For example, if sensitive or rare species such as wild trout are documented during an ARS, Commission staff will consider that factor in its determination of the passby flow recommendation to ensure protection of the aquatic community during periods of low flow. Another protective measure might involve a safeguard to avoid potential adverse impacts during a critical life cycle stage of a sensitive or rare species. If a sensitive species such as the Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*) were found during an ARS, Commission staff would recommend a seasonal restriction on initial construction of the intake structure to protect the species during the egg incubation period.

In addition to the systematic data collection conducted as part of the ARS program, Commission staff performed targeted research intended to assess whether or not surface water withdrawals for industry use were impacting aquatic communities within the Basin. In spring 2012, Commission scientists collected data upstream and downstream of 12 water withdrawal sites and three reference sites in headwater, cold water, and large warm water streams (Figure 15). Watershed size of the study sites ranged from 1.7 to 199.6 square miles and average daily water withdrawals ranged from 0.01 to 0.38 million gallons. The largest withdrawals relative to stream size were from headwater streams, where on average 6.8 percent of average daily flow (ADF) was withdrawn daily. Fish and macroinvertebrate assemblage similarity at study sites depended largely on the stream sampled, rather than position upstream or downstream of withdrawals. Regression techniques were used to determine if landscape related variables or withdrawal metrics better described variation in fish and macroinvertebrate metrics shown to be sensitive to flow alteration. The site-specific variables were responsible for the majority of observed variation in fish metrics. Macroinvertebrate models performed poorly, indicating that the stream sampled or variables not included in the analyses were responsible for the majority of variation. Overall, evidence suggests impacts of natural gas withdrawals within the Basin at the present state of flow alteration are limited. Potential reasons include protective measures such as passby flow restrictions, limits to maximum instantaneous and daily withdrawals, the relatively recent initiation of the withdrawals (with only one to three years of operation), and inconsistency or sporadic use of the withdrawals over time. This Commission-funded research resulted in a detailed internal report (Shank, 2013) and a peer-reviewed publication (Shank and Stauffer, 2015).

The results of this withdrawal research do not unequivocally indicate that withdrawals are not impacting fish and macroinvertebrate assemblages at sites included in this study. However, evidence suggests that withdrawals as conducted through 2012 are generally not impacting fish and macroinvertebrate assemblages to a greater magnitude than do watershed size and land use practices. To further examine the relationship between withdrawals and aquatic life communities, Commission staff is committed to compiling larger datasets for withdrawal sites that have been operating for a longer duration of time in each of the major stream types in this analysis. In addition, a broader gradient of withdrawal size should be examined within each stream type. Specifically, the largest withdrawals relative to stream size observed in this study were from headwater streams, which averaged 6.8 percent of ADF. Further research should be focused on withdrawals in small watersheds due to their sensitivity to changing conditions, and

should not be limited to gas industry withdrawals. Local site-level variables such as riparian land use, substrate characterization, and channel morphology characteristics should be included in future research efforts to improve modeling performance. Measures of flow alteration on different time scales, (e.g., seasonal) also warrant consideration for inclusion in future studies.

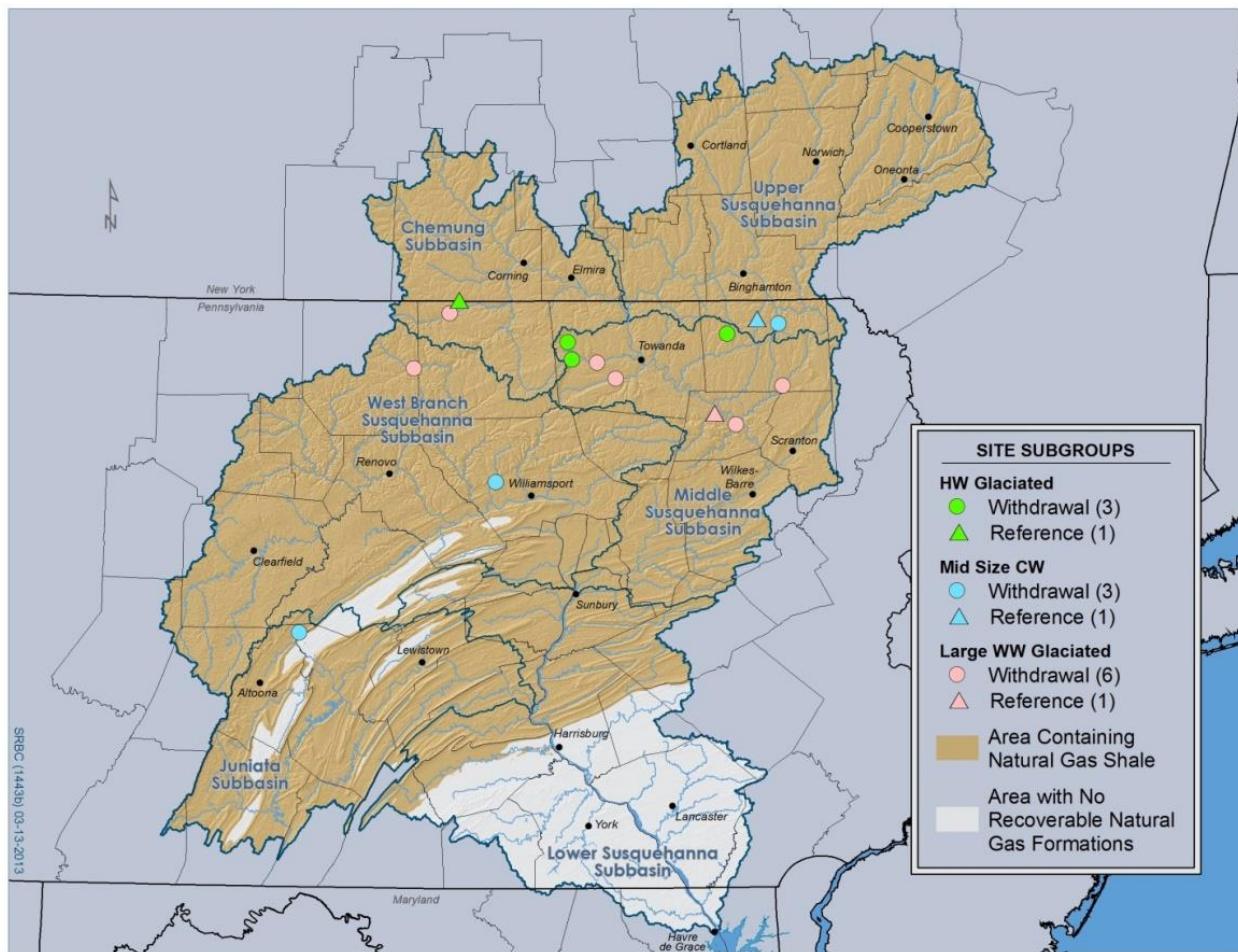


Figure 15. Locations of Withdrawal Research Sites, by Stream Type, in the Susquehanna River Basin

Based upon the results of the above research, Commission scientists have initiated a second phase of surface water withdrawal research that is focused on small watersheds. During 2013 and 2014, 41 headwater sites (watershed size 0.3 – 18.3 square miles) were sampled throughout the northern tier of Pennsylvania located within the Basin. Sites were located downstream of water diversions (10 sites), impoundments (17 sites), and at reference locations (14 sites) within eight USGS 8-digit hydrologic unit code (HUC8) watersheds. Fish and macroinvertebrate assemblages respond to a host of physical and chemical variables at various spatial scales. For this reason, in addition to estimating flow alteration, water chemistry, riparian and watershed land use, and channel morphology data were also collected at each site. This dataset is currently being analyzed and results will be available in late 2016 or early 2017. It is hoped that this additional information will enable more comprehensive conclusions to be drawn

regarding the possible impacts on aquatic ecosystems attributable to the water withdrawals associated with natural gas development within the Basin.

B. Remote Water Quality Monitoring Network

In January 2010, the Commission initiated the establishment of the Remote Water Quality Monitoring Network (RWQMN), a real-time, continuous water quality monitoring network, for the purpose of monitoring headwater streams for potential impacts associated with unconventional natural gas development. Funding provided by East Resources Inc. and Chesapeake Energy Corporation, along with the Pennsylvania Department of Conservation and Natural Resources and the New York State Energy Research and Development Authority, enabled the Commission to build an expansive network of monitors.

As of December 2015, there are 58 continuous water quality monitoring stations located throughout the Basin. These stations are located primarily in northern Pennsylvania and southern New York. Specific conductance, pH, turbidity, dissolved oxygen, and temperature are continuously monitored at all stations using a measuring device that can be deployed in the stream itself, referred to as a data sonde. Additional laboratory analyses (metals, nutrients, radioactive particles/isotopes) are performed on a quarterly basis for stream samples collected in the field, referred to as supplemental samples. The continuously monitored parameters are recorded every five minutes and transmitted to a public website on a two- to four-hour interval as provisional data. Commission staff conducts quality assurance and quality control inspections of the provisional data on a routine basis.

When initiating the network, several factors were considered in selecting the watersheds to be monitored:

- watershed drainage size; 30-60 square miles was considered optimal for the monitoring equipment;
- natural gas pad density and other natural gas-related infrastructure;
- non-impaired or minimally impaired watersheds;
- presence of wastewater dischargers and drinking water intakes;
- stream channel morphology; the data sonde must be in moving water at all times;
- local interest and property owner cooperation.

Each monitoring station is outfitted with a data sonde, data collection platform, and power source. The data sonde is placed in protective housing and placed in flowing water at each monitoring station. The data platform stores the data collected by the data sonde and transmits it to the Commission's website at scheduled intervals. The data platform is battery-powered and is recharged via solar power at the majority of the sites. Routine maintenance is performed on the data sonde every six to eight weeks to ensure data quality and minimize the chances for equipment malfunction.

In addition to the continuously monitored parameters, Commission staff collects supplemental water chemistry data quarterly. The supplemental sample parameters (Table 11) focus on specific pollutants that can adversely impact the water chemistry and aquatic organisms and are often associated with natural gas drilling activities. Macroinvertebrates are collected annually at each site as they are excellent indicators of water quality and stream health. Commission staff has collected water chemistry data in the areas underlain by natural gas containing shales since it began water quality monitoring in the 1980s; however, the RWQMN initiative targeted specific watersheds and added water chemistry parameters directly related to natural gas development activities.

Table 11. Water Chemistry Parameters

Alkalinity	Lithium*
Alkalinity, Bicarbonate*	Magnesium
Alkalinity, Carbonate*	Nitrate
Aluminum	pH
Barium	Phosphorus
Bromide*	Potassium
Calcium	Sodium
Carbon Dioxide*	Specific Conductance
Chloride	Strontium*
Gross Alpha*	Sulfate
Gross Beta*	Total Dissolved Solids
Hot Acidity	Total Organic Carbon

* Water quality parameters the Commission began to monitor because of natural gas drilling activities in the Basin.

The Commission has released three reports summarizing conditions at the monitoring station locations.

- *Remote Water Quality Monitoring Network Data Report of Baseline Conditions for 2010/2011* (Hintz, 2012)
- *Remote Water Quality Monitoring Network Data Report of Baseline Conditions for 2010-2012* (Hintz, 2013)
- *Remote Water Quality Monitoring Network Data Report of Baseline Conditions for 2010-2013* (Hintz and Steffy, 2015)

C. Results and Findings

From a geographical perspective, the natural gas development activities occurring in the Susquehanna River Basin are mainly located within three Level III Ecoregions: North Central Appalachian (NCA), Northern Appalachian Plateau and Uplands (NAPU), and Central Appalachian Ridge and Valley (Ridges and Valleys). The majority of the natural gas drilling is occurring in the NCA and NAPU Ecoregions. For that reason, 30 monitoring stations are located in the NCA Ecoregion, 22 monitoring stations are located in the NAPU Ecoregion, and only six stations are located in the Ridges and Valleys Ecoregion (Figure 16).

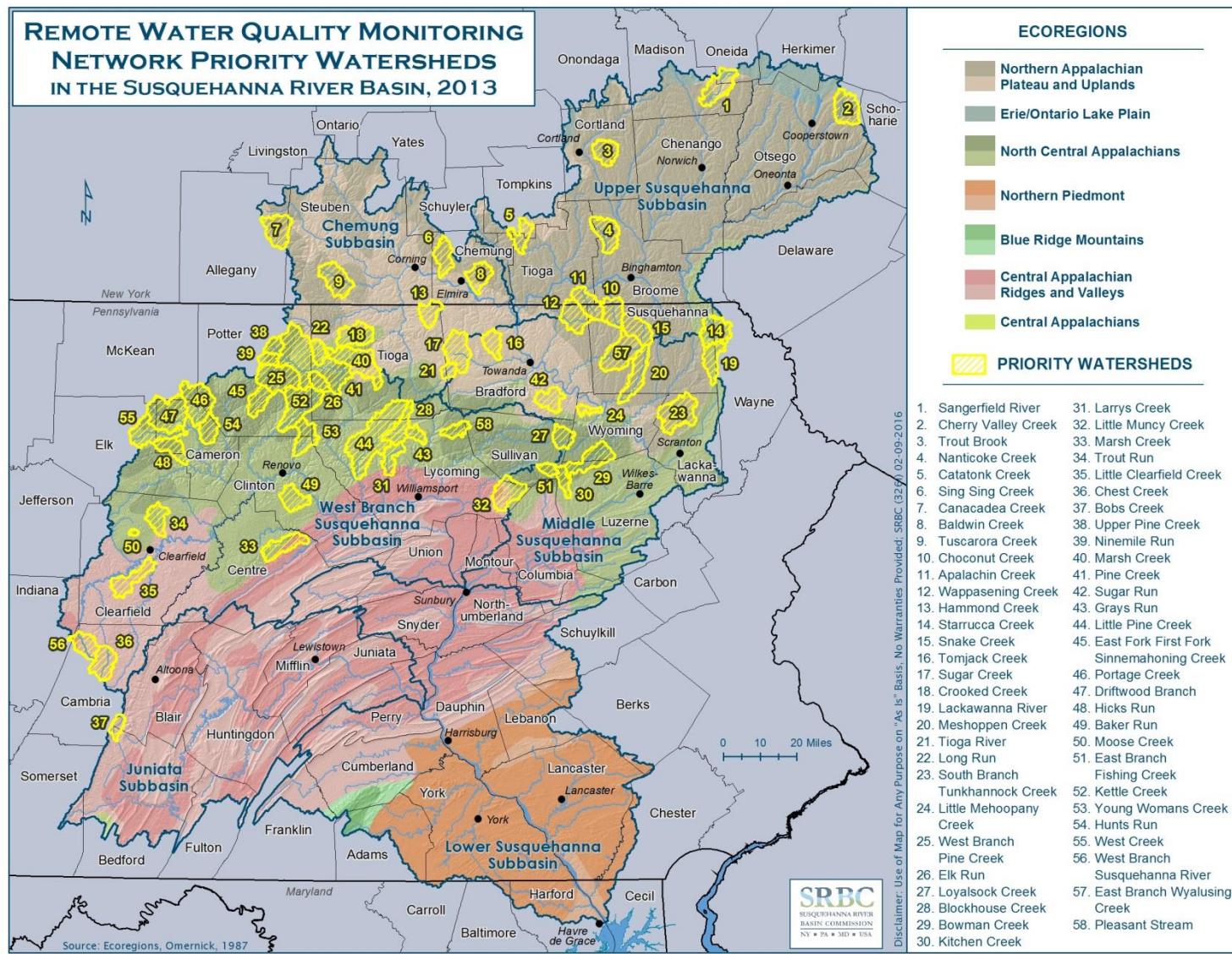


Figure 16. RWQMN Stations Shown with Level III Ecoregions

The NCA Ecoregion is predominantly forested; 25 of the 30 monitored watersheds in this ecoregion are over 80 percent forested. This forested land use plays an important role in the water chemistry observed at the monitoring stations. The continuous data show mean dissolved oxygen concentrations range from 10.3 to 11.8 mg/l with 20 stations having a mean dissolved oxygen concentration of over 11 mg/l. Overall, the water temperatures remain cool in these streams with mean temperatures ranging from 8.4°C to 12.1°C. The large forested tracts provide canopy cover which helps to maintain cooler water temperatures which in turn sustains higher dissolved oxygen levels. The range of median pH values show slightly acidic to neutral systems (5.9 to 7.5). Specific conductance values range from 26 to 164 µS/cm in the NCA streams. Of the 30 monitoring stations, only four stations average specific conductance concentrations over 100 µS/cm. These low specific conductance concentrations indicate minimal influences to the water chemistry by human activities. The mean and median ranges of the water chemistry parameters have been consistent over the four years of continuous monitoring.

The NAPU Ecoregion is also predominantly forested, but the RWQMN watersheds are less forested when compared to the watersheds in the NCA Ecoregion, and several of the watersheds are comprised of over 50 percent agricultural lands. The continuous data show mean dissolved oxygen concentrations range from 8.8 to 11.7 mg/l with only two stations having mean concentrations of less than 10 mg/l. Mean water temperatures range from 7.9°C to 16.1°C with the highest temperatures located in watersheds with the least amount of forested lands. Median pH values, range of 7.0 to 8.1, indicate neutral to marginally basic systems.

Specific conductance shows the greatest range of all of the parameters (86 to 452 µS/cm) between the monitoring stations in this ecoregion. The NAPU can be divided into two sub-ecoregions: six monitoring stations are located in the Northeastern Uplands and the remaining stations are located in the Glaciated Low Plateau. The mean specific conductance range in the Northeastern Uplands is 94 to 152 µS/cm and 86 to 452 µS/cm in the Glaciated Plateau sub-ecoregion. Glacial till geology underlays the majority of the NAPU ecoregion and can influence specific conductance.

The six monitoring stations located in the Ridges and Valleys Ecoregion have varying watershed characteristics and water chemistry parameters exhibit these differences. For example, continuous data show specific conductance concentrations range from 76 to 634 µS/cm. Bobs Creek, with a mean concentration of 76 µS/cm, is 92 percent forested and has no impaired stream miles; while the West Branch Susquehanna River, with a mean concentration of 634 µS/cm, is 73 percent forested and has 37 stream miles (63 percent of its total stream miles) impaired, predominantly by abandoned mine drainage. The remaining four stations have concentrations scattered throughout the observed range. The water temperature ranges from 9.7°C to 14.5°C, which may be linked to forested land use and tree canopy cover. Dissolved oxygen concentrations do not vary significantly between the six monitoring locations (10.6 to 11.2 mg/l) nor do the pH values. The pH ranged from 7.2 to 7.8 indicating slightly basic systems.

It is neither financially nor technically feasible to monitor for every individual chemical used in the hydraulic fracturing process conducted by the industry; however, specific conductance is a very good surrogate indicator for any fracturing fluids entering a given water

body. Fracturing flowback waters have very high specific conductance levels. Consequently, any significant surface spill or leak of these fluids should be detectable by the data sondes. For these reasons, the following paragraphs detail specific statistical analyses associated with specific conductance.

A two-way ANOVA, which is a simple statistical test used to analyze any significant difference among and between a group of variables, was performed to determine if there was a significant difference ($\alpha=0.05$) in specific conductance levels by ecoregion over time (Figure 17). There is no significant difference in specific conductance from the analyses for 2010 through 2013 ($p=0.44$). The Tukey Method groupings in Figure 20 indicate the relationship between ecoregion and years. Within the NCA ecoregion, each of the years was more closely related to each other than any year in the NAPU or Ridges and Valleys ecoregions. While there was no significant difference ($p=0.44$) between the years in each of the NAPU and Ridges and Valleys ecoregions, the groupings indicate that years 2010 and 2011 in the NAPU ecoregion and years 2012 and 2013 in the Ridges and Valleys ecoregion were more closely related compared to the other years in the ecoregions.

The West Branch Susquehanna River station data (Ridges and Valleys ecoregion) were removed from the dataset when determining the significant difference between ecoregions and ecoregion and year. This station is severely impacted by AMD and has the highest mean conductance concentration of all the stations. The West Branch Susquehanna River station was not installed until the end of 2012 while the other five stations in the ecoregion were installed in 2010. When the data were included, a significant difference was seen by year within the Ridges and Valleys ecoregion. 2013 was significantly different from 2012, 2011, and 2010; however, this was a product of the high conductance concentrations being added from the West Branch Susquehanna River rather than conductance values changing at stations.

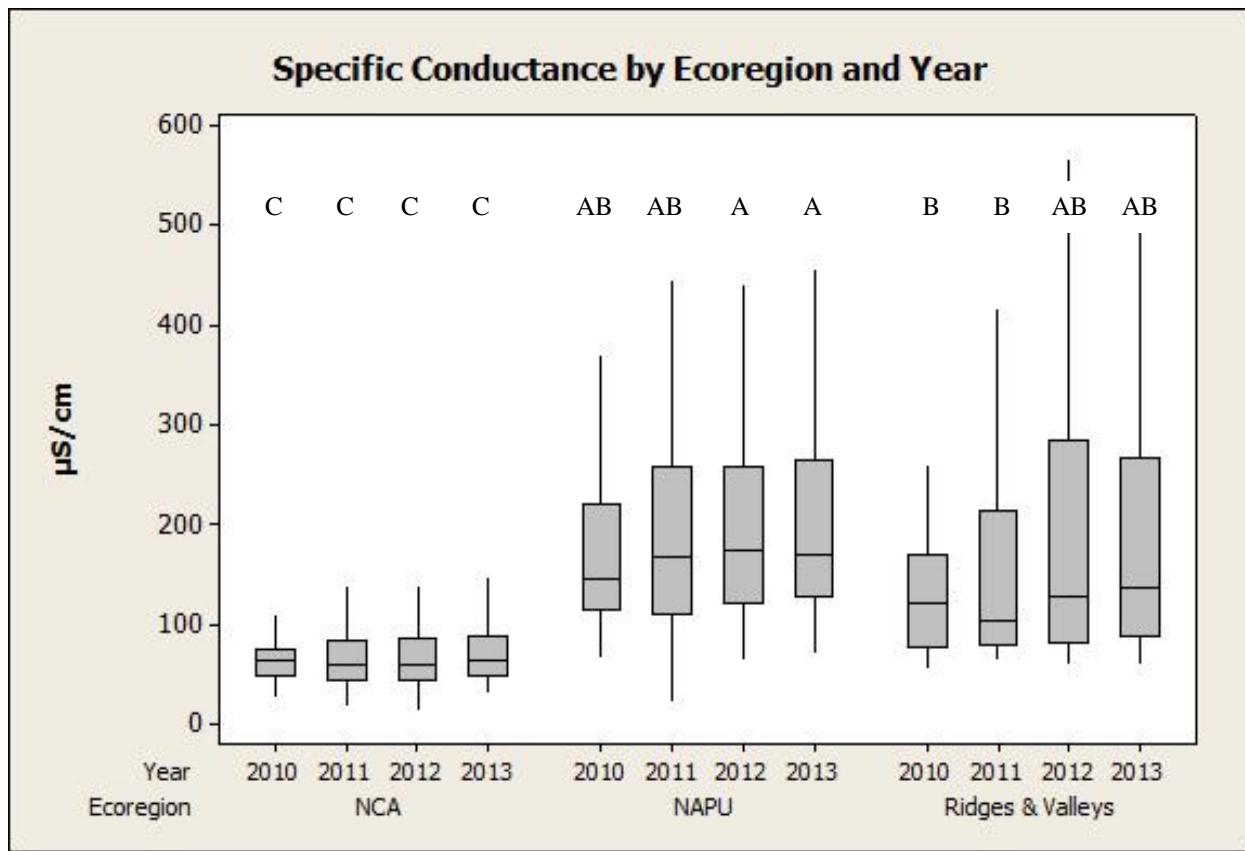


Figure 17. *Specific Conductance by Ecoregion and Year*

Impacts of natural gas development, including drilling, hydraulic fracturing, and related infrastructure activities, on stream biota are a significant concern to the Commission and to the general public. Macroinvertebrate samples were collected at the monitoring stations annually and the taxa were identified and scored through a number of individual metrics which were combined to calculate the Index of Biotic Integrity (IBI) score (PADEP, 2013). This IBI score, based on a scale of 0-100, is a representation of the quality of the aquatic macroinvertebrate assemblage based on six separate metrics which describe different aspects of the community, including richness, diversity, and pollution tolerance. Watershed size, geology, and season are all factored into the Pennsylvania IBI score and a higher IBI score indicates a healthier macroinvertebrate community. Within the RWQMN coverage area, the natural gas well density gradient ranges from zero wells per square mile to 3.7 wells per square mile.

Box plots were used to analyze for any potential relationship between IBI scores and natural gas well density. Box plots show the median value and quartile ranges of the data in each box. The lower and upper edges of the box represent the lower and upper quartiles, respectively, and the line inside the box represents the median value. Twenty-five percent of the data are less than the lower quartile and 25 percent of the data are greater than the upper quartile. The lines (whiskers) extending from the box represent the maximum and minimum values excluding outliers.

There was no strong relationship observed between natural gas well density and Pennsylvania IBI scores for 2011, 2012, or 2013 (Figure 18), with the spacing between the different parts of the boxes showing a high degree of dispersion regardless of what well density gradient is considered. Well density was not a good predictor of macroinvertebrate IBI scores. In watersheds with no natural gas well drilling occurring upstream of the monitoring points, IBI scores ranged from 29 to 100, which represents the lowest and highest IBI scores observed throughout the entire three years of sampling. As a result of the low sample size ($n=2$) in the greater than 2.5 wells per square mile group, even a small change at either of the two sites can cause a large shift in the box plot. Therefore, those results should be considered with that limitation in mind. More than 30 percent of all macroinvertebrate samples collected for the RWQMN project through 2013 were in watersheds where no natural gas wells have been drilled. Box plots constructed with existing data show no significant difference between IBI scores at sites with zero gas wells per square mile and those that have some degree of gas well development, even up to 3.7 wells per square mile.

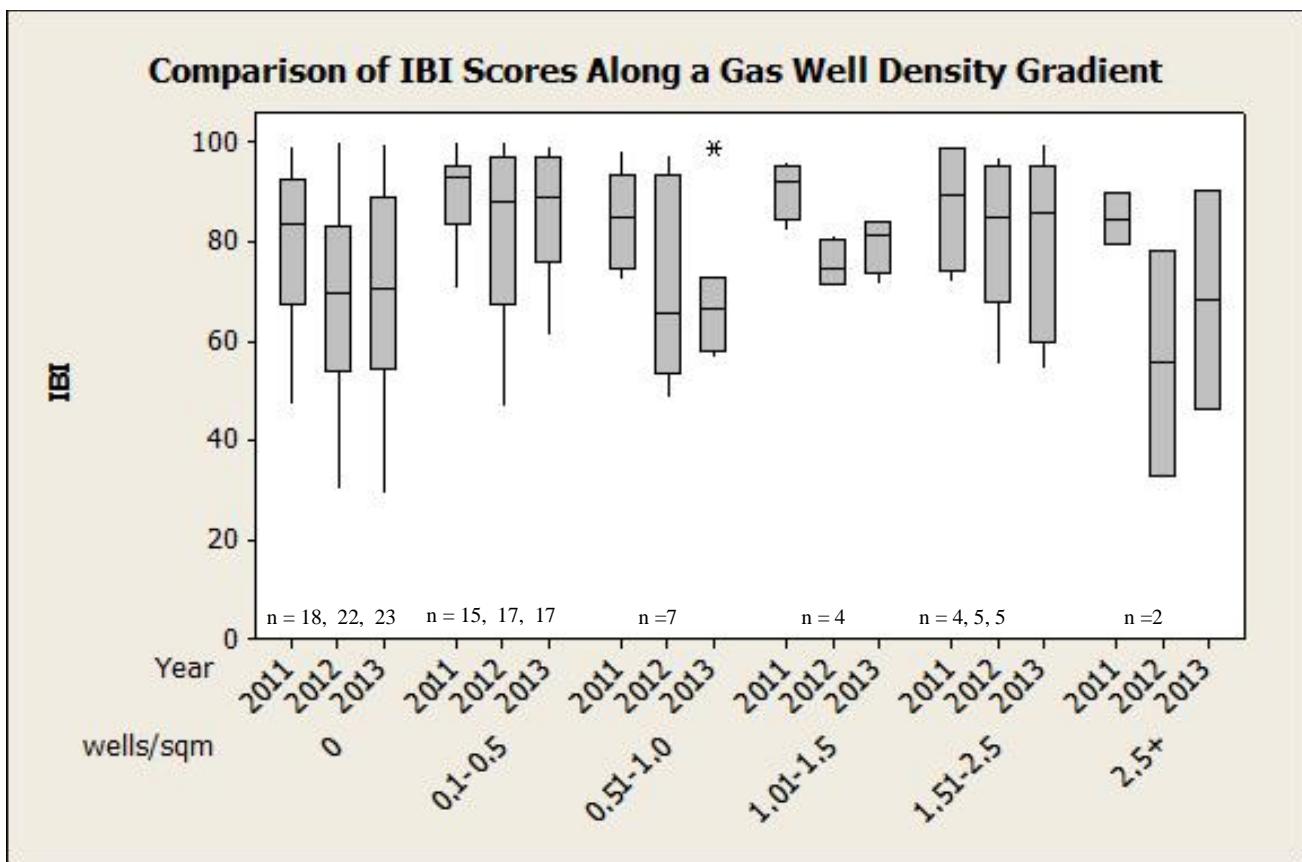


Figure 18. IBI Scores Related to Gas Well Density from 2011-2013

As data continue to be collected, future data analyses will remain focused on water quality trend analysis, biological integrity, and parameter correlation with weather conditions. In addition to the Commission's ongoing data analyses, there have been numerous universities, government agencies, and non-profit groups engaged in using these same data for their own assessments of natural gas drilling impacts, climate change initiatives, and road salt impacts.

The sharing of these important monitoring datasets remains one of the primary goals of the Commission.

The relevance and importance of a continuous, real-time water quality monitoring network is not limited to the impacts of natural gas development. The RWQMN allows the Commission and other agencies and environmental groups to gain a better understanding of water quality conditions in headwater streams and monitor impacts from any activities occurring within those watersheds. Continuous monitoring has the benefit of early detection of impacts to water chemistry that cannot be accomplished with traditional infrequent sampling.

VI. Compliance Program

The primary objective of the Commission's Compliance Program is to ensure that all projects subject to Commission regulation are complying with all applicable regulations, approvals, orders, and other requirements of the Commission. As a result of the rapid growth of the industry within the Basin, the Commission expanded the total number of compliance staff; opened a Compliance Office in Sayre, Pennsylvania, located in the heart of the shale gas region; and implemented several new technology-based tools to more effectively and efficiently monitor the water use activities of the natural gas industry through field inspections of gas-related water withdrawals and well pad construction occurring in the northern tier of Pennsylvania.

A. Compliance Inspections of the Industry by Quarter and Year

In response to the increasing level of industry activities occurring within the Basin, the Commission increased the number of Compliance Program staff in 2009. The primary emphasis of the Compliance Program is to conduct site inspections to ensure gas operators obtained necessary approvals and maintained compliance with relevant Commission regulations and with the specific conditions contained in each approved project.

As the number of natural gas-related inspections continued to grow through 2009 and into 2010, more demands were placed on the staff assigned to the Compliance Program. In 2010, the Commission's Information Technology (IT) Department, in concert with the Compliance Program, developed better communication systems and mobile computer-based tools to assist field inspectors with categorizing, tracking, and archiving inspection results and reports. These tools were introduced in late 2010 and dramatically increased the efficiency and effectiveness of the Compliance Program.

Figure 19 illustrates the number of compliance site inspections conducted by Commission staff on the natural gas industry by quarter and by year beginning with the second quarter of 2011.

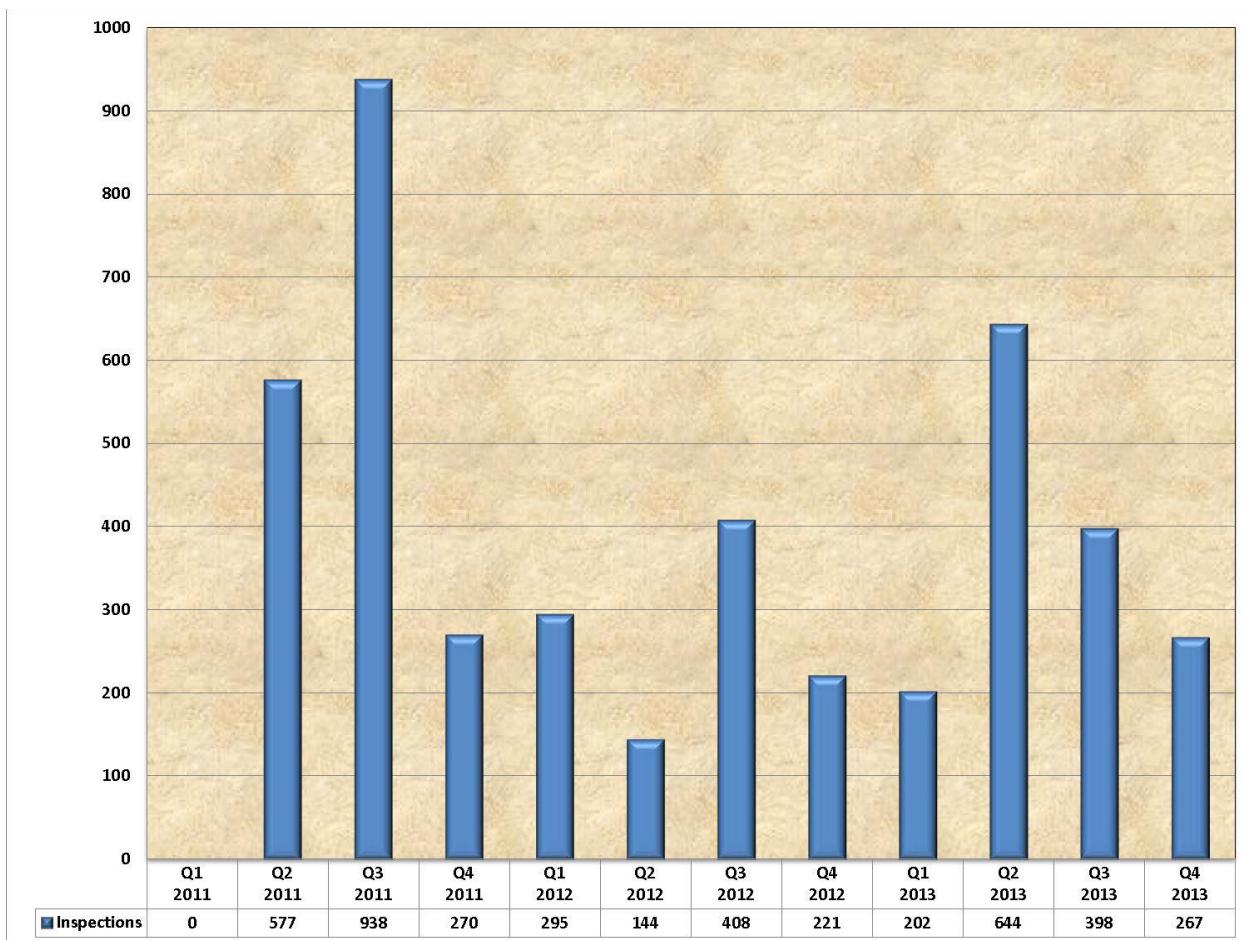


Figure 19. Number of Natural Gas Inspections Conducted Per Quarter, 2011-2013

B. Notices of Violation Issued by Quarter and Year (Natural Gas Industry Only)

The Compliance Program has issued a total of 150 Notices of Violation (NOVs) from 2009 through 2013 to both approved and unapproved gas industry projects located within the Basin. A NOV is an official letter written by the Commission to a project sponsor with notification given that, based upon information available to the Commission, the project may have violated a Commission regulation, order, directive, or condition of an approval.

As noted earlier in this document, all unconventional natural gas development projects located within the Basin that withdraw water (either surface water or groundwater) or consumptively use water are required to first request the appropriate Commission review and obtain written approval before initiating any project activities. Once approval is granted, the industry is required to record and report all daily water withdrawals and daily consumptive water uses (beginning at the first gallon) to the Commission. The majority of these reports are submitted on a quarterly basis and are reviewed by staff for compliance with Commission regulations and project-specific approval conditions. Any noted non-compliance action can

result in the issuance of a NOV. The Compliance Program can also issue NOVs outside of the quarterly reporting sequence for violations discovered through periodic data review and random site inspections.

As previously noted, the level of activity associated with the industry was relatively modest within the Basin prior to mid-2008. During the early stages of expansion, the Commission made efforts to ensure that an appropriate and effective regulatory structure was put into place to adequately monitor water-related activities associated with the growing industry. This build-out of Commission capabilities took place between 2008 and 2009. Consequently, there were no NOVs issued to the industry in calendar year 2008. However, the Commission did enter into several settlement agreements to resolve violations. The majority of those settlement agreements were entered into as a result of natural gas operators proactively contacting Commission staff and informing them of violations at various project locations. At that time, the Commission was issuing Cease and Desist Orders to projects that violated Commission regulations and/or policies. In order to obtain all necessary Commission approvals to facilitate additional development on the sites in violation, project sponsors were required to resolve all past violations and sign settlement agreements, which were used as a tool to regain compliance.

It is important to note that because no NOVs were issued to the industry in 2008, the number of NOVs issued in calendar year 2009 may have included some violations that occurred during calendar year 2008. It is also important to note that in 2013, the Commission altered the manner in which it accounts for and invoices natural gas operators for consumptive water use mitigation. Historically, the Commission required operators to account for the consumptive use of water at the pad sites. In 2013, however, the Commission implemented a procedure that considered water to be effectively consumed once it was taken from the source from which it originated. This change was primarily made to assist the Commission in accounting and quarterly tracking (or accounting) practices for consumptive water use mitigation. Consequently, the manner in which projects reported daily water withdrawals and daily consumptive use were slightly altered, which may have impacted to some degree the number of subsequent NOVs issued in 2013.

C. Nature of Notices of Violations Issued Over Time

Reports of water withdrawals and consumptive water uses are generated by each project sponsor and electronically submitted on a quarterly basis to the Commission in an online format referred to as the Monitoring Data Website (MDW). Approximately 70 percent of all NOVs issued to the natural gas industry are administrative in nature. These violations consist primarily of late submission of the quarterly reports or late payment of relevant consumptive water use fees.

The remaining 30 percent of the NOVs issued to the gas industry involve more significant violations such as operating without Commission approval or exceeding approved limits or thresholds. These violations are most often identified during field inspections or during record audits. From 2009 through 2013, the Commission experienced a relatively steady increase in the number of NOVs issued. This trend is believed to be attributable in part to the number of new natural gas companies entering the Basin that were initially unfamiliar with

Commission requirements and regulations. This trend is also believed to be due in part to the increased effectiveness of the Compliance Program's ability to detect violations.

As noted above, in 2013 the Commission altered the manner in which natural gas operators report quarterly monitoring data to the Commission. This change appeared to have resulted in some confusion within the natural gas industry as the number of NOVs issued in 2013 increased from the previous year. Staff expects the number of administrative NOVs to decrease over time assuming current reporting requirements remain unchanged. Figure 20 illustrates the nature of the NOVs issued per quarter and year.

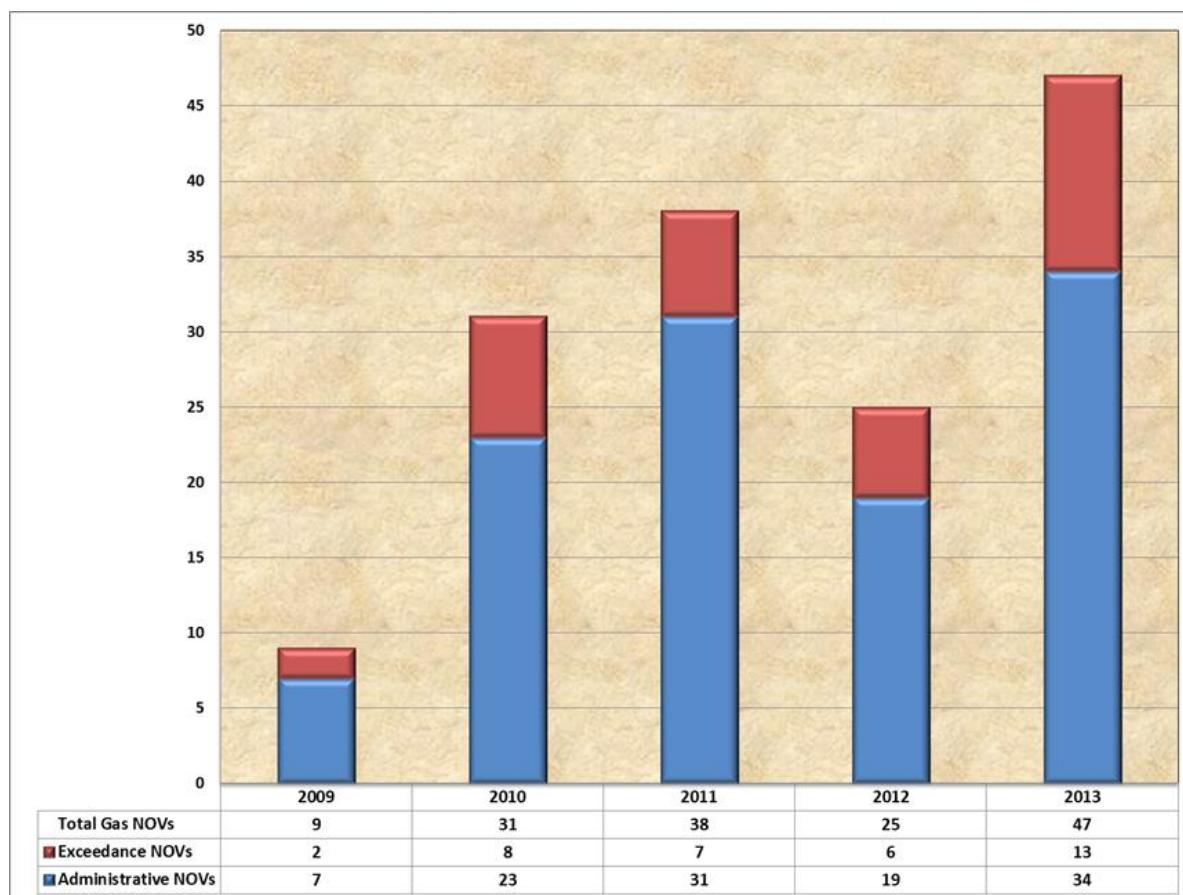


Figure 20. Nature of NOVs Issued to Natural Gas Industry, 2009-2013

D. Comparison of Notices of Violation for Natural Gas Projects vs. Non-Gas Projects

A total of 525 NOVs have been issued from 2009 through 2013 by the Commission to project sponsors operating within the Basin. This number includes both natural gas-related projects and non-gas related projects. Of that total, 150 were issued to natural gas operators. Generally speaking, the industry has been compliant with Commission regulations and often times proactively informs Commission staff of potential violations. The industry is accustomed

to being regulated; however, some of the subcontractors and third-party water purveyors operating in support of the natural gas industry have presented enforcement challenges to the Commission. Figure 21 presents a comparison of the number of NOVs issued per year to natural gas projects versus non-natural gas projects. The number of NOVs issued annually to the natural gas industry comprised approximately 30 percent of the total NOVs issued by the Commission.

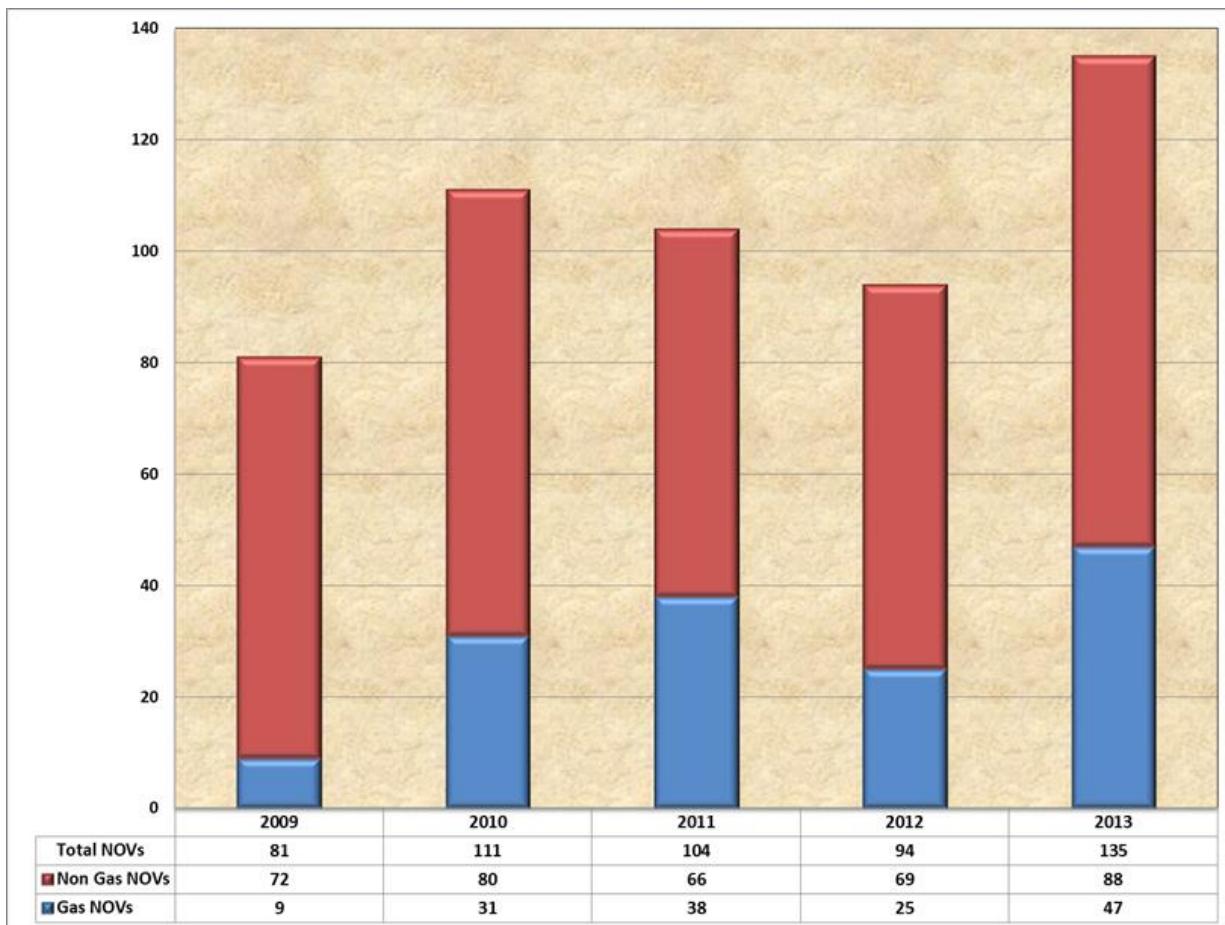


Figure 21. Number of Natural Gas Versus Non Gas NOVs Issued Per Year, 2009-2013

E. Summary of Settlements with Natural Gas Operators

In an effort to expedite the resolution of non-compliance issues and more effectively utilize Commission resources and funding, the Commissioners have generally directed staff to attempt to resolve all violations through settlement agreements before resorting to the assessment of civil penalties to projects that were unwilling to enter into a settlement agreement. A total of 32 settlement agreements were entered into by and between the Commission and various project sponsors between 2008 and 2013. Of that total, 21 settlement agreements were between the Commission and natural gas operators, for amounts totaling around \$2.3 million.

Of the 21 settlement agreements, 12 addressed projects that were undertaken prior to receiving Commission approval, and nine involved failure to comply with Commission regulations or conditions imposed as part of approvals listed. Some examples of the latter include failure to post required signage, use of water from unapproved sources, failure to install meters, and failure to submit post-hydrofracture reports.

The nature of the violations has changed over time. Initially, most violations involved failure to receive prior approval from the Commission before initiating gas development activities. More recently, the violations involved failure to comply with conditions imposed as part of the approvals issued to the project sponsors.

In general, compliance efforts associated with the industry have proven to be very effective. Nonetheless, occasional violations still occur and appropriate enforcement actions are taken by the Commission. Ensuring compliance requires constant vigilance. The Commission's Compliance Program will continue to refine and adapt strategies to quickly identify and address those violations.

VII. Part IV. General Observations and Conclusions

A. Looking Back

One of the primary objectives of the Commission since its inception has been the management of the finite water resources of the Basin in a sustainable manner as demands grow over time, whether from new water uses entering the Basin or changes in existing uses. When the unconventional natural gas industry arrived in the Basin, the Commission was responsible for developing relevant and fair regulations to accommodate the new water user while addressing the need to maintain sustainable water resources throughout the Basin. As such, the Commission focused on ensuring that all water used by the industry would come from approved sources.

The primary competition for water resources associated with the industry has occurred not between the industry and other human water needs, but between the industry and the natural aquatic ecosystems existing within the Basin—especially the small, lower-yielding watersheds in which the industry has been active. The industry's presence in these headwater settings raised concerns related to the delicate balance between water use and availability. The Commission undertook incremental policy and regulatory adaptations to successfully address the potential for conflict between the industry and the local aquatic ecosystems for the protection of sensitive habitats and the Basin's finite water resources.

The policy and regulatory adaptations used by the Commission were based upon the best available science. These strategies included new regulatory controls, including the "Gallon One" modification, as well as employing and/or adapting existing procedures for performing environmental screenings and on-site aquatic resource surveys to characterize and evaluate proposed water withdrawal sites, applying limitations on instantaneous and daily water

withdrawal rates, and reviewing for potential cumulative impacts related to multiple withdrawals in a watershed. The Commission's updated low flow protection policy was especially useful in maintaining adequate instream flows to avoid exacerbating naturally occurring low flow conditions.

The relative speed with which the Commission developed, revised, and expanded its regulatory program was a distinct strength. This agility enabled the Commission to keep pace with the industry's dynamic water demands.

Commission interest in avoiding the impacts of excessive withdrawals during low flow periods resulted in many sources being approved as interruptible. In response to the interruptible nature of these withdrawals, the industry continues to develop a dynamic water storage and distribution system, allowing water to be obtained when stream conditions allow and stored for later use.

The monitoring and reporting requirements imposed by the Commission for all approved water withdrawals and consumptive water uses enabled an accurate and useful accounting of the industry's water use characteristics during the assessment period. The Commission's Compliance Program, responsible for tracking and documenting the industry's adherence to Commission regulations, was supported by the Commission's very effective and efficient IT Program. The IT support greatly increased the effectiveness and efficiency of the Compliance Program's monitoring and inspection activities through automation, enabling staff to keep track of an enormous amount of compliance data.

Water quality monitoring and assessment work performed by the Commission also started to establish baseline conditions and identify potential impacts on the water resources of the Basin posed by the industry's activities. These field-oriented activities employing sophisticated instrumentation and other methods for assessing the chemical and biological health of streams in the region provided the Commission and the general public with data collected at many locations within the portion of the Basin in which the industry has been most active. Especially for the smaller watersheds and streams in the region, very little data had been collected in any regular manner prior to 2008.

Overall, the considerable amount of data collected and analyzed by the Commission during the report period support the following conclusions:

- Generally, the quantity of the Basin's water resources are sufficient in magnitude to accommodate the water demands of the industry concurrently with other water users currently operating within the Basin.
- Concerns related to the impacts of water sources are focused on the timing and location of the withdrawals and are adequately addressed by the low flow protection measures and other protective operating conditions.

- To date, the Commission's monitoring programs have not detected discernible impacts on the quality of the Basin's water resources as a result of natural gas development, but continued vigilance is warranted.

B. Looking Ahead

The Commission will use the observations made and conclusions drawn from the report to inform and direct its future efforts. Some future challenges and opportunities that will be addressed by the Commission include the following:

- Through future regulatory practices, encourage a more robust and sophisticated industry-wide water delivery systems anchored in larger, more sustainable and uninterrupted water features of the Basin.
- Enhance water quality monitoring and assessment methods to assist our member jurisdictions with ensuring preservation of the quality of the Basin's water resources.
- Expand the use of technology to enable Commission staff to work more effectively and transparently and to be more responsive to inquiries from the general public and the regulated community.
- Facilitate greater use of lesser quality waters within the Basin to reduce the reliance on higher quality streams and rivers.
- Continue to encourage the incorporation of produced fluids into the industry's water delivery system to decrease the need for future disposal of these fluids and to reduce the reliance on fresh water resources for future hydraulic fracturing activities.

Overall, this report provided the framework for the Commission to review and reflect upon its role in managing industry activities during the start of natural gas development in the Basin, and as a result, it will better insure continued sustainable management of the water resources of the Basin into the future.

The information contained in this report may be periodically revised and updated as new information is received and processed by the Commission.

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