Water Use Associated With Natural Gas Development In The Susquehanna River Basin: An Update Of Activities Through December 2018

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Paula B. Ballaron, P.G.
Manager, Policy Implementation and Outreach

Bret Wagner
Database Developer

Jeffrey Zimmerman, Jr.
GIS Developer

SRBC
SUSQUEHANNA RIVER BASIN COMMISSION
NY ▪ PA ▪ MD ▪ USA

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I. INTRODUCTION

A. Objectives

The Susquehanna River Basin Commission (Commission or SRBC) has authority over water withdrawals and consumptive uses to regulate individual and cumulative impacts to the water resources of the Susquehanna River Basin (Basin). When the unconventional natural gas industry emerged as a significant new water user in 2007-2008, Commission regulations required that well construction, drilling, and hydraulic fracturing could not commence without prior approval of the water use associated with natural gas development.

Water withdrawn by or for natural gas development is subject to the Commission's consumptive use regulations, as implemented by an administrative process referred to as Approval by Rule (ABR). ABRs are issued on a drilling pad site (or well pad) basis. All water consumed must come from sources that have been approved by the Commission for such use. The Commission's water use approvals imposed monitoring and reporting requirements for all water withdrawals and consumptive uses. In doing so, the Commission has collected extensive and accurate data concerning some characteristics of the industry's water use.

The Commission summarized its understanding of the industry's water use during the initial stages of the unconventional natural gas development activities in the Basin from 2005 to 2013 in a comprehensive report (Richenderfer and others, 2016). That report also describes regulatory changes and water quality monitoring activities undertaken by the Commission to address this new and previously unfamiliar activity.

This new report extends the analysis of water withdrawal and use data in the Basin during the five-year period, January 2014 through December 2018. The previously published data through 2013 are included in figures and tables to provide context and continuity. The study, focusing only on water withdrawal and use, was conducted to evaluate the ongoing evolution of water use characteristics of the unconventional natural gas industry, to assess any developing long-term trends and basin-wide implications of that use, and to review the industry's activities from a water management perspective. The Commission has completed separate reports describing its ongoing water quality monitoring activities, including the following: Remote Water Quality Monitoring Network Data Report of Baseline Conditions 2010-2013, Publication No. 297 (Hintz and Steffy, 2015); Continuous Water Quality Trends Adjusted for Seasonality and Streamflow in the Susquehanna River Basin, Publication No. 312 (Hintz and Markowitz, 2016); Estimation of Suspended Sediment Concentrations and Loads Using Continuous Turbidity Data, Publication No. 306 (Steffy, 2016); and, Remote Water Quality Monitoring Network/PA Department of Conservation & Natural Resources Technical Summary, Publication No. 316 (Berry, 2019).

B. Unconventional Natural Gas Development in the Basin

Approximately 85 percent of the Susquehanna River Basin is underlain by black gas-bearing shales – including the Marcellus, Burket, Mandata, Utica/Antes, Geneseo, Middlesex, Needmore, and Rhinestreet formations – that occur a mile or more beneath the surface (Figure 1). The natural gas is classified as "unconventional" because it is trapped in rock with very low permeability, while conventional natural gas is held as a pocket of gas beneath a low permeability rock layer. The Marcellus Shale is a sedimentary rock formation that holds one of the richest deposits of natural gas in the lower 48 states.

Figure 1. Extent of Natural Gas Shales in the Susquehanna River Basin

Although the Marcellus Shale formation has been most targeted in the Basin by the natural gas industry, the other shale formations are becoming viable energy sources. Since 2012, development activity has gone beyond the Marcellus to include the Utica, Geneseo, and Burket formations. As of December 31, 2018, 69 gas wells on 35 drilling pads had been completed in the other shale formations in the Basin (6 in 2015, 7 in 2016, 14 in 2017, and 21 wells in 2018).

Water is critical to the processes of removing natural gas from shale formations. Extracting natural gas from these shales is economically feasible due to technological improvements that include the combination of horizontal drilling and high volume hydraulic fracturing. Horizontal drilling describes a process by which a vertical bore hole is drilled to the depth of a shale deposit, redirected to a near horizontal orientation, and extended for thousands of feet into the target formation, dramatically increasing the wellbore's exposure to the gas-bearing formation to improve the efficiency of natural gas production. Subsequently, large volumes of water mixed with sand and chemical additives are pumped under high pressure into perforations in the well casing to shatter the formation. The network of millions of small, interconnected fractures propagate for large distances into the surrounding shale. The sand particles hold the partings open and allow the release and collection of the trapped gas. The chemicals used in hydraulic fracturing largely help reduce friction and prevent bacterial and mineral growth. Together, these processes increase the pay zone and extraction rate of a well and create the commercially viable enterprise.

As part of the Marcellus Shale natural gas boom, the Pennsylvania Department of Environmental Protection (PADEP) permitted over 14,000 unconventional natural gas wells on approximately 4,200 well pads in the Basin between 2007 and 2018. While the PADEP permits natural gas wells, the Commission issues ABRs for consumptive use of water on a well pad basis (Figure 2). Nearly 5,600 wells have been drilled on these well pads.

In the Basin, this explosive growth of the shale drilling activity peaked in 2011, then declined due to falling and low natural gas prices and the necessary development of infrastructure to link product to users. Overall, unconventional natural gas production shows an upward trend, with volumes increasing through time among the major producing regions. In a comparison among producing states, Pennsylvania is number two in gross natural gas production (Figure 3). Unconventional natural gas production in Pennsylvania tripled between 2012 and 2018 (from 2,042,900 million cubic feet in 2012 to 6,123,400 million cubic feet in 2018) (U.S. Energy Information Administration, 2019).

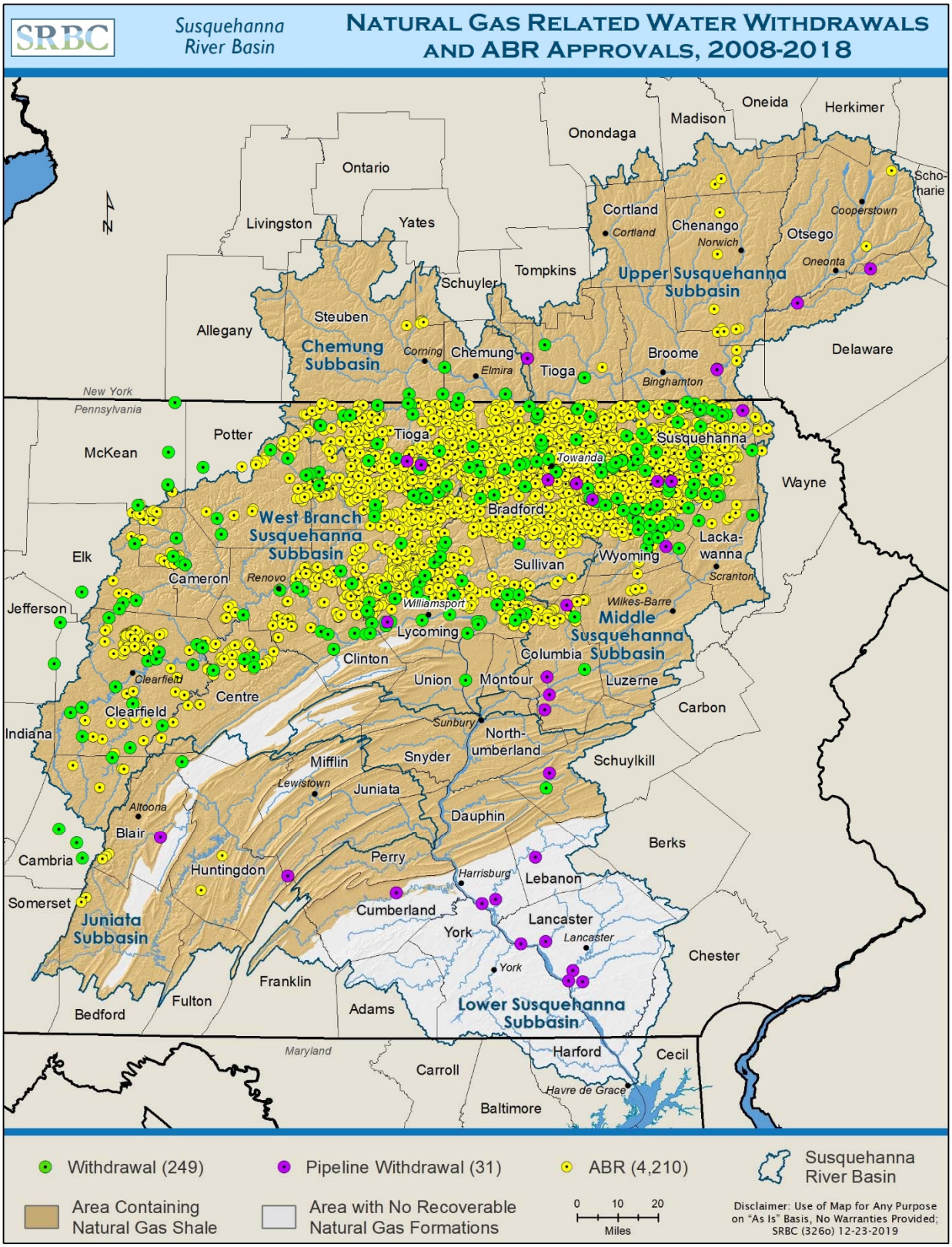

Figure 2. Natural Gas Related Water Withdrawals and Drilling Pad Approvals (referred to as ABRs) in the Susquehanna River Basin, 2008-2018

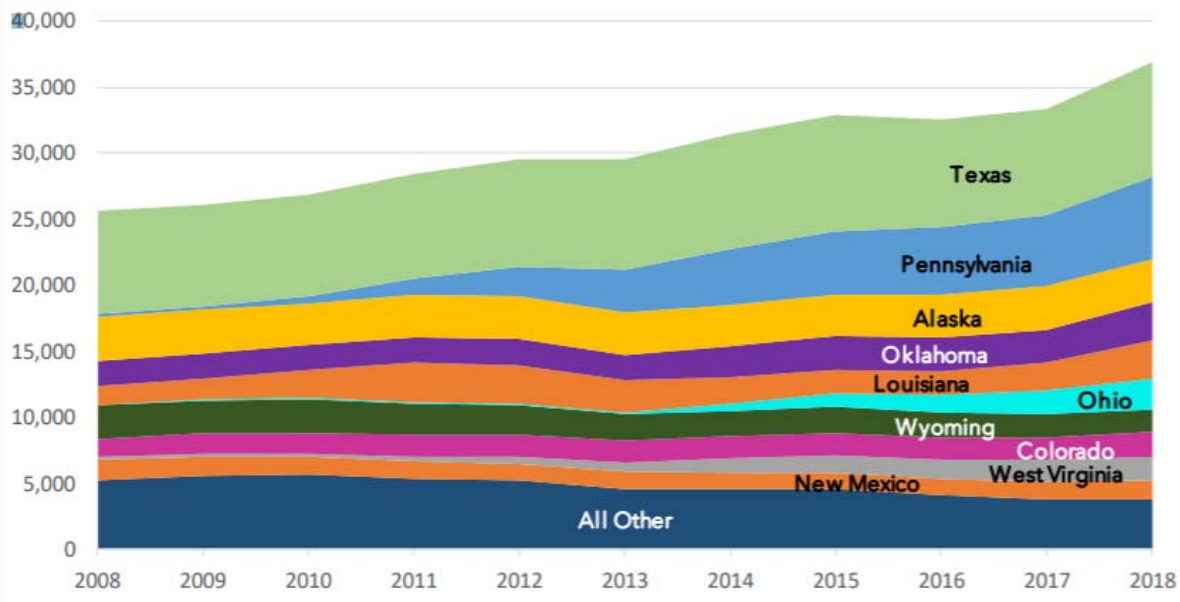

Figure 3. Gross Natural Gas Production (bcf) for Calendar Years 2008 through 2018, by State (From All Well Types) (Source: U.S. Energy Information Administration)

Figure 4 shows county-level natural gas production volume for the 2018 calendar year. Four counties (Susquehanna, Washington, Greene, and Bradford) comprised two-thirds of statewide production, two of which are in the Basin (Susquehanna and Bradford). Six counties in the Basin were among the top ten leaders for production in 2018: Susquehanna (ranked 1), Bradford (4), Lycoming (5), Wyoming (6), Tioga (7), and Sullivan (9) (Pennsylvania Independent Fiscal Office, 2019).

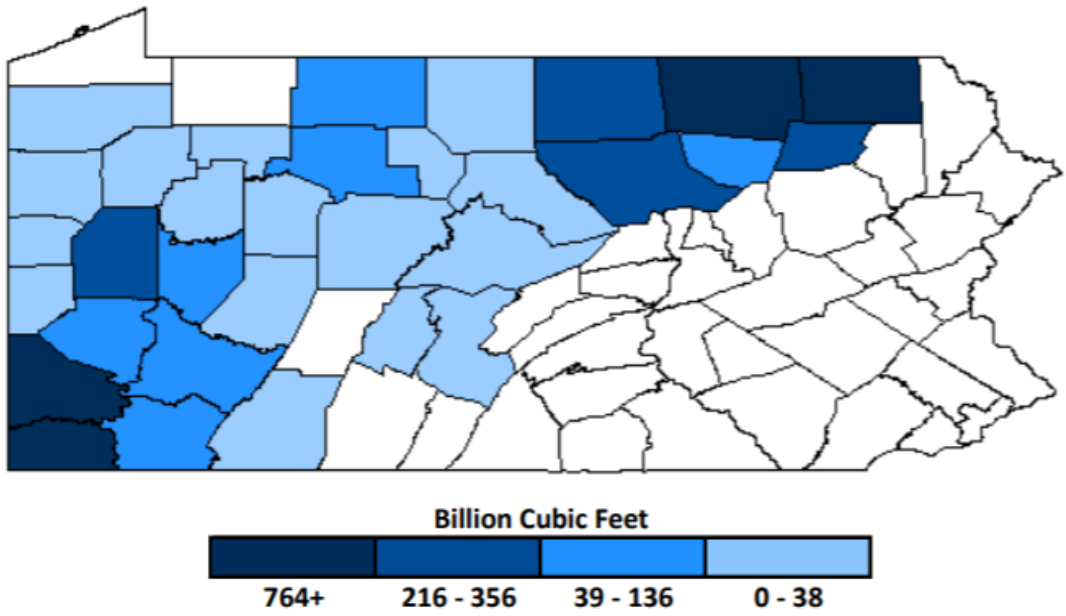

Figure 4. Natural Gas Production in Pennsylvania for Calendar Year 2018, by County (Horizontal Wells Only) (Source: Pennsylvania Independent Fiscal Office)

C. Update of Changes to the Commission's Regulations and Policies

The Commission has taken a dynamic approach in its development of policies and regulations for the natural gas industry to make certain that the right set of management controls are in place for the activity to occur where permitted by the member jurisdictions, while avoiding any adverse impacts to water resources. Although Pennsylvania allows unconventional natural gas development, two of SRBC's member jurisdictions have decided not to permit unconventional natural gas activities. The State of New York officially prohibited high volume hydraulic fracturing in its State Environmental Quality Review Act (SEQR) Findings Statement released in June 2015, following a comprehensive, seven-year review. In April 2017, Maryland became the second state in the country to ban high volume hydraulic fracturing.

The Commission also has modified its policies and regulations to better coordinate with changes to PADEP's regulatory program. In 2012, Pennsylvania adopted the Oil and Gas Act (Chapter 32, Act 13 of 2012) that significantly revised the Commonwealth's oil and gas laws and directed PADEP to promulgate regulations to implement its environmental enhancements. The existing requirements in Chapter 78, Subchapter C dated from 2001, and revisions were needed to ensure that oil and gas resources were developed safely, responsibly, and in a manner that protects the environment. PADEP's goals were to modernize its regulatory program to recognize advances in extraction technology, specify acceptable practices to prevent spills and releases, and otherwise protect public resources to minimize impacts from oil and gas drilling. The final-form rulemaking regarding surface activities related to unconventional natural gas well development was published in October 2016.

The various amendments to Commission regulations through 2013 have been previously described. The Commission continues to make adjustments and refinements in its regulatory program to respond to changes in the programs of member jurisdictions, new water use practices and demand of the industry, and improved understanding of ecosystem impacts.

SRBC's Hydrocarbon Development Rule

The Commission adopted a new hydrocarbon development rule, which became effective on January 23, 2015, to clarify those water uses involved in hydrocarbon development that are subject to the consumptive use regulations, as implemented by the ABR (Approval By Rule) program. Specifically, the rulemaking revised the definition of "hydrocarbon development project" to clarify that hydrocarbon development projects cover all water-related activities and facilities on the drilling pad site as well as more limited, specific uses of water off the drilling pad site. The rulemaking defined "drilling pad site" to cover the physical four corners of the well pad where drilling actually occurs or is intended to occur. On the drilling pad site, activities and facilities associated with the production, maintenance, operation, closure, plugging, and restoration of wells or drilling pad sites that require consumptive water usage are required to have an ABR under 18 C.F.R. §806.22(f). Off the drilling pad site, the regulated uses are water used for hydro-seeding or other revegetation activities, dust suppression, and hydro-excavation of access roads and underground lines, as well as tank cleanings, related to a drilling pad site or centralized impoundments.

Under the rulemaking, an ABR is required for all projects from the initiation of activity until all post-plugging restoration has been completed according to applicable member jurisdiction regulations. Existing projects that had allowed their ABRs to expire had to apply for renewal for coverage to continue operations until restoration is certified by the state's program. The rulemaking also authorized the Executive Director to issue approvals under the ABR program.

Alternative Analysis

Although not specific to the natural gas industry, amendments to Commission regulations adopted in June 2017 contain some changes to application requirements and standards for the review of regulated projects. The changes generally improve clarity and largely align the regulations with existing practice. Of importance to the natural gas industry was a change regarding when an alternatives analysis is required. In addition to the previous provision to request an alternatives analysis at the discretion of the Commission, an alternatives analysis is now required in specific settings as part of the application for new surface water withdrawal projects and for major modifications that seek to increase a surface water withdrawal volume/use. The alternatives analysis must document the consideration of various alternatives including sources, withdrawal locations, and other measures during the planning of the proposed project.

Consumptive Use at the Source

On January 1, 2013, the Commission began a different accounting system for consumptive use by the unconventional natural gas industry that provides for daily water use monitoring of the amounts delivered or withdrawn by source instead of by approved drilling pad site. By focusing on where the water is obtained, this methodology both simplified reporting for natural gas operators and improved the tracking of water quantities used for natural gas development. The day and location of the withdrawal/delivery better aligns with the time and place of the impact of the consumptive use. In addition to direct withdrawals from streams and wells by project sponsors with docket approvals, natural gas operators also report daily quantities from other water sources including public and municipal water suppliers, wastewater treatment systems, and water from third-party brokers.

Low Flow Protection Policy

In December 2012, the Commission adopted Policy No. 2012-01, named Low Flow Protection Policy (LFPP) (SRBC, 2012), to replace the policy (adopted in 2003) used to make passby flow and conservation release determinations related to withdrawal approvals. The LFPP better reflected contemporary science and flow standards, as described in Ecosystem Flow Recommendations for the Susquehanna River Basin (DePhilip and Moberg, 2010) by The Nature Conservancy.

The LFPP is primarily aimed at addressing the flow recommendations for the low flow component and also provides flexibility to impose withdrawal limits to protect seasonal flows and avoid unacceptable levels of hydrologic alteration. Although the details will not be described here, the policy is available at the Commission's website under 'Policies & Guidance.'

The LFPP has had a major influence on the natural gas industry considering its breadth of activity in the Basin and primary reliance on surface water withdrawals. The limited term of these approvals required renewal under the new policy, such that by the close of 2018, all water withdrawals by the natural gas industry align with the policy objectives.

For withdrawals that exceed *de minimis* thresholds, the LFPP specifies calculation of the variable monthly low flow protection thresholds using either the percent exceedance value method or the Pennsylvania-Maryland Instream Flow Study (PA-MD IFS) method. Flexibility is afforded for determination of low flow protection requirements for withdrawals from exceptional quality and impaired waters. To incentivize development of water sources from lesser quality waters, 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).

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 unacceptable levels of hydrologic alteration. 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.

II. CONSUMPTIVE USE FOR NATURAL GAS DEVELOPMENT

A. Consumptive Use Approvals

The Commission considers water withdrawn by or for natural gas development to be 100 percent consumptively used. Since 2008, when the Commission adopted its Approval by Rule (ABR) process, consumptive use approvals have been issued on a drilling pad site (or well pad) basis and require that all water consumed come from Commission-approved sources.

The number of ABRs issued to the industry for consumptive use at well pads within the Basin from 2009-2018 are presented in Table 1. All consumptive use approvals for the industry are issued under the natural gas specific ABR regulation (18 C.F.R. § 806.22(f)) and have a limited term of 5 years. Rulemaking adopted in 2015 requires that the approval must be maintained until all restoration has been completed according to regulations of the member jurisdiction. The Commission began to issue renewals in November-December 2013 and these approvals are included in the table, undifferentiated.

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

County	ABRs Issued by Year										County Totals
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Bedford	0	1	1	0	2	0	1	0	0	0	5
Blair	2	2	0	0	0	0	4	0	0	0	8
Bradford	79	346	145	93	36	117	241	137	54	17	1265
Cambria	0	0	3	1	0	0	1	0	1	0	6
Cameron	4	6	5	0	0	6	10	3	0	0	34
Centre	16	26	3	0	0	7	12	6	2	0	72
Clearfield	18	37	31	5	1	0	47	10	3	3	155
Clinton	12	16	12	3	3	11	15	7	1	1	81
Columbia	2	10	10	0	0	0	1	1	0	0	24
Elk	0	3	1	0	0	2	4	0	0	0	10
Huntingdon	0	1	0	0	0	1	1	0	1	0	4
Lackawanna	3	3	0	0	0	0	0	0	0	0	6
Luzerne	0	7	0	0	0	0	0	0	0	0	7
Lycoming	37	101	66	51	34	33	110	66	41	23	562
McKean	0	1	0	0	0	1	2	0	0	0	4
Potter	4	11	13	0	0	2	12	3	1	2	48
Sullivan	0	41	20	17	4	11	34	17	8	1	153
Susquehanna	69	93	77	90	71	126	91	66	84	58	825
Tioga, PA	70	234	61	24	6	81	163	69	20	15	743
Wayne	1	7	0	0	0	0	0	0	0	0	8
Wyoming	4	34	24	9	12	19	36	14	9	9	170
Broome (NY)	0	3	0	0	0	0	0	0	0	0	3
Chenango (NY)	0	7	0	0	0	0	0	0	0	0	7
Madison (NY)	0	2	0	0	0	0	0	0	0	0	2
Otsego (NY)	1	1	0	0	0	0	0	0	0	0	2
Schuyler (NY)	0	0	0	0	0	0	4	0	0	0	4
Steuben (NY)	0	0	0	0	0	0	1	0	0	0	1
Tioga, NY	0	0	0	1	0	0	0	0	0	0	1
Annual Totals	**322**	**993**	**472**	**294**	**169**	**417**	**790**	**399**	**225**	**129**	**4210**

Table 1 lists the number of ABR approvals issued, the counties in which they were issued, and the years in which they were issued. As the data indicate, a total of 4,210 ABR approvals were issued by the Commission to the industry for the consumptive use of water occurring between 2009 and 2018; 1,960 of these approvals were issued from 2014 to 2018.

The Commonwealth of Pennsylvania is the only Basin jurisdiction that permits natural gas development using unconventional high volume hydraulic fracturing technology. Although high volume hydraulic fracturing is currently prohibited in New York State, the Commission issued 20 ABRs in counties there between 2009 and 2016. Most of the ABRs in New York expired or were rescinded before natural gas wells were developed on drilling pads. However, five of these ABRs were issued in 2015 for existing well pads where wells had been previously drilled (but not hydraulically fractured). These approvals will remain active and water use will be

tracked until the wells are plugged and restoration has been completed. No ABRs have been issued in Maryland.

The concentration of activity continues to be predominantly in northern Pennsylvania. The four counties with the greatest number of ABRs are Bradford with 1,265, Susquehanna with 825, Tioga with 743, and Lycoming with 562. Together, these four counties contain approximately 80 percent of the total number of ABRs issued by the Commission to the industry for consumptive water use.

The total number of ABR approvals differs from the number of active drilling pads in the Basin as it includes duplication due to ABR renewals for existing drilling pads, ABRs that have expired, and ABRs that have been rescinded at the request of the natural gas operator. At the close of 2018, a total of 1,982 drilling pads remained active. Thirty natural gas companies were operating in the Basin in 2018. Seven of these natural gas operators each held more than 100 ABRs, and accounted for 1,548 ABRs or 78 percent of the total active ABRs.

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

From January 2005 through December 2018, a total of 14,440 unconventional natural gas wells were permitted by PADEP within the Basin.[1] The well permits issued to the unconventional natural gas industry by PADEP, the well completion reports filed by the natural gas industry with PADEP, and the post-hydraulic fracturing reports submitted by the natural gas industry to the Commission were used to compile the information by calendar year presented in Table 2. The data span the period from the first quarter of 2005 through the fourth quarter of 2018. The information summarized in Table 2 pertains only to unconventional natural gas wells located within the Pennsylvania portion of the Basin. No conventional natural gas wells located within the Basin nor conventional or unconventional natural gas wells located outside the Basin were included in the summary.

[1] PADEP regulations require the natural gas industry to obtain permits before drilling conventional and unconventional natural gas wells and to file well completion reports within 30 days after the permitted wells are drilled.

Table 2. Summary of Unconventional Natural Gas Wells Permitted-Drilled-Fractured by County within the Susquehanna River Basin between 2005 and 2018

	Wells Permitted-Drilled-Fractured														County Totals
	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Calendar Year	Number of Gas Wells
PA County	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Permitted-Drilled-Fractured
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	0-0-0	0-0-0	0-0-0	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	0-0-0	0-0-0	0-0-0	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	540-94-132	224-43-53	37-17-30	99-0-56	78-45-92	3919-1240-1244
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	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	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	54-26-12	23-17-11	19-1-7	1-0-18	18-12-0	160-72-53
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	3-1-0	4-1-0	3-0-2	3-0-0	1-0-0	206-41-36
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	15-0-6	12-0-0	1-0-0	7-0-0	1-1-0	454-111-87
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	11-2-2	8-2-0	6-3-4	0-0-2	8-5-0	206-80-67
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	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	9-0-1
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	61-24-6	90-38-0	26-13-0	28-2-0	59-26-4	499-160-14
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	0-0-0	0-0-0	0-0-0	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	0-0-0	0-0-0	0-0-0	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	0-0-0	0-0-0	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	210-86-116	91-17-30	76-3-9	100-0-10	115-34-45	2070-904-742
McKean	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	0-0-0	51-33-11	37-17-0	5-37-11	9-36-0	102-123-22
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	15-0-0	16-5-0	27-16-0	28-0-2	26-12-6	352-93-21
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	106-35-20	32-4-10	15-6-15	32-0-22	32-10-15	467-114-143
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	461-238-227	289-152-129	201-84-106	194-0-146	217-174-141	3065-1481-1386
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	119-30-46	85-17-19	107-31-26	112-0-43	126-57-28	2238-906-592
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	130-58-67	42-16-17	19-7-5	10-0-33	29-11-15	611-259-252
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	1725-594-634	967-345-280	574-198-204	619-39-343	719-423-346	14440-5593-4667

Notes:

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

As indicated in Table 2, it was not until 2008 that substantial numbers of natural gas wells were permitted and drilled in the Basin, and it was not until 2009 that significant numbers of those wells were hydraulically fractured. According to the PADEP data, the total number of wells drilled and hydraulically fractured within the Basin by December 31, 2018, were 5,593 and 4,667, respectively. Long-term, approximately four out of every ten wells permitted by PADEP were subsequently drilled, and approximately 85 percent of the wells drilled were subsequently hydraulically fractured.

Annual totals of wells drilled and hydraulically fractured in the Basin increased from 2005 through 2011-12. As indicated in Table 2, numbers of wells drilled and fractured declined in 2013 and have continued to decline through 2018. The peak year for well completions was 2012, with 836 wells hydraulically fractured. Although well construction and completion activities in 2017-18 show an upward trend, the data in Table 2 indicate the overall level of contraction in the industry since the boom years. Figure 5 presents a graphic summary of the wells permitted, drilled, and hydraulically fractured by calendar year. The fluctuation in average daily consumptive water use is also shown in Figure 5.

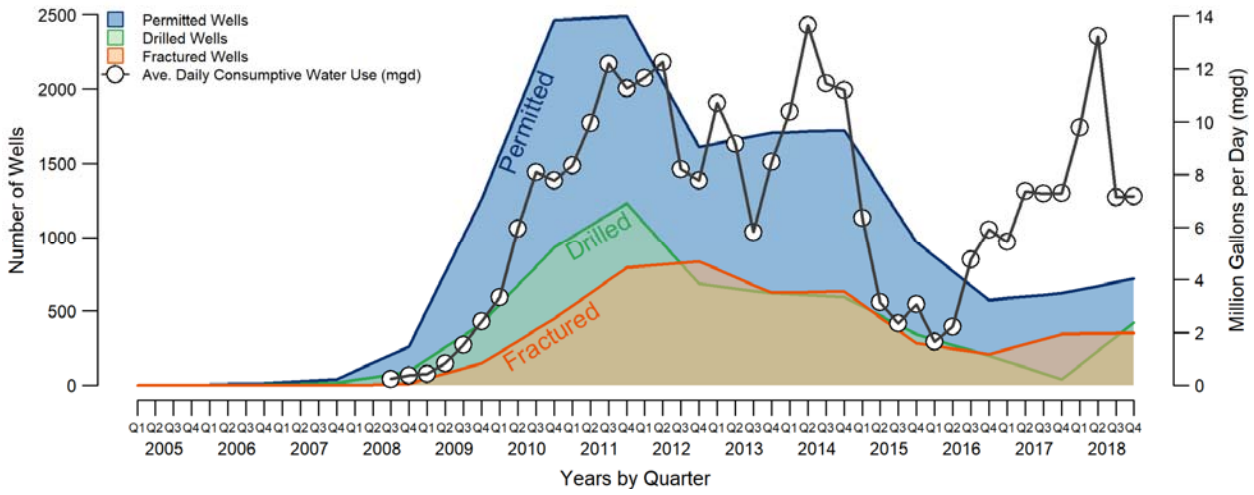

Figure 5. Wells Permitted, Drilled and Hydraulically Fractured from 2005-2018

C. Total Consumptive Use

The total amount of water consumptively used by the industry from July 2008 through December 2018 was 26.3 billion gallons. Fresh water used by the industry originates from surface water sources and diversions or groundwater sources. Water purchased from public water systems or third parties can be comprised of a combination of both surface water and groundwater sources. Table 3 provides a breakdown 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, by quarter and by calendar year. The data span the study period from the third quarter of 2008 through the fourth quarter of 2018.

The long-term average daily consumptive use was approximately 6.8 mgd. Quarterly averages of daily consumptive use during seven of eight quarters in 2017 and 2018 exceeded the long-term average, ranging from 5 to 93 percent. The highest average daily consumptive use calculated by the Commission on a quarterly basis for the report period was 13.6 mgd and occurred during the second quarter of 2014 (Table 3). Average daily consumptive use nearly matched this peak during the second quarter of 2018, at 13.2 mgd. Note that 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 use (in gallons) reported by the industry for a given quarter, by the number of days in that quarter.

Likewise, the average daily water volume from 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. Docketed sources include direct withdrawals plus other sources approved pursuant to 806.22(f). The same procedure was followed for the calculation of the average daily water volume from non-docketed sources. 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. Therefore, these average daily values represent calculated averages and not daily averages directly reported by the industry.

Although 60 to 90 percent of water consumptively used by the industry originated from public water systems from 2008 through the third quarter of 2009, the primary sources of water for the industry transitioned to individual surface water withdrawals approved (and docketed) specifically for use in hydrocarbon development by the Commission. By the first quarter of calendar year 2013, the percent of water taken from public water systems and consumptively used by the natural gas industry had dropped below 5 percent of the total water used. Water sourced by the industry from public water supply systems has remained below 10 percent through 2018.

Table 3. Quarterly Summary of Consumptive Water Use, Water Withdrawals, and Water Diversions by the Unconventional Natural Gas Industry within the Susquehanna River Basin from the Third Quarter 2008 through the Fourth Quarter 2018

(Column 1) Quarter/Year	(Column 2) Total Quarterly Consumptive Use (Gallons)[1]	(Column 3) Average Daily CU Rate by Quarter (GPD[2])	(Column 4) Docketed Quarterly Groundwater Withdrawals (Gallons)	(Column 5) Docketed Quarterly Surface Water Withdrawals (Gallons)	(Column 6) Docketed Quarterly Diversions Into Basin (Gallons)	(Column 7) Average Daily Docketed Sources (GPD)	(Column 8) Non-Docketed Approved Surface Water Withdrawals (Gallons)[3]	(Column 9) Average Daily Non-Docketed Sources (GPD)	(Column 10) 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
Q1-2014	933,971,431	10,377,460	127,702,889	861,343,693	0	10,989,406	20,630,074	229,223	1,009,676,656
Q2-2014	1,241,821,235	13,646,387	116,428,004	986,467,586	74,130	12,120,546	40,222,387	442,004	1,143,192,107
Q3-2014	1,062,562,513	11,549,593	50,385,421	948,212,884	0	10,854,329	87,490,152	950,980	1,086,088,457
Q4-2014	1,030,174,204	11,197,546	57,474,261	895,958,818	0	10,363,403	68,012,966	739,271	1,021,446,045
Q1-2015	571,674,253	6,351,936	104,459,175	463,105,571	12,715,009	6,447,553	62,413,121	693,479	642,692,876
Q2-2015	286,642,979	3,149,923	86,664,207	292,866,330	443,058	4,175,534	3,109,523	34,171	383,083,118
Q3-2015	215,657,424	2,344,102	46,642,028	138,950,657	73,429,734	2,815,461	1,396,954	15,184	260,419,373
Q4-2015	282,572,786	3,071,443	15,151,494	167,444,200	61,971,630	2,658,340	13,511,991	146,869	258,079,315
Q1-2016	150,954,125	1,658,837	6,591,133	143,657,894	15,429,834	1,820,647	2,724,133	29,936	168,402,994
Q2-2016	203,255,544	2,233,577	2,002,163	190,677,397	15,108,186	2,283,382	10,616,902	116,669	218,404,648
Q3-2016	439,675,037	4,779,076	20,009,591	409,665,506	3,023,200	4,703,242	27,789,426	302,059	460,487,723
Q4-2016	545,301,651	5,927,192	17,146,360	516,546,800	6,170,949	5,868,088	1,875,135	20,382	541,739,244

Continued on next page

(Column 1) Quarter/Year	(Column 2) Total Quarterly Consumptive Use (Gallons)[1]	(Column 3) Average Daily CU Rate by Quarter (GPD[2])	(Column 4) Docketed Quarterly Groundwater Withdrawals (Gallons)	(Column 5) Docketed Quarterly Surface Water Withdrawals (Gallons)	(Column 6) Docketed Quarterly Diversions Into Basin (Gallons)	(Column 7) Average Daily Docketed Sources (GPD)	(Column 8) Non-Docketed Approved Surface Water Withdrawals (Gallons)[3]	(Column 9) Average Daily Non-Docketed Sources (GPD)	(Column 10) Subtotals of Docketed and Non-Docketed Water Sources (Gallons)[4]
Q1-2017	488,279,812	5,425,331	12,567,832	444,691,909	22,477,658	5,330,416	4,302,951	47,811	484,040,350
Q2-2017	669,880,641	7,361,326	39,472,424	649,055,221	28,434,412	7,878,704	475,274	5,223	717,437,331
Q3-2017	668,872,826	7,270,357	42,883,529	650,209,877	16,001,594	7,707,554	8,934,719	97,117	718,029,719
Q4-2017	670,556,827	7,288,661	18,193,101	639,575,343	3,924,530	7,192,315	6,418,048	69,761	668,111,022
Q1-2018	880,931,015	9,788,122	15,291,701	845,301,486	24,500,908	9,834,379	3,959,738	43,997	889,053,833
Q2-2018	1,202,945,031	13,219,176	36,722,251	1,165,903,481	4,851,773	13,268,984	1,831,256	20,124	1,209,308,761
Q3-2018	666,898,767	7,248,900	18,180,592	680,245,334	11,624,559	7,717,940	5,449,994	59,239	715,500,479
Q4-2018	660,757,535	7,182,147	20,215,581	634,243,120	13,354,878	7,258,843	4,833,816	52,541	672,647,395
Long-Term Totals (Gallons)	26,285,081,018		1,852,586,549	21,489,757,850	351,602,193		2,348,101,209		26,042,047,801
Long-Term Daily Averages (GPD)		6,854,477				6,178,550		611,003	

Footnotes:

[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 SRBC from PADEP data. The unshaded numbers in Columns 8 and 9 were reported by the natural gas industry directly to SRBC.

[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.

Other Sources of Water and Discrepancies

During the report period, the total reported consumptive use (26.3 billion gallons) exceeds the combined total reported withdrawals and diversions (25.6 billion gallons) by approximately 237 million gallons, or 1 percent of the total consumptive use. A value of 5 percent or less offers confidence that accurate and comprehensive water use tracking is occurring.

III. WATER ACQUISITION AND WATER WITHDRAWAL APPROVALS ISSUED FOR THE NATURAL GAS INDUSTRY

The Commission began issuing water withdrawal approvals for natural gas well development in June 2008. Water used by the industry originates from surface water or groundwater sources, from either inside or outside the Basin, and is sometimes purchased from a public water supply or other facility. The industry also captures minor amounts of stormwater on well pads and top-hole water encountered during drilling activities.

A. Surface Water Withdrawals

From 2008 through 2018, Table 4 shows that the Commission approved a total of 261 surface water withdrawals for use in natural gas development. Of these, 96 expired and were not renewed. Fewer than 70 of the approved surface water withdrawals were actively used as water sources for the industry during any one year of this period. A total of approximately 21.5 billion gallons of surface water were withdrawn from waterways within the Basin and consumptively used by the industry during the 10-year period. An additional 2.35 billion gallons of water were withdrawn within the same time period from other approved surface water sources, primarily public drinking water systems. Together, these two major sources of water comprised approximately 93 percent of the total amount of water withdrawn and consumptively used by the industry.

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

Summary of Water Withdrawal Approvals for Unconventional Natural Gas Industry Use (Includes All Approvals Located within the Susquehanna River Basin Issued to the Natural Gas Industry and to Third-Party Water Purveyors)												
Statistics	**Calendar Year 2008**	**Calendar Year 2009**	**Calendar Year 2010**	**Calendar Year 2011**	**Calendar Year 2012**	**Calendar Year 2013**	**Calendar Year 2014**	**Calendar Year 2015**	**Calendar Year 2016**	**Calendar Year 2017**	**Calendar Year 2018**	**Subtotals**
Surface Water Withdrawals (SW):												
New SW Approvals Issued	51	57	33	42	30	7	9	7	18	2	5	261
Expiring SW Approvals Renewed	0	0	0	0	13	22	24	21	12	23	27	142
Expiring Approvals Not Renewed	0	0	0	0	17	25	11	18	14	6	5	96
SW Approvals Actively Withdrawing Water	3	19	39	57	52	46	68	57	46	61	67	-----
Groundwater Withdrawals (GW):												
New GW Approvals Issued	0	0	2	2	4	0	0	0	1	0	0	9
Expiring GW Approvals Renewed	0	0	0	0	0	0	1	1	2	1	1	6
Expiring GW Approvals Not Renewed	0	0	0	0	0	0	2	1	1	0	0	4
GW Approvals Actively Withdrawing Water	0	0	2	3	3	4	4	5	3	3	3	-----

Descriptive Notes:

1. According to SRBC 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, one in 2013, one in 2014, and one in 2016.
   All of the diversions originated from within the Ohio River Basin. Only 3 of the 13 diversions approved from the Ohio River Basin were actively used as of Dec. 31, 2016.

Of the approved surface water withdrawals, 37 were from lesser quality waters, including three discharges from wastewater treatment plants and 34 from abandoned coal mine discharges. Thirteen of the lesser quality water sites were actively used by the industry during the report period, with a total of approximately 865 million gallons of impaired water withdrawn.

Table 5 lists the top watersheds used by the industry, which are the same watersheds reported in the prior five-year period (2008-2013), although the ranking has changed. Twenty individual watersheds accounted for approximately 96 percent of the approximately 21.5 billion gallons of surface water withdrawn by the industry. The locations of these watersheds are presented in Figure 1. Water withdrawals from the top five watersheds (mainstem Susquehanna River, Tunkhannock Creek, Wyalusing Creek, Meshoppen Creek, and West Branch Susquehanna River) constituted approximately two-thirds of the total surface water withdrawn by the industry.

Table 5. Top 20 Watersheds Used as Water Sources by the Unconventional Natural Gas Industry (2008-2018)

Watershed Name	Drainage Area of Watershed[1] (mi^2)	Number of Well Pads Approved (as ABRs) within Watershed[2]	Surface Water Withdrawals Approved by Watershed	Approved Surface Water Withdrawals Actively Used	Total Surface Water Withdrawn (2008-2018) (Gallons)	Indiv. Watershed Withdrawal as % of Total Withdrawal (%)	Cumulative Withdrawals as % of Total Withdrawal (%)
Susquehanna River, Mainstem (Above Sunbury)	11,310	1,598	35	19	7,931,053,723	37.0	37.0
Tunkhannock Creek	414	160	15	6	2,220,682,592	10.4	47.3
Wyalusing Creek	220	140	18	8	1,718,712,223	8.0	55.3
Meshoppen Creek	114	146	6	5	1,169,288,998	5.5	60.8
Susquehanna River, West Branch	6,979	820	28	9	1,093,984,926	5.1	65.9
Pine Creek	981	232	16	6	1,002,688,152	4.7	70.6
Sugar Creek	189	166	8	6	846,927,800	3.9	74.5
Martins Creek	52	34	5	3	826,238,804	3.9	78.4
Lycoming Creek	272	101	10	5	711,093,061	3.3	81.7
Loyalsock Creek	496	143	4	2	595,182,958	2.8	84.4
Bowman Creek	120	7	2	2	398,772,271	1.9	86.3
Arnot #5 Mine Drainage	N/A	N/A	1	1	390,520,882	1.8	88.1
Cowanesque River	300	39	7	5	294,062,298	1.4	89.5
Chemung River	2,595	339	4	3	265,273,748	1.2	90.7
Towanda Creek	277	128	5	2	257,252,438	1.2	91.9
Tioga River (PA)	456	220	10	4	201,596,114	0.9	92.9
Fishing Creek (Clinton County)	181	0	1	1	180,922,742	0.8	93.7
Fall Brook (Tioga County)	9	12	1	1	153,486,095	0.7	94.4
Muncy Creek	204	54	6	3	150,195,293	0.7	95.1
Choconut Creek	57	10	1	1	135,190,812	0.6	95.8
Subtotals for Top 20 Watersheds Listed Above	See Note 1 Below	See Note 1 Below	183	92	20,543,125,930	95.8	-----
Totals for Entire Basin	See Note 1 Below	See Note 1 Below	261	120	21,453,506,684	-----	-----
Difference	See Note 1 Below	See Note 1 Below	78	28	910,380,754	-----	4.2

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 261 surface water withdrawals were approved for natural gas industry use between 2008 and 2018.
4. A total of 120 surface water withdrawals, or 46 percent of the total, were actively used during that same time period.
5. The remaining 141 approved surface water withdrawals were never actively used.
6. Ninety-two of the total 120 surface water approvals actively used are represented in the top 20 watersheds listed above.
7. The balance of 28 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 2008-2018 time period.

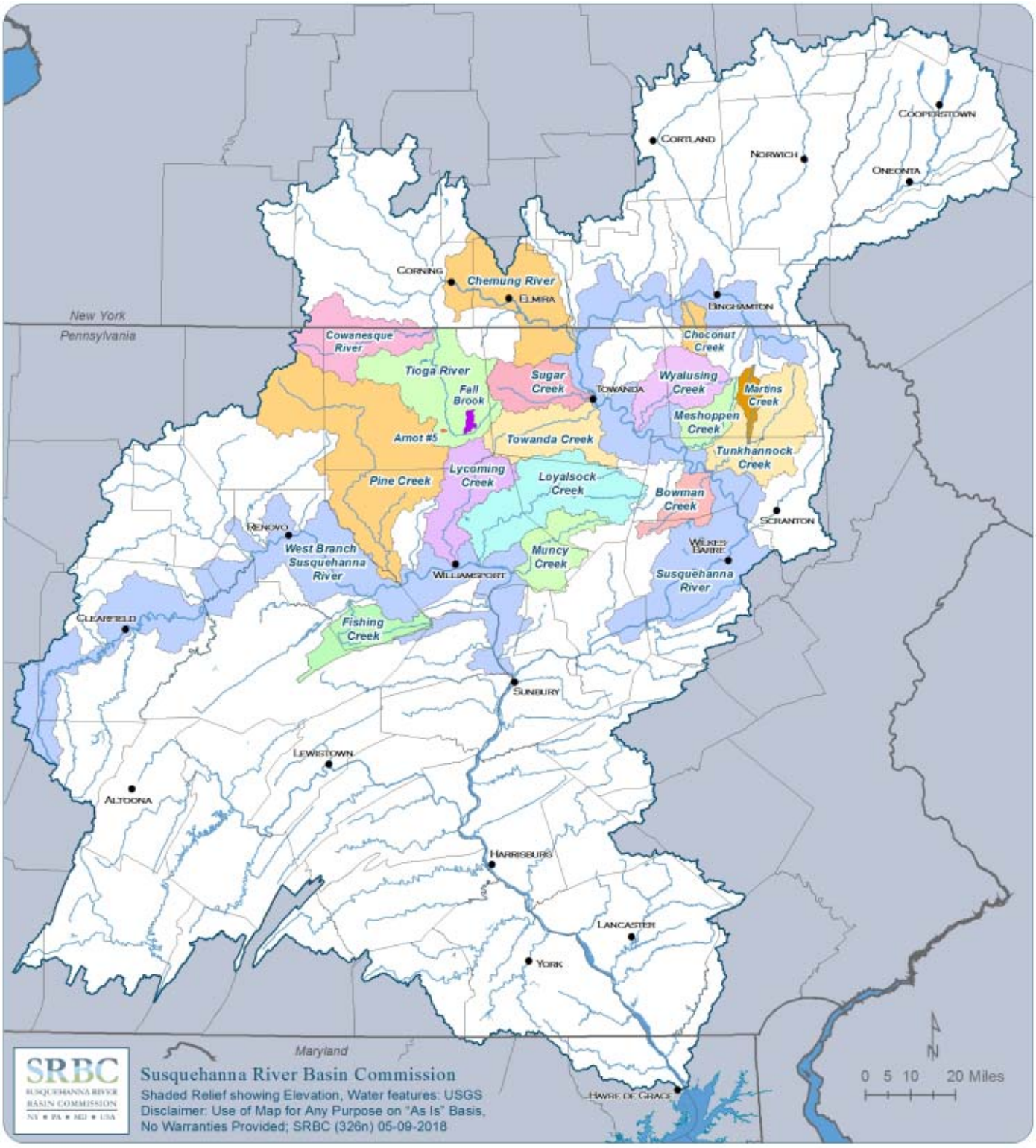

Figure 6. Locations of the Top 20 Watersheds Used as Water Sources by the Industry

B. Groundwater Withdrawals

The Commission approved nine groundwater withdrawals for use by the natural gas industry. Five of those groundwater withdrawals were actively used as water sources for the industry during the last five years. A total of 854 million gallons, or 6.6 percent of the water consumptively used by the industry from 2014 through 2018, originated solely from groundwater sources. The percentage of groundwater used consumptively by the industry during the prior five-year period (2008-2013) was 7.5 percent, which demonstrates little change in the fresh water acquisition strategy.

C. Total Diversion of Water Into the Basin

The Commission has approved 13 diversions of surface water for use by the natural gas industry, all of which originated within the Ohio River Basin. As of December 2018, only three of the approved diversions had been actively used. Over the 10-year period, the total amount of water diverted into the Basin for unconventional natural gas development was approximately 351 million gallons. This quantity constitutes approximately 1.3 percent of the total amount of water consumptively used by the industry.

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

Since 2008, when the Commission adopted its ABR process, each fracturing event for every stimulated well within the Basin is captured in a post-hydraulic fracturing report submitted to the Commission. A profile of the water used to hydraulically fracture natural gas wells was developed from these post-hydraulic fracturing reports and quarterly reports of the quantities of water withdrawn from approved withdrawal locations and water purchased from public water systems. As the data in Table 6 indicate, more than 4,600 natural gas wells were reported as hydraulically fractured within the Basin between July 2008 and December 2018. The water use profile for the industry indicates that 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 6 indicate that the long-term average water used for well fracturing events between July 2008 and December 2018 was approximately 6.8 million gallons of water. On average, 83 percent was comprised of fresh water and 18 percent was comprised of recycled flowback/produced fluids.

Table 6. Summary of Average Water Injected per Well Fracturing Event and Proportions of Fresh and Flowback Waters Used in Those Events

Col 1	Col 2	Col 3	Col 4 (Col 5 / Col 2)	Col 5	Col 6	Col 7	Col 8	Col 9
Quarter/Year	Wells Fractured During Quarter	Reported Quarterly Consumptive Water Use[1] (Gallons)	Quarterly Ave. Water Used Per Frack 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 Subtotals[3]	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**	-----
Q1-2014	147	918,963,760	6.65	978,174,484	781,721,573	80	201,724,023	21
Q2-2014	171	1,206,880,961	6.65	1,136,420,024	876,611,016	77	252,128,655	22
Q3-2014	168	1,035,088,156	7.53	1,264,766,589	1,061,918,782	84	212,708,182	17
Q4-2014	148	1,021,633,958	7.49	1,108,960,647	882,695,705	80	221,921,559	20
Yearly Subtotals	634	**4,182,566,835**	-----	**4,488,321,744**	**3,602,947,076**	-----	**888,482,419**	-----

Continued on next page

Col 1	Col 2	Col 3	Col 4 (Col 5 / Col 2)	Col 5	Col 6	Col 7	Col 8	Col 9
Quarter/Year	Wells Fractured During Quarter	Reported Quarterly Consumptive Water Use[1] (Gallons)	Quarterly Ave. Water Used Per Frack 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)
Q1-2015	99	571,646,480	7.18	711,137,824	604,466,982	85	104,439,840	15
Q2-2015	70	286,932,523	6.78	474,903,867	384,914,384	81	89,989,483	19
Q3-2015	67	216,791,016	6.86	459,753,199	318,029,831	69	154,590,758	34
Q4-2015	44	252,445,181	7.91	348,192,786	226,745,257	65	73,389,701	21
Yearly Subtotals	280	**1,327,815,200**	-----	**1,993,987,676**	**1,534,156,454**	-----	**422,409,782**	-----
Q1-2016	41	151,951,798	9.81	402,084,316	290,136,378	72	128,800,270	32
Q2-2016	37	204,074,868	8.74	323,310,584	259,765,447	80	63,545,137	20
Q3-2016	68	443,408,003	8.72	593,109,502	495,940,085	84	102,244,999	17
Q4-2016	58	545,866,388	8.20	475,477,462	381,419,378	80	90,225,236	19
Yearly Subtotals	204	**1,345,301,057**	-----	**1,793,981,864**	**1,427,261,288**	-----	**384,815,642**	-----
Q1-2017	74	489,098,472	10.25	758,441,874	555,382,574	73	190,097,508	25
Q2-2017	86	670,593,177	9.82	844,109,220	652,540,510	77	201,942,339	24
Q3-2017	91	669,476,593	9.57	870,962,509	678,341,394	78	210,426,343	24
Q4-2017	92	671,080,569	9.94	914,533,532	749,013,414	82	171,830,352	19
Yearly Subtotals	343	**2,500,248,811**	-----	**3,388,047,135**	**2,635,277,892**	-----	**774,296,542**	-----
Q1-2018	88	881,427,772	11.59	1,020,163,245	865,124,642	85	169,043,573	17
Q2-2018	107	1,203,160,630	12.03	1,287,120,731	1,122,836,879	87	180,053,523	14
Q3-2018	80	657,826,844	10.38	830,162,351	702,734,215	85	185,637,126	22
Q4-2018	71	661,347,350	11.58	821,921,260	632,749,295	77	188,267,411	23
Yearly Subtotals	346	**3,403,762,596**	-----	**3,959,367,587**	**3,323,445,031**	-----	**723,001,633**	-----
Column Totals	**4667**	**26,117,121,034**	-----	**28,529,846,372**	**23,383,560,906**	-----	**5,323,609,963**	-----
Long-Term Averages	-----	-----	**6.59**	-----	-----	**82.84**	-----	**17.93**

Notes:
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 (Col. 5) and the combination of Total Fresh Water Injected (Col. 6) plus Total Flowback Injected (Col. 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.

Table 6 presents a summary of the average water injected per well fracturing event and the average proportions of fresh water and flowback/produced fluids used in those events on a quarterly basis beginning in the third quarter of 2008 and extending through the fourth quarter of 2018. The average amount of water used per fracturing event was relatively low in 2008 and 2009, ranging from 1.6 to 2.1 million gallons per event, believed to be primarily due to exploration companies performing limited fractures on vertical wells and short laterals in horizontal wells. These wells were used to hold leases and test the productivity of the target formations. As the industry transitioned from the exploratory phase to the production phase, natural gas companies drilled horizontal wells with longer laterals to fracture more gas-bearing rock. Longer well laterals and changes in well completion designs over the decade increased the amount of water used per fracturing event.

Hydraulically fractured wells in Pennsylvania used, on average, about 3 times as much water in 2018 than they did in 2009, as the average length of laterals increased from 2,200 feet to 7,000 feet from 2,200 feet. Water use per foot of well fractured also increased: early usage was in the range of 1,000 to 1,500 gallons per foot, increasing to a range of 1,500 to 1,900 gallons per foot after 2014. Currently, an industry average for completion design is about 2,200 gallons of water per linear foot.

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. The average amount of water used per fracturing event rose 175 percent between 2013 and 2016, from an average of approximately 5.4 to 9.5 million gallons, even as the pace of well development slowed in response to low natural gas prices. Volumes continued to increase in 2017 and 2018, to a peak average amount of 12.03 million gallons per fracturing event in second quarter 2018. Fewer wells were drilled during this period than in early stages of the fracking boom but more water was used because longer laterals and stage designs required fracturing more rock. Overall, average water use per well for fracturing rose 600 percent between 2009 and 2018.

The natural gas industry began reusing flowback in subsequent fracturing events in 2009, increasing the amount on an annual basis from 2009 through 2014. The reuse of flowback waters represents an offset in the amount of fresh water needed for subsequent fracturing events and reduced the amount of waste fluids requiring disposal or treatment. Quantities reused may be limited, in part, by the availability of flowback. Although the annual quantity of flowback reported as injected has remained relatively steady since 2014, the percent of the total injected remains significant at 15 percent or greater, reaching a peak of 34 percent during the third quarter of 2015.

IV. COMMISSION POLICIES INFLUENCING INDUSTRY WATER USE

A. Low Flow Protection Policy (LFPP)

Through a combination of cumulative water use assessments, low flow protection requirements, and withdrawal limits, the LFPP has created a mechanism for addressing potential impacts of cumulative water use on instream flows and other water users. All natural gas withdrawals have been reviewed under the LFPP, either as new projects or renewals. As of December 2018, LFPP-based low flow protection requirements have only been applied to two

non-natural gas development or transportation (pipeline) projects. Of the 165 approved surface water withdrawals for the industry, 97 were approved as interruptible; conditioned with site-specific low flow thresholds below which the water withdrawal activities must cease. The restrictions are defined within Commission dockets as low flow protection for downstream water users and instream aquatic ecosystems, and subject to additional review prior to future renewal.

The LFPP specifies monthly passby flow values assigned based on Aquatic Resource Class (ARC) rather than coarse annual thresholds. By using monthly instead of annual flow statistics, the LFPP passby flow standards were able to represent seasonal variation in streamflow and ecosystem flow needs. Low flow protection thresholds are considered relative to historic flows for each month rather than an annual average. Not only does this better address seasonality of streamflow and ecosystem needs, but it also avoids unnecessary withdrawal restrictions during seasonal and high flow conditions in summer months.

The LFPP specifies increased levels of low flow protection for withdrawals from small streams (ARC 1 and 2) to recognize that these stream systems have limited water availability and increased sensitivity to withdrawal impacts. Increased protection translates to more interruptions of a withdrawal and fewer days of operation, which may act as a disincentive to siting withdrawals on headwater and small streams. When examined by ARC, the greatest number of natural gas industry withdrawal sources with LFPP-based low flow protection requirements are found in ARC 3. There are fewer approved withdrawals with low flow protection (25 percent) from ARC 1 and 2 sources.

The LFPP may not act as a strong disincentive to natural gas operators because source selection is often constrained by proximity to active well pads, density of their operations, land ownership, and other factors. Although natural gas operators have some flexibility regarding their selection of water sources, their water acquisition strategy is dominated by economics, especially water transportation costs. Produced water management is also a consideration.

The withdrawal rates associated with LFPP-conditioned sources do not always exceed the monthly *de minimis* withdrawal threshold. Accordingly, withdrawals may have low flow protection requirements for some months and not others. Monthly *de minimis* withdrawal thresholds are typically larger during the months of December through June and smaller for July through November. During the traditional low flow months of July through November, nearly all natural gas industry withdrawal sources are conditioned with low flow protection requirements. Low flow protection requirements during the wetter winter and spring months are usually associated with withdrawals from smaller sources and/or at higher withdrawal rates. About 50 percent of withdrawal sources with low flow protection have passby flow requirements in April. All withdrawal sources with low flow protection have passby flow requirements in September.

The Commission recently examined the effect of LFPP conditioned withdrawals in reducing water use during low flow periods. Monthly approved water use reductions from 101 withdrawal sources with LFPP passby flow/conservation release requirements (85 of which are for natural gas development) by low flow condition are depicted in Figure 7. The amount of water use reduction by month is directly related to the number of sources with low flow protection requirements by month and is greatest (108 mgd) in October.

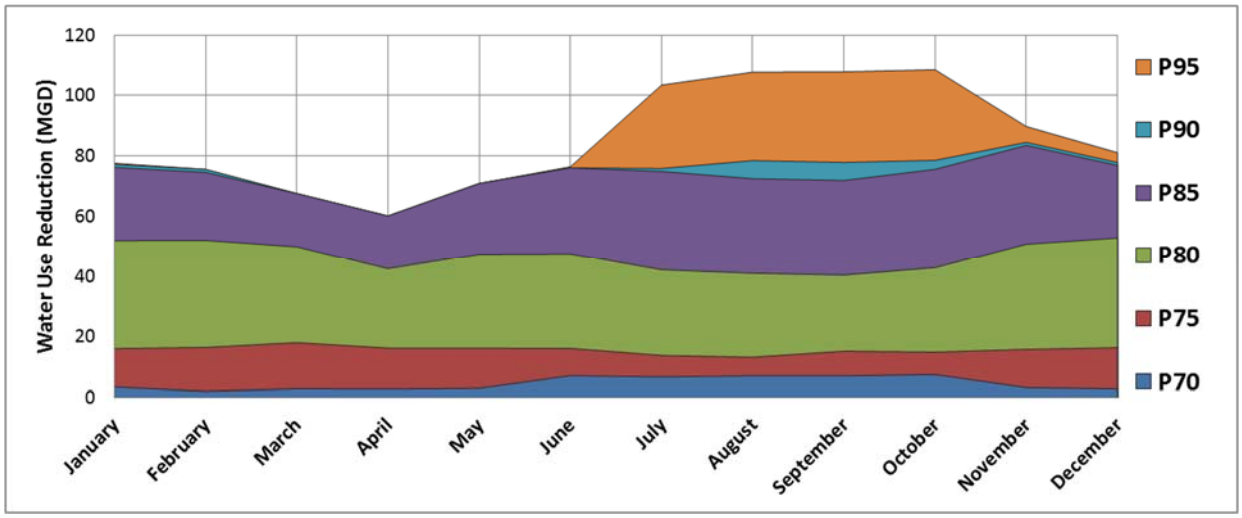

Figure 7. Monthly Water Use Reductions From LFPP Passby Flow/Conservation Release Requirements by Low Flow Condition

B. Use of Lesser Quality Waters

The Commission created an incentive for water users, including the natural gas industry, to use lesser quality waters for their operations when possible. 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 primary incentives are in the form of discounted application fees associated with water withdrawals from these sources and/or relaxed passby flow restrictions consistent with SRBC Resolution No. 2012-01, Use and Reuse of Lesser Quality Water.

Any use of lesser quality water must be seen as positive because of the offset to fresh water supplies. The natural gas industry holds fewer than 40 approvals using water sources having compromised quality, and used less than one-third. Many of the approved withdrawal sources involve AMD. As of December 2018, PADEP had not finalized a guidance document regarding the use of AMD but initial indications are that double-lined impoundments would be required. The combination of increased costs of transportation, increased construction costs for freshwater impoundments, perceived increased risk, and lessor concerns often result in the elimination of AMD sources from consideration by natural gas operators.

Impaired streams may also be evaluated as potential water sources by the industry. Considerations such as the size of the drainage area, flow that meets consumptive use demands, nature of the impairment and overall water quality concerns/treatment costs, and most importantly proximal location, determine whether an impaired stream may be a viable water source.

C. Consumptive Use by the Natural Gas Industry, in Context with Other Users

The total amount of water withdrawn and consumptively used by the natural gas industry from 2008 through 2018 was approximately 26.3 billion gallons. The long-term, average daily usage rate is approximately 6.9 million gallons per day (mgd), based on withdrawals occurring 365 days per year. However, unlike many other consumptive users in the basin, the natural gas industry does not withdraw and consumptively use water consistently year-round; its withdrawals are highly variable and intermittent. From 2010-2018, the average occurrence of natural gas-related water withdrawals ranged from 93 to 150 days per year.

In *The Cumulative Water Use and Availability Study* (CWUAS, 2016), SRBC conducted a comprehensive evaluation of water use and availability throughout the Basin. Reported consumptive quantities for specific sectors and projects can vary substantially due to the frequencies that water is withdrawn, used, and subsequently reported. SRBC concluded that consumptive water use reported by 'days used' was preferable because it reflected a more conservative and realistic impact on water resources. Consumptive use, reported by days used, also becomes more comparable among water users of different sectors within the Basin.

As an example, in 2014, the natural gas industry reported withdrawals on only 131 days, resulting in a computed average of 27.2 million gallons per day based on actual days used instead of an average daily use of 11.1 million gallons per day based on 365 days. Compared with other water users in 2014, the natural gas industry (27.2 mgd) ranks as the third largest consumptive water user, after electric power generators, including nuclear power plants (95.5 mgd), and agriculture (51.0 mgd) (CWUAS, 2016).

In 2018, the average occurrence of natural gas-related water withdrawals was 125 days. Consumptive use was calculated to be 9.5 mgd and 24.3 mgd, based on water use reported by average daily use (over 365 days) or actual days used, respectively. The reported consumptive use value based on actual days used is approximately 2.5 times the reported consumptive use value based on total days in 2018. Average reported consumptive use by major sectors in 2018 is shown in Figure 5. Compared with other water users in 2018, the natural gas industry (24.3 mgd) ranks as the third largest consumptive water user, after public water supply (using a 15 percent CU factor for projects in the basin and 100 percent for diversions) and electric power generation.

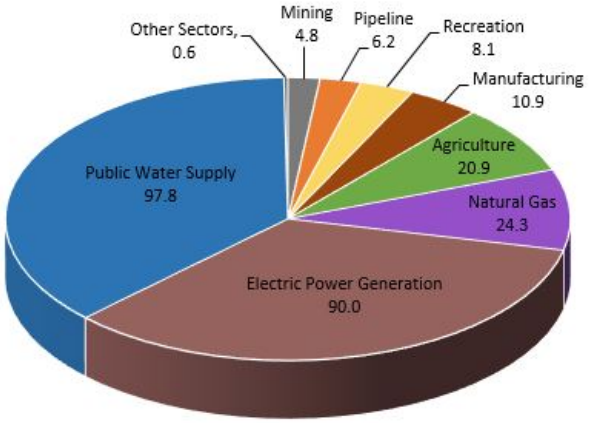

Figure 8. Average Consumptive Water Use (MGD) Based on Actual Days Used in 2018

V. GENERAL OBSERVATIONS AND CONCLUSIONS

The unconventional natural gas industry emerged as an important new water user in the Susquehanna River Basin in 2008. Through 2018, more than 4,600 natural gas wells were hydraulically fractured and the total amount of water consumptively used was 26.3 billion gallons.

After 10 years of high-volume hydraulic fracturing activity, this report provides a more accurate picture of the industry's water use than earlier studies that relied on early years of data. Throughout the decade, even during years of limited development and production, the water use for hydraulic fracturing has remained steady or increased (Figure 9). From 2010 to 2018, water use per well increased from an average of approximately 4 million gallons (mgal) to12 mgal.

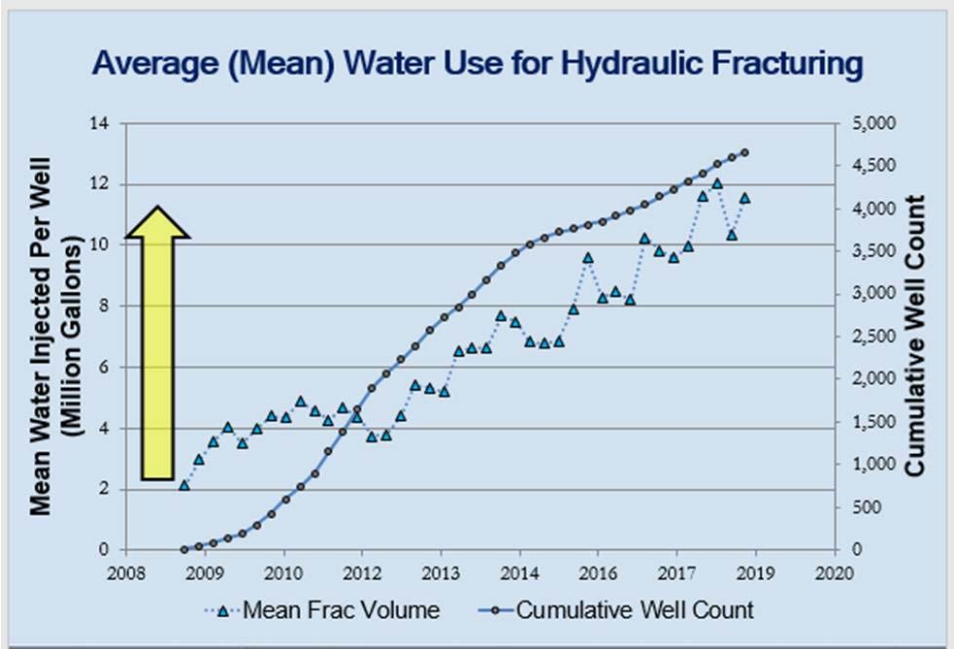

Figure 9. Average Volume of Water Injected in Well Fracturing Events (2008-2018)

The increase in the average consumptive use amount for hydraulic fracturing processes was evidently related to industry infrastructure build-up, technology changes, and increasing lateral lengths of new wells.

In the Susquehanna River Basin, the natural gas industry primarily relies on surface water sources to provide water for hydraulic fracturing. Although 165 surface water withdrawal locations have been approved, only about half of these withdrawals have ever been used. A small number of watersheds provide the bulk of the water used for hydraulic fracturing. Logistical constraints primarily related to transportation costs are a primary factor that limit viable withdrawal points. The top five watersheds supplied approximately two-thirds of the water withdrawn by the industry.

Potential adverse impacts to water sources are focused on the quantity, timing, and location of the withdrawals. Concerns related to impacts to streams, including those related to withdrawals from headwater streams, have been addressed by protective operating conditions. The LFPP provides an effective framework where withdrawal limitations and interruptions are based on credible, ecologically meaningful science backed up by on-site verification. Conservative seasonally variable flow recommendations (as opposed to fixed annual flow standards) and generally focusing on low flow protection during the summer and fall are likely protective of streams. Long-term monitoring should continue to ensure that low flow provisions provide adequate protection for aquatic communities, including fish, or show that more conservative flow standards are needed. In the future, if water demand significantly increases, some watersheds and areas with concentrated withdrawals may need targeted management strategies.

Water used for hydraulic fracturing makes up a significant fraction of the consumptive use in the Susquehanna River Basin. Further, the natural gas industry's water demands have been concentrated in a small number of watersheds, potentially creating conflicts over water availability on a local scale. In the coming years, competition and conflicts over water may erupt as a management issue if potential drought–related water supply constraints are coupled with intense development of natural gas reserves. Various strategies could be implemented to reduce the strain on local freshwater resources, including the use of alternative water sources, additional water storage facilities, and efforts to recycle more of the produced water. The use of recycled water as a source for well completions is particularly important as its use directly offsets freshwater demands.

The highly mobile, decentralized, and unique use patterns of the natural gas industry's water use pose an ongoing challenge for management and oversight. The period from 2014 through 2018 captures a general slowdown in the natural gas industry, although the number of new shale gas wells recovered somewhat in 2018. The natural gas industry's high magnitude but low frequency use, controlled to a large extent by fluctuating market forces, creates uncertainty for long-term planning of the natural gas industry's demand for water.

If the downturn continues, new issues related to an aging Marcellus natural gas field such as produced water management and water requirements for eventual well closure need to be better understood and tracked to prepare for appropriate management. However, the oil and gas industry is historically cyclical. Even as economics affected its activity level, the natural gas industry continued its experimentation and innovation in processes and extended its exploration into other shale formations in the Basin that may become viable energy sources in the future. Recovery to drilling levels seen during 2010 and potential future development of other tight shale formations would increase water use significantly.

The natural gas industry's needs regarding water sources and water use patterns will need to continue to be monitored, assessed, and managed, and associated impacts better understood. Ongoing evaluation of industry trends will be necessary to plan for and implement appropriate adaptive measures that balance energy development and sustainable water resources.

REFERENCES

Balay, J.W., Z. Zhang, J.L. Zimmerman, P.O. MaCoy, C.G. Frank, G.D. Markowitz, and C. Liu. 2016. Cumulative Water Use and Availability Study for the Susquehanna River Basin. (CWUAS). Publication No. 303. Susquehanna River Basin Commission: Harrisburg, Pennsylvania.

DePhilip, M. and T. Moberg. 2010. Ecosystem Flow Recommendations for the Susquehanna River Basin. The Nature Conservancy: Harrisburg, Pennsylvania.

Pennsylvania Department of Environmental Protection. 2019. Statewide Data Downloads By Reporting Period. Oil and Gas Reporting Website. www.depreportingservices.state.pa.us. Harrisburg, Pennsylvania.

Pennsylvania Independent Fiscal Office. 2019. Natural Gas Production Report, 2018 Q4. http://www.ifo.state.pa.us/.

Richenderfer, J.L., B. Wagner, M.K. Shank, J. Balay, D. Hintz, J. Hoffman, P.B. Ballaron, S. McFeaters, and J. Zimmerman. 2016. Water Use Associated with Natural Gas Development: An Assessment of Activities Managed by the Susquehanna River Basin Commission-July 2008 – December 2013. Publication No. 299. Susquehanna River Basin Commission: Harrisburg, Pennsylvania.

U.S. Energy Information Administration. 2019. U.S. Natural Gas Production Hit a New Record High in 2018. https://www.eia.gov/.

U.S. Energy Information Administration. 2015. Annual Energy Outlook 2015 with Projections to 2040. DOE/EIA-0383(2015).