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March 30, 2018

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Dear Mr. Tambini and Commissioners:

The American Petroleum Institute (“API”) submits the following comments in response to the Delaware River Basin Commission’s (the “Commission’s” or “DRBC’s”) Notice dated November 30, 2017 requesting comment on its *Proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities; Additional Clarifying Amendments*.

### **Background and Statement of Interest**

API represents over 625 oil and natural gas companies, leaders of a technology-driven industry that supplies most of America’s energy, supports more than 9.8 million jobs and 8 percent of the U.S. economy, and, since 2000, has invested nearly \$2 trillion in U.S. capital projects to advance all forms of energy, including alternatives. The oil and natural gas industry is committed to an approach that promotes safety and environmental performance while securing the tremendous benefits of domestic energy production for our nation. API is a leader in developing the industry technical standards and programs that enhance the safety of operations worldwide.

Since 1924, API has led in the establishment, maintenance, and dissemination of hundreds of standards to ensure the safe and sustainable development of oil and natural gas in the U.S. and across the world. The process to create and manage the standards has been accredited by the American National Standards Institute (“ANSI”), the body that accredits similar programs at several U.S. national laboratories. This method brings together academics, government regulators and industry experts to improve and advance the safety of energy development. Each standard is reviewed at least every five years to maintain their integrity. API’s standards represent industry safety practices based on the best available science and research. This is one reason they are widely cited, and often incorporated, in federal and state regulations. International regulators often reference the standards in their country’s regulations, as well. As these standards are implemented and their effects measured, they add to the body of knowledge of industry best practices and lessons learned, and deliver significant improvements to system integrity,

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Reliability, and integrated safety. API maintains a portfolio of more than 700 standards that cover all aspects of the oil and natural gas industry, including 260 focused specifically on exploration and production activities.

It is also clear that producing the energy that the U.S, and its allies, rely upon to fuel the nation's economy has also been a proven tool for job creation, economic stimulation, federal revenues, and national security.

### **General Comments and Approach**

On November 30, 2017, API was pleased to see the DRBC finally release its notice of proposed rulemaking on *Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities*. However, as API promotes forward-looking burden-reducing policy decisions promoting domestic energy resources, the organization was disappointed to see a seven-year stalemate on the Commission's 2010 regulatory proposal be replaced with a new proposal to prohibit high volume hydraulic fracturing ("HVHP") within the Delaware River Basin.<sup>1</sup>

The DRBC proposed regulations are unnecessary and, in many ways, duplicative and/or conflicting with Pennsylvania Department of Environmental Protection ("DEP") oil and natural gas regulations, and do not respond to a legislative mandate or clearly demonstrate factual need. The specific issues addressed in this comment letter and the supporting detailed report prepared for API by ALL Consulting, LLC ("ALL" -- see Appendix A -- "*Response to Key Technical Issues Requested by the Delaware River Basin Commission in its Proposed New 18 CFR Part 440 Review*") bear this out and substantiate our position. API has expressed its strong opposition to the proposed prohibition of HVHF during the series of public hearings, speaking at the January 23, January 25, February 22, and March 6, 2018 sessions.

Further, in its November 30, 2017 website announcement of the Notice of Proposed Rulemaking and Public Hearing, the DRBC expressly requested comment on the effects the proposed rules may have within the basin on conservation, utilization, development, management, and control of the water and related resources of the Delaware River Basin. The DRBC requested information on topics such as water availability, the control and abatement of water pollution, economic development, the conservation and protection of drinking water supplies, the conservation and protection of aquatic life, the conservation and protection of water quality in special protection waters ("SPW"), and the protection, maintenance, and improvement of water quantity and quality basin-wide.<sup>2</sup> While addressing all of these aspects of the proposal was simply not possible within the time constraints provided by the comment period, API did request assistance from ALL to develop analysis covering several key technical issues. Appendix A to this comment letter -- builds on work carried forward by ALL in its

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<sup>1</sup>High Volume Hydraulic Fracturing (HVHF) is not terminology used within the industry but is being repeated in this letter to reflect the DRBC proposal.

<sup>2</sup>[http://www.state.nj.us/drbc/meetings/proposed/notice\\_hydraulic-fracturing.html](http://www.state.nj.us/drbc/meetings/proposed/notice_hydraulic-fracturing.html)

previous report to the DRBC (submitted on April 12, 2011)<sup>3</sup> – and includes detailed information on the following topics:

- Water and land use comparing reasonably foreseeable development levels versus no development; water resource availability and potential use compared to other use sectors; and water quality considerations, including SPW and industry's focus on protecting water quality;
- Estimates of the economic benefits that could be brought to the region with an anticipated annual rate of development, including the number of jobs (direct and indirect), wages, income projected from lease and royalty payments, and revenues from taxes paid by the industry;
- Speculation about risks associated with altering landscapes and disturbances to the drainage areas of SPW; and
- Review of the current and future produced water treatment technology landscape including implementation successes across the United States.

### **DRBC Decisions Must Consider Economic Impacts**

The current Vision Statement of the DRBC states that its mission for comprehensive watershed management will be accomplished by seven key actions<sup>4</sup>:

- Serving primarily basin-wide and interstate interests; and national, state-wide, regional, and local watershed interests as the need arises;
- Resolving interstate disputes through mediation;
- Regularly updating the Comprehensive Plan;
- Adopting and implementing policies to manage the basin's water resources in an integrated, planned fashion;
- Integrating environmental and economic needs;
- Basing decisions on sound science; and
- Providing meetings, conferences, seminars, and other opportunities for public education, information exchange, involvement, and resolution of issues.

According to its mission, the DRBC must be committed to integrating environmental and economic needs in its decision to amend its *Special Regulations* to prohibit HVHF in shale and other rock formations. We would argue that the Commission has failed to meet this aspect of its mission. The preamble to the DRBC proposal fails to incorporate any economic information for consideration by the commenting public on what could be lost by a continued prohibition on oil and natural gas development

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<sup>3</sup>Data/information from ALL's April 12, 2011 report to the DRBC was used to respond to the content in the November 30, 2017 DRBC proposal for comparison purposes only. This is not an indication of API's support for the DRBC's previous December 9, 2010 proposed Natural Gas Development Regulations, which we believe were unnecessary and well beyond the jurisdiction of the Commission.

<sup>4</sup>Found on the DRBC website at [http://www.state.nj.us/drbc/library/documents/DRBC\\_vision-mission.pdf](http://www.state.nj.us/drbc/library/documents/DRBC_vision-mission.pdf)

in the basin or conversely, what could be gained economically from a less aggressive approach. In response, API is providing several levels of economic information.

At the macro level, a Price Waterhouse Coopers study, released by API in July of 2017 shows that oil and natural gas production in Pennsylvania supports more than 320,000 jobs in the Commonwealth. This includes direct industry jobs as well as jobs in the wholesale/retail, construction, manufacturing and other sectors. This same study shows that these jobs resulted in roughly \$23 billion in wages paid to individual Pennsylvanians in 2015. These jobs are the cornerstone of a nearly \$45 billion value-added economic benefit to the Commonwealth. It is indisputable that this industry has made a substantial contribution to Pennsylvania's economy overall.<sup>5</sup>

Appendix A to this letter (ALL's Report) provides more specific analysis of the economic picture and potential opportunities lost in six basin counties, if the DRBC finalizes the proposed prohibition regulations.<sup>6</sup> Based on an oil and natural gas development estimate of 40 wells drilled per year in the six counties combined, with no prohibition, the economic benefit to the Commonwealth is quantified conservatively at \$250 million annually (\$6.2 million per well times 40 wells). This potential benefit does not include the: i) lease bonus payments and royalties which would go directly to the landowner (estimated as a bonus payment per acre of between \$500 and \$2,500); ii) unconventional gas well impact fee paid by the operator to the six basin counties (estimated to be over \$125 million for the producing life of the 40 wells drilled annually); iii) the DEP permit fees (estimated at \$1.5 million for the 40 wells over a conservative ten-year period of payment); and iv) a conservative estimate of state income tax paid by individuals and corporations as a result of increased oil and natural gas development activity and associated royalty and lease bonus income, wages, and corporate profits.

### **DRBC Decisions Must Be Based on Sound Science**

As stated above, beyond the DRBC's commitment to integrating environmental and economic needs in policy or rulemaking Commission decisions must be based on facts and sound science. In the proposed rulemaking, the Commission relies heavily on two specific studies to support its claims of the risks and vulnerabilities associated with HVHF and thus, the proposed prohibition – these include the U.S. Environmental Protection Agency's ("EPA's" or "Agency's") hydraulic fracturing water resources study (initiated in 2010) and the New York Supplemental Generic Environmental Impact Statement ("SGEIS").

#### **A. EPA Study**

EPA publicly released the Draft Assessment Report titled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* on June 4, 2015. The Agency

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<sup>5</sup>[http://www.api.org/~media/Files/Policy/Jobs/Economics-Nat-Gas-Oil/API\\_OilEconomy\\_Pennsylvania.pdf](http://www.api.org/~media/Files/Policy/Jobs/Economics-Nat-Gas-Oil/API_OilEconomy_Pennsylvania.pdf)

<sup>6</sup> According to the U.S. Energy Information Administration's analysis of the Appalachian Basin, six northeastern Pennsylvania counties have viable oil and natural gas production potential and as a result, could be affected by the DRBC proposal. The six counties are Carbon, Lackawanna, Luzerne, Monroe, Pike, and Wayne counties.

concluded its year-long formal peer review by the EPA Chartered Science Advisory Board (“SAB”) with the submission of a Recommendations Report to the EPA Administrator on August 11, 2016. Afterwards, the Agency released its Final Assessment Report on December 13, 2016 retitled *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States* (EPA 600-R-16-236ES).

The EPA Chartered SAB Recommendations Report suggested that EPA needed more quantitative support of its June 2015 Draft Assessment topline and accurate conclusion of **“no systemic widespread impacts from hydraulic fracturing,”** As a result, API developed and shared two reports with the EPA Office of Research and Development (“ORD”) – i) *Industry Practices and Trends Protecting Water Resources During Hydraulic Fracturing: Information for US EPA’s Draft Assessment (October 2016)* and ii) *Quantitative Support for EPA’s Finding of No Widespread, Systemic Effects to Drinking Water Resources from Hydraulic Fracturing (November 2016)*. Both reports are available on the API website.<sup>7</sup>

In its December 2016 Final Assessment, EPA altered its original topline conclusion and provided a new conclusion *“that activities under the hydraulic fracturing water cycle can impact drinking water resources under some circumstances.”* Based on the facts at hand, API strongly disagreed with this unsubstantiated reversal by EPA.

The 2016 Final Assessment identified certain conditions under which impacts from hydraulic fracturing activities can be more frequent or severe:

- Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources;
- Spills during the handling of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;
- Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources;
- Injection of hydraulic fracturing fluids directly into groundwater resources;
- Discharge of inadequately treated hydraulic fracturing wastewater to surface water; and
- Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources. (*Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States -- EPA 600-R-16-236ES – Page 1*).

EPA reported that impact generally occurred near hydraulically fractured oil and natural gas production wells and ranged in severity. EPA further stated that data gaps and uncertainties in the available data

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<sup>7</sup><http://www.api.org/oil-and-natural-gas/wells-to-consumer/exploration-and-production/hydraulic-fracturing/scientific-evidence-in-epa-study-confirm>

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prevented ORD staff from calculating or estimating the national frequency of impacts on drinking water resources from activities in the hydraulic fracturing water cycle or fully characterize the severity of impacts. While unable to quantitatively determine a national impact frequency, EPA claimed to qualitatively describe factors that affect the frequency or severity of impacts at the local level.

However, in this very report, in Chapter Six -- *Well Injection* -- the Agency references several studies which support the fact that the possibility of fluids rising from fracturing operations into the shallow water table is highly unlikely:

“...due to the very **low permeabilities** of shale formations; this means that hydraulic fracturing operations are **unlikely** to generate sufficient pressure to drive fluids into shallow drinking water zones (Flewelling and Sharma, 2014 – Page 6-52).”

“Some natural conditions could also create an upward hydraulic gradient in the absence of any effects from hydraulic fracturing. However, these natural mechanisms have been found to cause very low flow rates over very long distances, yielding **extremely small vertical fluxes** in sedimentary basins. These translate to some estimated travel times of 100,000 to 100,000,000 years across a 328 ft (100 m) thick layer with about 0.01 nD (1 . 10–23 m<sup>2</sup>) permeability (Flewelling and Sharma, 2014 – Page 6-52).”

“In deep, low-permeability shale and tight gas settings and where induced fractures are contained within the production zone, flow through the production formation has generally been considered an **unlikely pathway** for migration into drinking water resources (Jackson et al., 2013d – Page 6-53).”

After six years and over \$30 million spent on this study, EPA’s 2016 key findings (noted above) were nothing new. These were acknowledged by industry at the study’s beginning and emphasized by industry repeatedly throughout the research stages and Assessment development process. Specifically, the industry recognized that strong industry standards and operational practices, robust state regulatory programs, and federal environmental statutes work together to address all the potential impacts identified.

API contends that the science and data clearly demonstrate that hydraulic fracturing can be and has been done safely and responsibly and the U.S. taxpayer has witnessed a huge expense and time expended only to see draft final conclusions – supported by science -- changed to final conclusions based in political ambiguity. API cautions that the DRBC is on a similar poorly devised course and offers that there are a host of reputable studies by government agencies and academic institutions, coupled with empirical evidence, that lead one to firmly conclude that hydraulic fracturing is not a threat to drinking water resources (see Attachment 1 to this letter).

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A recent example worthy of note is a two-year study released in mid-2017 by the Academy of Medicine, Engineering, and Science of Texas (“TAMEST”).<sup>8</sup> This work analyzed the overall impacts of oil and natural gas development in Texas – a state with a development history that dates to 1866. The report identifies data gaps and areas of concern (most notably under transportation), while recognizing that these are all being addressed by state and federal regulations and industry practices. The report concluded – based on facts – that hydraulic fracturing is being done in a safe and environmentally friendly manner with economic benefits provided to the state. This report also supports the EPA original fact-based assertion above, that hydraulic fracturing is not a significant threat to drinking water supplies, in its statement:

“Direct migration of contaminants from targeted injection zones is highly unlikely to lead to contamination of potential drinking water aquifers.” (The Academy of Medicine, Engineering and Science of Texas, *Environmental and Community Impacts of Shale Development in Texas* – Page 128.)

#### B. New York State Study

The second study that the DRBC relied upon to justify its prohibition was the New York State Department of Public Health's (“NYSDOH”) report titled “*A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development.*” The review, in its conclusion, presumed that there were still unanswered questions and unaddressed risks to public health that could result from allowing shale development in New York. Based on the review’s recommendation, the DEC passed a de facto moratorium against “high volume hydraulic fracturing” in the state. API studied the NYDOH review and our findings raise serious questions about the DRBC’s reliance on the review to support its current proposal. API found the methodology used to conduct the NYSDOH public health review flawed. The conclusions lacked reproducibility, and the process of how the Agency arrived at their conclusion was not transparent (see Attachment 2 to this letter titled “*Critique of New York State Department of Public Health HVHF Health Review*”). Overall, NYSDOH did not consider how the risk mitigation and management activities recommended in the SGEIS would have reduced or eliminated potential exposures. Regardless of the failings of NYSDOH review, the review is now dated and should not be a primary resource for the DRBC in its decision-making on health implications of its current proposal.

Instead, API urges the Commission to review the 2017 assessment conducted by the Colorado Department of Public Health and Environment (“CDPHE”) and its utilization of a process that was transparent, reproducible, and scientifically defensible. The review included a systematic review of the literature, assessed study quality, and included a screening assessment of potential exposures and health effects. CDPHE concluded, based on its systemic review, that the risk of harmful health effects associated with oil and natural gas development is low.

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<sup>8</sup><http://tamest.org/wp-content/uploads/2017/07/Final-Shale-Task-Force-Report.pdf>

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API believes that DRBC would be better served by performing its own review of local investigations and studies and assessing the evidence using best available scientific methods within the context of the basin.

As a final comment on the necessity for sound science in this deliberative process, on February 1, 2018, New Jersey Governor Phil Murphy held a press conference in Phillipsburg, New Jersey located immediately across the Delaware River from Easton, Pennsylvania.<sup>9</sup> His announcement was simply that he would cast the New Jersey vote in favor of the proposed DRBC rulemaking prohibiting hydraulic fracturing. His declaration was inappropriate and premature. This, considering the public comment period on the proposal remained open until March 30, 2018 and only two of the six public hearings (including one teleconference) had taken place at the time. In each session, the public was specifically instructed at the start of each meeting by the DRBC Hearing Officer that all statements were videotaped and recorded for the Commissioners (none of whom were in attendance) to view before the close of the formal comment period and for inclusion in a final Response to Comment document. Following those steps – expected to take until late spring or early summer – the proposal would be placed before the Commissioners for a final vote.

At the end of his February press conference, Governor Murphy stated, “Whether we always agree with the decisions or not, let’s get back to making decisions based on the science and based on the facts.” Despite his premature pronouncement, API could not agree more: science and fact-based analysis and decision-making should be the underpinning of this and all DRBC’s initiatives.

### **The Oil and Natural Gas Industry’s Management of Water and Waste**

During the six public hearings scheduled by the DRBC, numerous statements were made by engaged participants about how oil and natural gas development in the basin would result in detrimental effects on groundwater, private drinking water wells, and the Delaware River.

These and many other statements about the oil and natural gas industry’s operations were either grossly exaggerated or flat-out wrong, and no opportunity was provided to industry to correct the record during the hearings. API is therefore addressing these water and waste management issues briefly in this comment letter.

#### **A. Protection of Water Resources**

Hydraulic fracturing has been conducted for nearly six decades, and during this time industry has developed techniques for improving well drilling, cementing, and casing to protect freshwater sources, restrict fluids to the intended zone, and enable efficient hydrocarbon production. The primary means of ensuring that underground sources of drinking water are protected is by carefully casing the well with a steel pipe and cementing it into place to create a tight seal. Several redundant layers of steel casings and

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<sup>9</sup>The February 1, 2018 press conference can be viewed via this link: <https://www.youtube.com/watch?v=5MV6ObQf9Gs>



cement sheaths are sequentially installed to provide layers of protection. After installation the cement is tested to evaluate its strength and seal.<sup>10</sup>

In addition to well integrity being a top priority for protecting subsurface water resources, the industry carefully manages water at the surface at all stages of operations. This applies throughout the water cycle and includes sourcing, transportation, and use as well as treatment, reuse, or disposal. Technological, and in certain cases, state regulatory advances have allowed producers to minimize use of fresh water sources in favor of non-potable, lower quality water, or produced water. Water reuse within the oil and natural gas industry is also encouraging development of more efficient, more mobile water treatment technologies that could eventually be scaled and utilized by other industries.

The federal government creates framework environmental laws that often prescribe regulatory minimum thresholds for states to follow. For example, the Clean Water Act (“CWA”) applies to oil and natural gas operations, particularly where water resource protection, and in certain cases, restoration is concerned. The CWA allows for the establishment of the National Pollutant Discharge Elimination System (“NPDES”), which, in most states, regulates how oil and natural gas operators manage stormwater and other wastewater discharges from their sites. Operators must seek coverage under construction and operating permits; prepare compliant Stormwater Pollution Prevention Plans (“SWPPP”); and implement best management plans (“BMPs”) and controls (including routine inspections and testing of upstream discharge points) to prevent impacts to receiving water bodies. In Pennsylvania, stormwater discharges are permitted through PA’s ESCGP-2 general permits. The NPDES program further requires permits and engineering and other controls (including routine inspections and testing) for any discharge of wastewater from oil and natural gas sites. Further, a separate provision of the CWA, the Oil Spill Prevention, Control, and Countermeasures (“SPCC”) Regulation requires oil and natural gas operators to prepare SPCC plans, implement controls, and establish BMPs to prevent impacts to receiving water bodies from tanks and other structures that hold oil on site.

Under the federal structure, states are authorized to be the primary stewards and regulators of their water. Most states producing shale energy have extensive water quality and quantity regulations overseen by a wide range of agencies. States typically mandate considerable disclosures for water use permitting requiring applicants to demonstrate the water sources they plan to use, as well as show that their expected uses will not have an adverse impact on other users or the environment even in times of floods or droughts. Many states also require companies to show how they plan to transport, store, treat, and dispose of the water safely and in accordance with the law.

Specific to Pennsylvania, in 2010 DEP established new regulations affecting the discharge of produced water with elevated total dissolved solids (“TDS”). The regulations established four revised effluent standards for TDS, chlorides, barium, and strontium – which publicly-owned treatment works

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<sup>10</sup>[http://www.api.org/~media/Files/News/Infographics/Cementing\\_A\\_Seal\\_For\\_Safety.pdf](http://www.api.org/~media/Files/News/Infographics/Cementing_A_Seal_For_Safety.pdf)

("POTWs") and centralized waste treatment ("CWT") facilities were required to meet. In May of 2011, DEP asked operators to stop discharging shale produced water to POTWs and CWTs because of water quality concerns downstream of municipal discharge points. The DEP request shut down this type of treatment of shale produced water in Pennsylvania, although produced water from conventional or traditional shallow wells is still being discharged to these facilities. The DEP Fact Sheet on Marcellus

Shale Development outlines the numerous state requirements in place concerning water use and wastewater disposal activities in the Commonwealth.<sup>11</sup>

"Large volumes of water are required to complete a Marcellus Shale natural gas well, and large volumes of waste water are generated as part of the process. This wastewater is considered industrial wastewater and is a residual waste in Pennsylvania. DEP, in cooperation with the Susquehanna and Delaware River Basin Commissions, has created additional permit guidelines for drilling in the Marcellus Shale formation to create consistent rules for water withdrawal, usage, treatment, and disposal in all areas of the state, and to ensure that the water quality and uses of waters of the Commonwealth are not threatened by drilling operations.

As part of the permit application process, the applicant must develop a Water Management Plan to identify where it plans to obtain and store the water, identify withdrawal quantity, rate, timing, and pass-by flow requirements. When applying for a permit, the applicant must specify the withdrawal locations of source water and demonstrate the following: proposed withdrawal will not adversely affect quantity or quality for other uses or users, designations and uses of the source water body will be maintained, water quality in the entire watershed will not be adversely impacted and a reuse plan for water used to hydraulically fracture the wells will be provided.

Drilling companies must also identify where produced wastewater will be stored, treated, and disposed. Pits or impoundments with an embankment for temporarily storing drilling wastes must meet DEP standards for construction (e.g., synthetic liners) and may also require a DEP dam permit.

Wastewater (fluids) must be recycled, treated at an authorized wastewater treatment facility, or disposed at an authorized waste disposal facility. DEP approval is required before the receiving treatment or disposal facility can accept the wastewater for processing and/or disposal."

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<sup>11</sup> <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=4947&DocName=8100-FS-DEP4217.pdf>

## B. Chemical Disclosure

Approximately 99.5 percent of the contents of most hydraulic fracturing fluid systems are well-known and widely disclosed: water (90 percent by volume) and a proppant (typically sand or other non-toxic material, which constitutes 9.5 percent by volume). The substances that are most commonly found in the additional 0.5 percent of hydraulic fracturing fluid systems are also commonly found in food, cosmetics, detergents and other household products.<sup>12</sup> These substances are essential for efficient delivery of the proppant to the rock fractures, reduction of friction, which in turn reduces the energy required to pump, and in the prevention of corrosion and scale build up, which is detrimental to equipment and overall production. The combination of chemicals used by certain service companies, who typically carry out the actual fracturing operations, can be of a proprietary nature and receive similar protections from disclosure offered to other industries. The industry generally protects specific ingredients within additives that commonly represent less than a thousandth of a percent (0.001 percent) of the total hydraulic fracturing fluid volume. Even in those narrow circumstances, where precise chemical identification is not publicly released, the industry typically provides chemical category information that allows the public to identify the class and function of the chemical. Further, several states require that the precise identity of these ingredients be disclosed to regulators, physicians, and emergency personnel.

As a part of stakeholder engagement and to maintain a high level of transparency with communities, companies report specific information about fracturing fluid used at an individual well via a voluntary, publicly accessible website: FracFocus.org. This chemical disclosure registry was developed in 2011 by the Groundwater Protection Council and the Interstate Oil and Gas Compact Commission, two organizations comprised of state regulators that oversee the oil and natural gas industry. FracFocus.org also serves as a reporting method to meet state disclosure requirements for 24 states, including Pennsylvania. To date, chemical information on over 130,000 wells is contained within the registry.

Finally, safety data sheets (“SDSs”) contain safety, health, and environmental information for all ingredients (including those denoted as proprietary). SDS documents must be available onsite for the substances used in the hydraulic fracturing process as required by the Occupational Safety and Health Administration (“OSHA”).

## C. Waste Management

Waste from oil and natural gas drilling and production activities are managed in accordance with state and federal environmental laws and numerous industry recommended practices and standards. In many states, companies submit waste management plans as part of the permitting process to ensure that waste management options are carefully considered long before drilling ever begins. The industry generally manages waste by employing a tiered decision-making process based on a hierarchy of control that is

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<sup>12</sup> Department of Energy/Groundwater Protection Council: Modern Shale Gas Development in the United States: A Primer (2009)

designed to best protect public and environmental health: reduce, reuse, recycle, treat, and dispose. Reduction involves efforts which decrease the volumes of waste generated and determining if more environmentally friendly (but equally effective) chemical substitutes are available for use. The second tier involves reclaiming and reusing as much waste as possible, using treatments that allow materials to be reused, and reduce the residual waste produced, thereby reducing the amounts that must be disposed. The third tier involves environmentally sound and responsible methods of disposing of generated wastes.

As a final note regarding oil and natural gas wastes, a common topic raised during the public hearings was radioactivity or naturally occurring radioactive material (“NORM”). Low levels of NORM are all around us.<sup>13</sup> They are in the foods we eat and the houses we live in, and in the air, rocks, and soil in the environment. Consequently, some of the water and wastes resulting from exploration and production of oil and natural gas may contain low levels of radioactivity through contact with underground formations. The industry operates under federal, state, and local regulations to manage, store and dispose of these materials in a safe manner, which protects both workers and the community.

Protecting workers, individuals, and the community who are near oil and natural gas operations is of paramount importance to the industry. Companies are dedicated to implementing internationally-recognized standards and best practices, which provide for safe work environments and the public safety. The way the industry handles NORM is no different. For decades, companies have effectively managed and disposed of these materials from production and processing equipment, as well as waste products, such as production fluid and cuttings, all in compliance with federal and state regulations. Currently, operators identify, store, and dispose of any naturally occurring radioactive material in compliance with state environmental laws and OSHA regulations. Due to varying background levels of NORM, NORM-specific regulations are the responsibility of states. However, remediation guidelines for sites undergoing closure may be subject to EPA’s requirements concerning allowable soil and surface water limits.

Generally, states distinguish between levels of radiation that are non-hazardous and hazardous. In any question of worker protection, state health standards combined with OSHA regulations determine permissible exposures. Associated reporting and transparent activities work together to create an environment where the oil and natural gas industry can effectively monitor, manage, and disclose its work around NORM.<sup>14</sup>

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<sup>13</sup>According to EPA, NORM is defined as, “Materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as radium, uranium, thorium, potassium, and their radioactive decay products, that are undisturbed as a result of human activities. Further, background radiation, which is present in terrestrial, cosmic, man-made or cosmogenic sources, is all around us.” Technologically Enhanced Naturally Occurring Radioactive Materials (“TENORM”) are “NORM materials that have been concentrated or exposed to the accessible environment as a result of human activities, such as manufacturing, mineral extraction or water processing.”

<https://www.epa.gov/radiation/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm>

<sup>14</sup>A 2015 peer-reviewed Pennsylvania DEP [study](#) titled *Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) Study Report* (revised in May 2016) stated that there is “little potential for harm to workers or the public from radiation exposure due to oil and gas development.”

## **The Delaware River Basin Commission Lacks Authority to Prohibit Hydraulic Fracturing**

Purporting to “protect and conserve the water resources of the Delaware River Basin,” Proposed 18 C.F.R. § 440.1(a), the DRBC proposes to regulate, among other things, “high-volume hydraulic fracturing,” defined as “hydraulic fracturing using a combined total of 300,000 or more gallons of water during all stages in a well completion . . .,” Proposed 18 C.F.R. § 440.2.<sup>15</sup> Pursuant to the proposed regulations, “[h]igh volume hydraulic fracturing in hydrocarbon bearing rock formations is prohibited within the Delaware River Basin.” Proposed 18 C.F.R. § 440.3(b).

Because the Commission’s authority to issue regulations derives solely from the Delaware River Basin Compact (“Compact”), and the Compact does not give the Commission authority to prohibit hydraulic fracturing, the proposed regulation should be rejected.

### *A. The Compact’s Origins Constrain the Scope of the Commission’s Authority.*

The Constitution grants Congress the authority to “regulate Commerce . . . among the several States.” U.S. Const. art I, § 8, cl. 3. The United States Constitution’s Compact Clause permits a State to enter into an agreement or compact with other States, but only with “the Consent of the Congress.” U.S. Const., art. I, § 10, cl. 3.

The Compact between New York, New Jersey, Pennsylvania, Delaware, and the United States arose from long-running litigation over the allocation of water along the Delaware River. “In order to meet its increasing need for supplies of public water, New York City in 1929 began to plan the diversion of the waters of the Delaware River.” *Badgley v. City of New York*, 606 F.2d 358, 362 (2d Cir. 1979). New Jersey promptly “commenced an original suit in the U.S. Supreme Court against the State of New York . . . to enjoin and restrain any *diversion* of the waters of the Delaware River . . .” *Id.* (emphasis added).

The Supreme Court referred the diversion dispute to a special master, who prepared a report subsequently adopted by the Court. *See New Jersey v. New York*, 283 U.S. 336, 344–45 (1931). The Court’s resulting order precluded New York from diverting from the Delaware River and its tributaries more than a set amount of water daily, required New York to install “an efficient plant for the treatment of sewage” before any diversion would be allowed, set limitations on the concentration of waste in waters returned to the Delaware River, and required New York to release additional water into the Delaware River if its depth fell below set levels in New Jersey. *See id.* at 346–47. In this way, the Supreme Court “intended to establish a comprehensive scheme of river regulation, all-inclusive as to all matters concerning the manipulation of the flow of the undiverted portions of the waters of the Delaware River.” *Badgley*, 606 F.2d at 368.

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<sup>15</sup>“Hydraulic fracturing,” in turn, is defined as “a technique used to stimulate the production of oil and natural gas from a well by injecting fracturing fluids down the wellbore under pressure to create and maintain induced fractures in the hydrocarbon-bearing rock of the target geologic formation.” Proposed 18 C.F.R. § 440.2.

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Following a subsequent New York City petition to the Supreme Court “to allow an increase in the diversion of the Delaware River waters,” New York, New Jersey, Pennsylvania, and Delaware entered into a consent decree further defining the States’ relative rights to the Delaware River’s waters. *Id.* at 362–63. The decree amended the allowable diversions, maintained the treatment requirements, and established a river master to administer the terms of the decree. *See New Jersey v. New York*, 347 U.S. 995, 996–1005 (1954).

Further formalizing their relationship, in 1961 New York, New Jersey, Pennsylvania, and Delaware entered the Compact, providing for, among other things, the creation of the Commission. *Badgley*, 606 F.3d at 363. Congress approved the Compact, which was then signed by the President and the governors of the signatory States. *See* Pub. L. No. 87-328, 75 Stat. 688 (1961); Compact at 38.

Consistent with its genesis in resolving long-running litigation among the States over water diversion, the Compact aims:

“to promote interstate comity; to remove causes of present and future controversy; to make secure and protect present developments within the states; to encourage and provide for the planning, conservation, utilization, development, management and control of the water resources of the basin; to provide for cooperative planning and action by the signatory parties with respect to such water resources; and to apply the principle of equal and uniform treatment to all water users who are similarly situated and to all users of related facilities, without regard to established political boundaries.”

Compact, Section 1.3(e). Similarly illustrating the Compact’s underlying preoccupation with water diversion, the States identified a number of goals, including to:

“provide effective flood damage reduction; conservation and development of ground and surface water supply for municipal, industrial, and agricultural uses; development of recreational facilities in relation to reservoirs, lakes, and streams; propagation of fish and game; promotion of related forestry, soil conservation, and watershed projects; protection and aid to fisheries dependent upon water resources; development of hydroelectric power potentialities; improved navigation; control of the movement of salt water; abatement and control of stream pollution.”

Compact, Part 1. Ultimately, the Compact relies on the “*regulation of stream flows toward the attainment of those goals.*” *Id.* (emphasis added).

**B. *The Compact’s Language, Structure, And Course of Dealing Preclude the Authority to Prohibit Hydraulic Fracturing.***

“The construction of a compact sanctioned by Congress under . . . the [Compacts Clause] of the Constitution presents a federal question,” and requires application of federal law. *Petty v. Tennessee-Missouri Bridge Comm’n*, 359 U.S. 275, 278, 280 (1959). Because “a congressionally approved

interstate compact” within the purview of the Commerce Clause is construed “just as if [it] were . . . a federal statute,” *Virginia v. Maryland*, 540 U.S. 56, 66 (2003) (quotation and alteration omitted); *see also New Jersey v. Delaware*, 552 U.S. 597, 610 (2008); *Cuyler v. Adams*, 449 U.S. 433, 440 (1981) (“[T]he consent of Congress transforms the States’ agreement into federal law under the Compact Clause.”), the “focus [is] on the text” of an interstate compact “to determine the scope of . . . authority” conferred. *EnergySolutions, LLC v. Utah*, 625 F.3d 1261, 1273 (10th Cir. 2010).

As the Supreme Court has made clear, “[s]tatutory construction must begin with the language employed by Congress and the assumption that the ordinary meaning of that language accurately expresses the legislative purpose.” *Gross v. FBL Fin. Servs., Inc.*, 557 U.S. 167, 175 (2009). *See also Virginia*, 540 U.S. 56, 66 (looking to the compact’s “plain language”); *Pievsky v. Ridge*, 98 F.3d 730, 733 (3rd Cir. 1996) (“The interpretation of the Compact must be grounded and based upon the very language of the instrument.”). This is particularly true for interstate compacts, which, “like treaties, are presumed to be the subject of careful consideration before they are entered into and are drawn by persons competent to express their meaning and to choose apt words in which to embody the purposes of the high contracting parties.” *New Jersey*, 552 U.S. at 615–16 (quotation omitted).

The Commission’s present assertion of authority to prohibit hydraulic fracturing rests on its general authority in the Compact over “projects,” *see* Proposed 18 C.F.R. § 440.1(b) (citing Sections 3.6(b), 3.8, 7.1, and 13.1), and its specific authorization to engage in pollution control, *see id.* (citing Section 5.2). Neither source supports a prohibition on hydraulic fracturing.

***1. The Compact’s provisions governing “projects” do not authorize the proposed hydraulic fracturing prohibition.***

Under the Compact, a “project” is “any work, service or activity which is separately planned, financed, or identified by the commission, or any separate [public or private] facility undertaken . . . **for** the conservation, utilization, control, development or management of water resources . . . .” Compact, Section 1.2(g) (emphasis added). Hydraulic fracturing is plainly not “for” the listed purposes that define a “project” covered by the Compact and, by extension, the Commission’s authority. That those purposes are a key feature of defining “projects” is clear from the Compact’s consistent usage of the term, which demonstrates a focus on water management projects such as diversion, treatment, and the like rather than regulation of oil and natural gas operations that happen to use water that may or may not originate from the Delaware River. *See Virginia*, 540 U.S. at 66 (comparing differing language of several sections of compact, illustrating compact’s intent and ability to draw distinctions among different citizens’ rights).

For example, the proposed regulations rely on Section 3.6(b) of the Compact. Proposed 18 C.F.R. § 440.1(b). But that provision permits the Commission to “[e]stablish standards of planning, design and operation of all projects and facilities in the basin which affect its water resources,” such as “water and waste treatment plants, stream and lake recreational facilities, trunk mains for water distribution, local flood protection works, small watershed management programs, and ground water recharging operations.” Compact, Section 3.6(b). While the Compact professes that Section 3.6(b) is “without

limitation” to the specific listed examples, *see id.*, each species is of the same genus—management of water availability and waste treatment. That focus is on all fours with the circumstances of the Compact’s formation and execution, and, indeed, the Supreme Court’s orders resolving the diversion disputes between New Jersey and New York. *See supra* (describing Supreme Court orders for managing water diversion and treatment in New York).

Other provisions evince a similar focus. *See, e.g.*, Compact, Part 1 (explaining that Compact is necessary because “water resources planning, and development is technical, complex, and expensive, and has often required fifteen to twenty years from the conception to the completion of a large dam and reservoir”); *id.* (“[T]he public interest requires that facilities must be ready and operative when needed, to avoid the catastrophe of unexpected floods or prolonged drought . . . .”); Compact, Compact, Section 3.6(a)–(g) (describing “General Powers” of Commission, including planning, research, and investigation relating to water resource management); Section 10.1 (“The commission may regulate and control withdrawals and diversions from surface waters and ground waters of the basin . . . .”); Compact, Section 10.3 (“[N]o person, firm, corporation or other entity shall divert or withdraw water for domestic, municipal, agricultural or industrial uses in excess of such quantities as the commission may prescribe by general regulation . . . .”); Compact, Section 13.1 (providing that “public and private projects and facilities” in a comprehensive plan are limited to what is “required, in the judgment of the commission, for the optimum planning, development, conservation, utilization, management and control of the water resources of the basin”).

Indeed, among “projects,” the Compact elsewhere lists “dams, reservoirs and other facilities.” Compact, Section 4.1. *See also, e.g., Delaware Water Emergency Grp. v. Hansler*, 536 F. Supp. 26, 31 (E.D. Pa. 1981) (considering challenged to proposed “pumping station” project). This strict focus on water management comports with the *Commission’s* underlying duty to “develop and effectuate plans, policies and projects relating to the water resources of the basin.” Compact, Section 3.1. *See also id.* (stating the Commission “shall encourage the planning, development and financing of water resources projects”). In other words, “projects” exist to promote the purposes of the Compact. *See* Compact, Section 3.2(b) (requiring the Commission to assess “the quantity and quality of water resource needs of the area . . . , balanced by existing and proposed *projects required to satisfy such needs*” (emphasis added)). It is such projects to which Compact Section 3.8’s requirement of Commission approval of a “project having a substantial effect on the water resources of the basin” applies. *See* Proposed 18 C.F.R. § 440.1(b) relying on Section 3.8).<sup>16</sup>

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<sup>16</sup>Prior to approving the Compact, the Congress obtained a legal opinion on its constitutionality. *See* Memorandum for the Honorable Fredrick G. Dutton, Special Assistant to the President, Re: Delaware River Basin Compact (April 25, 1961). Notably, that opinion similarly described the scope of “projects” contemplated by the Compact, explaining:

Under Articles 3 to 10, inclusive, [the Commission] could develop plans and construct projects relating to water supply, including the construction and operation of dams and reservoirs, construct and operate projects for pollution control, flood protection, and soil conservation and erosion control . . . . It would have the power to approve or disapprove a project of a privately owned public utility or a public agency (including federal projects) which might have a substantial effect on the comprehensive plan.



At bottom, “[t]he main purpose of the Compact is to regulate the allocation of water from the Delaware River among the four states that are parties to the Compact.” *Allen v. City of New York*, No. 05-cv-1559, 2006 WL 2052229, at \*5 (N.D.N.Y. July 21, 2006). The Compact’s terms must be read in light of this “central purpose.” *Oklahoma v. New Mexico*, 501 U.S. 221, 237 (1991) (relying on the “central purpose” of a compact “to settle the respective rights of the States to” the river’s water). In that light, the Compact’s reference to “projects”— which the Compact dictates must be directed “for” certain water management purposes, *see* Compact, Section 1.2(g); *supra*—cannot extend to private hydraulic fracturing operations for gas production simply because the operations may use water from the basin. A contrary reading would permit the Commission to regulate seemingly any activity within the basin, an absurd result at odds with the well-defined focus of the Compact. *See Griffin v. Oceanic Contractors, Inc.*, 458 U.S. 564, 575 (1982) (“[I]nterpretations of a statute which would produce absurd results are to be avoided if alternative interpretations consistent with the legislative purpose are available.”).

The Commission’s and signatory States’ course of dealing both under and outside the Compact confirms this reading. *See, e.g., New Jersey*, 552 U.S. at 618–19 (looking to course of conduct under interstate compact); *Tarrant Regional Water Dist. v. Herrmann*, 569 U.S. 614, 636 (2013) (same). As detailed in, among other places, the Comprehensive Plan developed under the Compact, “projects” are generally limited to water management and control projects, such as reservoirs, dams, and flood control. *See* 2001 Delaware River Basin Commission Comprehensive Plan at 10–37 (describing existing and proposed projects, including reservoirs, water supply systems, and flood control. Likewise, the Commission’s previously issued substantive regulations involve flood plains, *see* 18 C.F.R. Part 415, charges for supplying water, *see* 18 C.F.R. Part 420, and regulations for extracting groundwater in areas of southeastern Pennsylvania, *see* 18 C.F.R. Part 430.

By contrast, the individual State signatories of the Compact have independently and extensively regulated oil and natural gas operations, including hydraulic fracturing, within their borders. *See* New York Dep’t of Environmental Conservation, Final Supplemental Generic Env’t Impact Statement, Findings Statement (June 2015) (implementing ban on high-volume hydraulic fracturing), *available at* [http://www.dec.ny.gov/docs/materials\\_minerals\\_pdf/findingstatehvhf62015.pdf](http://www.dec.ny.gov/docs/materials_minerals_pdf/findingstatehvhf62015.pdf); Pennsylvania Dep’t of Environmental Protection, Final Regulations for Oil and Gas Surface Activities, *available at* <http://files.dep.state.pa.us/PublicParticipation/Public%20Participation%20Center/PubPartCenterPortalFiles/Environmental%20Quality%20Board/2016/February%203/Fact%20Sheet%20for%20Final%20Ch%2078%20Regulation.pdf>.

In addition to illustrating the stark difference in regulatory scope exercised by the Commission and the signatory States over oil and natural gas operations, the existence of competing State regulations raises a fundamental question of sovereignty. Reading the Compact to reverse the Commission’s longstanding practice with respect to “projects” and allow the Commission to supplant the signatory States’ oil and

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*Id. Cf. Oklahoma v. New Mexico*, 501 U.S. 221, 234 n.5 (1991) (noting that “a congressionally approved Compact is both a contract and a statute, and we repeatedly have looked to legislative history and other extrinsic material when required to interpret a statute which is ambiguous”).

gas regulations conflicts with “[t]he background notion that a State does not easily cede its sovereignty” that “inform[s] [the] interpretation of interstate compacts.” *Tarrant*, 569 U.S. at 631. The Compact’s definition of “projects” falls well short of the clear statement necessary to strip away a State’s sovereign authority within its borders.

2. ***The Compact’s provisions governing pollution control (Article 5) do not authorize the proposed hydraulic fracturing prohibition.***

The Commission’s reliance on the Compact’s pollution control provisions, *see* Proposed 18 C.F.R. § 440.1(b) (citing Compact Section 5.2), similarly fails to support the proposed hydraulic fracturing prohibition.

Pursuant to Article 5 of the Compact, the Commission “may undertake investigations and surveys, and acquire, construct, operate and maintain projects and facilities to control potential pollution and abate or dilute existing pollution . . . .” Compact, Section 5.1. This authority mirrors—and, indeed, includes—the Commission’s authority over “projects” that is textually and contextually restricted to Commission-led water management projects. Indeed, this focus comports with the litigation history that led to the Compact, as the Supreme Court ordered construction and maintenance of “an efficient plant for the

treatment of sewage” prior to any diversion by New York, and set limitations on the concentration of waste in waters returned to the Delaware River. *See New Jersey*, 283 U.S. at 346–47.

The Commission may also “assume jurisdiction to control future pollution and abate existing pollution in the waters of the basin, whenever it determines after investigation and public hearing . . . that the effectuation of the comprehensive plan so requires.” Compact, Section 5.2. But that authority is likewise limited. After the required public hearing, the Commission “may **classify** the waters of the basin and **establish standards of treatment** of sewage, industrial or other waste . . . .” Compact, Section 5.2 (emphases added). To these ends, the Commission can “adopt . . . rules, regulations and standards to control such future pollution and abate existing pollution, and to **require such treatment** of sewage, industrial or other waste . . . .” Compact, Section 5.2 (emphasis added). This language authorizes Commission water management activities aimed at reducing pollutants released into the Delaware River through specified means restricted to—again mirroring the Supreme Court’s predecessor requirements—“standards” and “treatment” of waste. *Compare id. with New Jersey*, 283 U.S. at 346.

The plain language of Article 5 therefore fails to authorize a blanket prohibition on any operation, much less oil and gas operations otherwise distinct from the Compact’s central purposes. *See supra*. Nor may prohibitory language be read into the plain language of the Compact. *See, e.g., Barnhart v. Sigmon Coal Co.*, 534 U.S. 438, 454 (2002) (declining read additional terms into “the unambiguous language of the statute”). This constructive canon is even more pronounced with respect to interpretation of an interstate compact where “federalism and separation-of-powers concerns . . . would arise were [a court] to rewrite an agreement among sovereign States, to which the political branches [of the United States Government] consented.” *EnergySolutions*, 625 F.3d at 1272 (quoting *Alabama v. North Carolina*, 560 U.S. 330, 352 (2010)). The signatory States’ independent regulation of oil and gas operations, including hydraulic fracturing, reinforces this reluctance, and leaves the Commission solely within the means of pollution control detailed in the Compact. Because the prohibition in the proposed regulations is not included, the

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Commission lacks the authority to proceed.<sup>17</sup> Therefore, the proposed prohibition on HVHF should be rejected as exceeding the Commission's authority under the Compact and decisional precedent from the U.S. Supreme Court.

### Conclusion

The oil and natural gas industry is committed to an approach within the Delaware River Basin that promotes safety and environmental performance while securing the tremendous benefits of domestic energy production for our nation. Further, API is a leader in developing the industry technical standards and programs that enhance the safety of operations worldwide. API urges the Commission to consider the scientific data, the available studies, state and federal regulatory frameworks, industry best practices, and the significant technology and engineering advancements in this industry that make safe and responsible oil and natural gas development possible. Upon having considered the above in an unbiased manner, you must conclude that existing controls (both involuntary and voluntary) are more than adequate to protect human health and the environment and that a complete prohibition on HVHF is not only unwarranted, it does not constitute effective policy for the four basin states or the nation.

Sincerely,



Erik Milito  
Group Director  
Upstream and Industry Operations  
American Petroleum Institute

cc: Pamela M. Bush, J.D., M.R.P, Commission Secretary, DRBC

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<sup>17</sup> The recent district court decision in *Wayne Land & Mineral Group, LLC v. Delaware River Basin Commission*, 247 F. Supp. 3d 477 (M.D. Pa. 2017), does not dictate a different outcome. The case—argued on appeal before the Third Circuit on November 20, 2017 and now awaiting decision—considered the Commission's authority to review all plans for "natural gas well pads and related facilities targeting shale formations." *Id.* at 484. Although the district court decided that such gas exploration and development plans constitute "projects" subject to approval under Compact Section 3.8, *see id.* at 502–03, it did not consider the separate question whether the Compact authorizes the Commission permanently to prohibit any oil and natural gas or hydraulic fracturing operations. At any rate, the district court's short discussion of "projects" subject to approval under the Compact is both contrary to the history and language of the Compact, *see supra*, and irrelevant to the Commission's separate allegation of authority under Article 5 of the Compact.

## ATTACHMENT 1

### Water Quality Studies From 2010 to 2017 Concluding that Fracturing is not a Major Threat to Drinking Water

- Vengosh et al., 2017 ([study link](#))
- U.S. Geological Survey (USGS), 2017 ([study link](#))
- Environmental Protection Agency (EPA), 2016 ([study link](#)).
- Wyoming Department of Environmental Quality, 2016 ([study link](#)).
- Townsend-Small et al., 2016 ([study results link](#)).
- Ladage et al., 2016 ([article](#) and study in German ([only](#))).
- Bureau of Economic Geology, University of Texas at Austin, 2016 ([study link](#)).
- Siegel et al., 2016 ([study link](#))
- Jackson et al., 2015 ([study link](#))
- Drollette et al., 2015 ([study link](#))
- Siegel et al., 2015 ([study link](#))
- Birkholzer et al. 2015 ([study link](#))
- California Council on Science and Technology (CCST), 2015 ([study link](#))
- Hammack et al., 2014 ([study link](#))
- Kresse et al., 2013 ([study link](#))
- Flewwelling et al., 2013 ([study link](#))
- Molofsky et al., 2013 ([study link](#))
- U.S. Government Accountability Office, 2012 ([report link](#))
- Cardno Entrix, 2012 ([study link](#))
- Massachusetts Institute of Technology (MIT) Energy Initiative, 2010 ([study link](#))

## ATTACHMENT 2

### *Critique of New York State Department of Public Health HVHF Health Review*

**Citation:** Zucker, H. A. (2014). A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development. *New York State Department of Health*.

**Background:** On December 14, 2014, based on the recommendation of the New York State Acting Commissioner of Health, Dr. Howard Zucker, the New York State Department of Environmental Conservation (DEC) recommended that High Volume Hydraulic Fracturing (HVHF) for oil and natural gas be prohibited in New York State. HVHF, as defined by the state, is a technique used by the oil and natural gas industry to extract resources from shale formations. The decision was the culmination of a regulatory process that lasted six years. The recommendation from Dr. Zucker was based on a public health review conducted by the State's Department of Health (NYSDOH). The review titled "*A Public Health Review of High Volume Hydraulic Fracturing for Shale Gas Development*" (PHR) consisted of a literature review, recommendations from experts, site visits, summaries of discussions that the NYSDOH engaged in with other environmental and health officials from States experiencing oil and natural gas development, and communications with a variety of stakeholders (Zucker, 2014). This critique reviews the methodology used to assess the public health related aspects of New York State (NYS) DEC's decision by assessing the review for key characteristics of evidence-based decision-making. The evidence-based decision-making process in the public health field includes a) the evidence gathering phase (the use of the best-available science, the use of contextual information, use of experts and knowledgeable stakeholders, and the assurance of the replicability, verifiability, and credibility of the evidence); b) evidence interpretation (looking at the strength of the evidence, stakeholder input and the ability to utilize the evidence within the relevant context; and c) the application of the findings.

Incorporating evidence-based strategies to improve public health analyses has both direct and indirect benefits which include the increased likelihood of successful programs and policies (Brownson et al., 2009). However, the challenging portion of evidence-based public health (EBPH) is determining when evidence is sufficient for action (Brownson et al., 1999).

**Summary of NYSDOH's Review Process:** To satisfy the requirements of NYS State Environmental Quality Review Act (SEQRA), DEC prepared a Supplemental Generic Environmental Impact Statement (SGEIS) that was to be used in conjunction with DEC's existing Generic Environmental Impact Statement (GEIS) to regulate the development of oil and natural gas in the State. However, during the process of public input into the SGEIS in 2009, and the revised SGEIS in 2011, the DEC received over 260,000 comments which included recommendations for the Agency to broaden the scope of the SGEIS to include a broad look at potential public health impacts that could be associated with HVHF. In response, the DEC Commissioner, in the fall of 2012, asked the NYS Commissioner of Health to assess if the regulations and mitigation efforts proposed in the SGEIS could adequately protect public health. After two years of contemplation, the NYSDOH released its public health review of HVHF for shale development (Zucker, 2014). While, the PHR was initially developed to assess the SGEIS in terms of its ability to mitigate potential negative public health outcomes, it was subsequently broadened to 1) evaluate the body of literature related to the potential health effects associated with oil and natural gas production; 2) include input from environmental and health officials from other States where oil and natural gas activities were taking place; and, 3) include input from a broad range of stakeholders including academicians, and local, state, and federal officials as well as international stakeholders.

**Study Conclusions:** Utilizing a precautionary approach, the PHR concluded that there was enough evidence to suggest that HVHF would put public health at risk and therefore recommended that New York not proceed with HVHF.

## **CRITIQUE OF THE PUBLIC HEALTH REVIEW REPORT**

According to the Institute of Medicine (IOM), decision-making in the public health field is driven by “*crises, hot issues and concerns of organized interest groups*” and that the tension between professional expertise and the political process can contribute to policy decisions being made without a comprehensive analysis of the scientific facts (Institute of Medicine, 1988). IOM recommended that public health officials charged with policy development should promote the use of the evidence-based scientific knowledge in the decision-making process as well utilizing a strategic approach based on the appreciation of the democratic political process. This implies that ethical considerations related to public health from all stakeholder perspectives involved in the decision process should be taken into consideration.

### **Gathering evidence**

***Seek out best available science:*** The NYSDOH in the PHR expressed the importance of “*an objective evaluation of the emerging scientific information on environmental impacts and public health effects of HVHF activity*” to the public health review process (Zucker, 2014). The Agency selected and reviewed studies that reported relationships between HVHF and public health outcomes, as well as other literature that was deemed relevant by the State. Brownson et al. (1999) describe the process of using evidence in public health decision-making as a process that works through principles of scientific reasoning which includes the use of systematic reviews of data. The systematic review process can be utilized in various disciplines such as epidemiology, biostatistics, health economics and behavioral sciences that when combined may provide input to create a narrative (if the assessment is qualitative), that can answer the questions being asked. Evidence should be searched systematically to ensure that all conclusive evidence on a topic is captured and that the effort is reproducible (Cochrane reviews). This is done by first pre-selecting literature search terms and criteria for the studies that the researcher wants to include

or exclude; second, identifying relevant studies; and then assessing study quality (Shea et al., 2007). NYSDOH, in their review did not provide information on how they selected their studies, or how they accessed the quality of the studies that were included in their review. While the PHR qualitatively described study quality, it did not provide uniform criteria on which the studies were judged. This would have been useful in strengthening the conclusion (Harbour et al., 2001).

***Contextual information:*** NYSDOH was able to develop answerable questions from a broad range of information that identified specific areas of concern (from both a science-based approach and democratic process approach). Identifying answerable questions is the first key step in the development of an evidence-based public health approach to policy decision-making process (Brownson, 1999). However, answering the questions may have been complicated because of varied inputs of evidence (interpreting studies, incorporating information collected in interviews, etc.) (Jacobs et al., 2012).

***Use of experts and knowledgeable stakeholders:***

**Meeting with Other State Agencies:** The NYSDOH Commissioner met with officials from California Department of Public Health (CDPH), California Department of Conservation (CDOC), Texas Department of State Health Services, Texas Railroad Commission (TRC), Texas Commission of Environmental Quality (TCEQ), Illinois Department of Public Health (IDPH), and the Illinois Department of Natural Resources (IDNR). Based on the meeting summaries, NYSDOH was interested in: the State's oil and natural gas activity history, the availability of regulations targeting HVHF, specifically the provisions regarding the management of *frac* chemicals and flowback fluids, whether the State had monitoring programs (for example, drinking water quality monitoring, air quality monitoring, health surveillance, and environmental contamination events monitoring), and if the state had any reported incidents of negative public health effects.

**Public Health Expert Consultation:** The state retained three consultants to respond to three charge questions:



- *Are there additional potential public health impacts of HVHF gas development that should be considered beyond those already discussed in the SGEIS?*
- *Are additional mitigation measures beyond those identified in the SGEIS needed to address the potential health impacts of HVHF? If so, what additional prevention or mitigation measures are recommended?*
- *Are existing and proposed environmental and health monitoring and surveillance systems adequate to establish baseline health indicators and to measure potential health impacts? If not, what additional monitoring is recommended?*

The experts provided comprehensive responses. The consultants identified common themes of concerns that included air quality impacts, truck traffic impacts, noise, wastewater management challenges, social disruption, stress, and indirect public health impacts related to the degradation of the environment (potential loss of wetlands, impacts to the food chain, and impact to recreational opportunities).

However, the NYSDOH was not transparent on how they selected the states that they visited nor did the State Agency justify why certain States were selected over others.

***Assurance of the replicability, verifiability, and credibility of the evidence:*** A systematic literature review framework was not used. This framework would have ensured that the literature search was objective, replicable, verifiable and credible capturing all available literature (Shea et al., 2007).

## **Evidence interpretation**

***The conclusions were not based on a weight of evidence (WOE) approach:*** While the phrase “weight of evidence” may have different connotations; in this critique, it refers to a process where “all” relevant evidence is reviewed and weighed, albeit qualitatively in the form of a narrative (Weed, 2005). The weight of evidence narrative includes a systematic review of the literature, as well as thorough interpretation of evidence (which may include the use of causal criteria like Hill’s list). Criteria on how conclusions and recommendations are made are also included in the WOE approach. While the PHR qualitatively summarizes findings and determines a public health action, the PHR does not offer a systematic process on how evidence was identified, rated, weighed or assessed.

***Lack of transparency:*** Transparency may help in establishing credibility. Agencies create new regulations that are intended to deliver benefit at a minimum cost to society- this includes public health benefits (Kilmartin & Mendelson, 2008). As some rules may have significant impacts (economic loss related to loss of jobs and income in the form of taxes paid by the industry or averted public health impacts as concluded by the PHR), it is important that transparency and public participation occur to enhance the quality of regulation as well as its legitimacy. This issue is addressed by the Task Force on Transparency and Public Participation that was convened by the Office of Management and Budget Watch. Among the Task Force's recommendation is:

- *Adopting best practices for establishing rulemaking dockets when agencies begin working on new rules and promptly including in these dockets all relevant background information (Kilmartin & Mendelson, 2008).*

This supports the IOM's view on the need for the use of best practices. The PHR process however, did not apply best practices as discussed above or did the Agency provide information on how the public health review was to be conducted.

***Threats to validity:*** The PHR did not address the limitations associated with the threats to validity. Regarding external validity, the studies reviewed may not have applied to New York. For example, it is anticipated that New York's Shale formations contain primarily dry gas. This resource-specific information was not considered by NYSDOH when selecting, reviewing, and incorporating key findings in its own PHR.

## **Application of findings**

***Precautionary principle versus acceptable risk framework:*** Ultimately the decision to prohibit shale oil and natural gas development in NYS rested on the NYS Department of Health Commissioner's adoption of the Precautionary Principle approach. This approach asserts that without sufficient information, an

outcome of harm is assumed. While on the surface this precautionary approach appears to be protective, there are leading scientists that argue that invoking the principle in this manner without any avenue for recourse is not sound public policy (Sunstein, 2005). The precautionary principle may be used in cases where no there are no benefits associated with the risk being presented. However, there are clear benefits associated with developing oil and natural gas. Instead, the use of the precautionary principle acts as a barrier and limits technological advancement; it also limits the assessment of other options and realizations.

In conclusion, the PHR, despite its limitations, laid the groundwork for other States looking for methodologies to use to assess the potential health effects related to HVHF. By acknowledging the flaws in the PHR approach, as discussed in this critique, it may be possible to develop a more thoughtful review process that is evidence-based, transparent and reproducible – all earmarks of a science-based decision-making process.

## References

- Brownson, R. C., Gurney, J. G., & Land, G. H. (1999). Evidence-based decision making in public health. *Journal of Public Health Management and Practice*, 5(5), 86-97.
- Brownson, R. C., Fielding, J. E., & Maylahn, C. M. (2009). Evidence-based public health: a fundamental concept for public health practice. *Annual review of public health*, 30, 175-201.
- Cochrane reviews. <http://www.cochrane.org/cochrane-reviews>
- Harbour, R., & Miller, J. (2001). A new system for grading recommendations in evidence-based guidelines. *BMJ: British Medical Journal*, 323(7308), 334.
- Institute of Medicine (US). Committee for the Study of the Future of Public Health. (1988). *The future of public health* (Vol. 88, No. 2). National Academy Press.
- Jacobs, J. A. (2012). Tools for implementing an evidence-based approach in public health practice. *Preventing chronic disease*, 9.
- Kilmartin, H., & Mendelson, E. (2008). Transparency and Public Participation in the Rulemaking Process.
- Shea, B. J., Grimshaw, J. M., Wells, G. A., Boers, M., Andersson, N., Hamel, C., ... & Bouter, L. M. (2007). Development of AMSTAR: a measurement tool to assess the methodological quality of systematic reviews. *BMC medical research methodology*, 7(1), 10.
- Sunstein, C. R. (2005). The precautionary principle as a basis for decision making. *The Economists' Voice*, 2(2).
- Tirilis, D., Husson, H., DeCorby, K., & Dobbins, M. (2011). Missing and accounted for: gaps and areas of wealth in the public health review literature. *BMC public health*, 11(1), 757.
- Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management*, 14(3), 207-222.
- Victora, C. G., Habicht, J. P., & Bryce, J. (2004). Evidence-based public health: moving beyond randomized trials. *American journal of public health*, 94(3), 400-405.
- Weed, D. L. (2005). Weight of evidence: a review of concept and methods. *Risk Analysis*, 25(6), 1545-1557.
- Zucker, H. A. (2014). A public health review of high volume hydraulic fracturing for shale gas development. *New York State Department of Health*.

**Response to Key Technical Issues  
Requested by the  
Delaware River Basin Commission  
on its  
Proposed New 18 CFR Part 440 Review**

**Hydraulic Fracturing in Shale and Other Formations:  
SUBCHAPTER B – SPECIAL REGULATIONS**

Prepared at the request of the  
**American Petroleum Institute**

Analysis By:  
ALL Consulting, LLC.

March 2018

**DISCLAIMER**

This report is an independent analysis by ALL Consulting. The analysis and observations contained herein are solely those of ALL Consulting and do not necessarily reflect the opinions of the American Petroleum Institute, or any other oil or natural gas entity or industry company.

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## Abbreviations and Acronyms

%R <sub>0</sub>	vitrinite reflectance	mg/L	milligrams per liter
ABR	Approval-by-Rule	Mgal/d	million gallons per day
ALL	ALL Consulting	Mgals	million gallons
APE	anticipated production extent	MVR	Mechanical Vapor Recompression
API	American Petroleum Institute		
bbl	barrel	NFR	nano-particle friction reducer
Bcf	billion cubic feet	NGDP	Natural Gas Development Plan
Bcf/d	billion cubic feet per day	NGL	natural gas liquids
Bgals	billion gallons	PA DEP	Pennsylvania Department of Environmental Protection
BLM	Bureau of Land Management		
BMP	best management practice	ppm	parts per million
CWT	centralized waste treatment	psi	pounds per square inch
DAF	dissolved air filtration	PWSA	Public Water Supply Agencies
DRB	Delaware River Basin	RFDS	Reasonable Foreseeable Development Scenario
DRBC	Delaware River Basin Commission	RO	Reverse Osmosis
ED	Electrodialysis	ROW	right-of-way
EDR	Electrodialysis Reversal	SAB	Science Advisory Board
EIA	U.S. Energy Information Administration	SPCC	Spill prevention control and countermeasure
EOR	Enhanced Oil Recovery	SPW	Special Protection Waters
EPA	U.S. Environmental Protection Agency	SRB	Susquehanna River Basin
		SRBC	Susquehanna River Basin Commission
EV	Exceptional Value		
gal	gallon	Tcf	trillion cubic feet
gals/d	gallons per day	TDS	total dissolved solids
GIS	geographical information system	TOC	total organic carbon
GOR	gas-to-oil ratio	TS	total solids
HQ	High Quality	TVR	Thermal Vapor Recompression
HVHF	high volume hydraulic fracturing	USGS	U.S. Geological Survey
KCl	potassium chloride	UV	ultraviolet
LSM	low slump mortar	VOC	volatile organic compound
Mcf	thousand cubic feet	WWF	Warm Water Fisheries

## Executive Summary

The Delaware River Basin Commission (DRBC) published proposed rules on November 30, 2017, which would prohibit high volume hydraulic fracturing (HVHF<sup>\*</sup>) within the Delaware River Basin (DRB). These rules would also strengthen DRBC policies to discourage importation of wastewater and exportation of water, and include rules regarding the inter-basin transfer of water and wastewater related to hydraulic fracturing. The draft rules also include requirements for safeguarding that the treatment and disposal of produced water from hydraulic fracturing does not impair or conflict with the preservation of the waters of the basin for uses in accordance with the DRBC Comprehensive Plan.

To investigate the impact of these proposed rules, an understanding of the amount of anticipated development needed to be prepared. An examination of the viable oil and natural gas resources within the DRB as outlined by the U.S. Energy Information Administration (EIA) was conducted. This examination suggested that the anticipated production extent (APE) would be limited to six northeastern Pennsylvania (PA) counties (Carbon, Lackawanna, Luzerne, Monroe, Pike, Wayne) where thermally mature Marcellus and Utica shales underlie approximately 1,787 square miles (1,143,680 acres).

A Geographical Information System (GIS) analysis was conducted on the APE to assess the amount of surface acreage that would be available to development given the previous DRBC Article 7 setback, landscape, and approval-by-rule (ABR) restrictions, issued in 2010. This analysis indicated that only ~897 square miles would be available for development without a variance (approval for well pad placement would be either by docket or ABR with an approved Natural Gas Development Plan (NGDP)). Of these ~897 square miles, ~696 square miles would be subject to forested site constraints, leaving only ~201 square miles for development within the APE.

To estimate the future oil and gas exploration and development activities that might reasonably be expected to occur in the DRB over the next 10 years, an analysis of the PA drilling permits issued and wells drilled between 2013 and 2017 within counties in proximity to the DRB was conducted. The forecast was based on the area's geology and historical and present activity, as well as factors such as economics, technological advances, access to oil and gas areas, transportation, and processing facilities. The analysis estimated a development potential of 40 wells drilled each year for the next ten years or 400 wells over the next decade.

The current hydrologic conditions in the Upper Region of the DRB were evaluated to determine the impact water withdrawals for HVHF might have on the current uses and environment. The DRBC reports that the hydrologic conditions over the past few years have been below-normal for precipitation in the Upper Region and there have been periodic reservoir releases conducted to augment late year streamflow lows and groundwater levels experiencing fluctuations below the 25th percentile. This reduced precipitation coupled with the reported normal withdraws can add stress to the watersheds.

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<sup>\*</sup> The oil & gas industry generally does not use the term “high volume hydraulic fracturing,” preferring to call the process merely “hydraulic fracturing.” However, the DRBC uses this term in its material and therefore we echo that usage in this report in order to maintain consistency and make it clear for the DRBC and other reviewers.

Water use within the APE was calculated using data provided by the U.S. Geological Survey (USGS) for the portion of the counties with underlying shale. This data indicated that a total of 54.68 million gallons per day (Mgal/d) or 19.97 billion gallons annually are currently being withdrawn from the APE within the six counties by various sectors. The DRBC, on the other hand, reports that the Upper Region withdraws about 1.5 Mgal/d for consumptive use and that that amount represents an estimated 1.0% of the withdrawals for the region. Based on the DRBC data, the daily withdrawal in the Upper Region would be approximately 150 Mgal/d.

The average quantity of water being used in HVHF treatments was examined using FracFocus disclosures (2013-2017) from Marcellus and Utica wells drilled in PA. The 5-year average volume for all disclosures over this period is 11,172,772 gallons (gals), for Marcellus-only disclosures 11,132,875 gals, and for Utica-only disclosures 13,145,825 gals. The increase in base fluid volume from the 3.5 Mgals per fractured well used in the 2011 report is likely a result of longer lateral wellbore lengths, greater depths drilled, optimization of multistage fractures, and new fracture methods being employed. Using the 5-year average volume and the estimated development rate of 40 wells per year indicates that a total of ~447 Mgals (1.22 Mgal/d) would be withdrawn for natural gas development within the APE annually. The 1.22 Mgal/d represents 2.23% of the estimated USGS daily withdrawal for the APE and only 0.81% of the DRBC reported withdrawals for the Upper Region.

Protecting water within the APE may involve the application of several best management practices (BMPs) suited to site-specific conditions as the entire area is designated as Special Protection Waters (SPWs). With this in mind, this report addresses the advances in spill protection, containment, and countermeasures to prevent surface and ground water adulteration from accidental hydrocarbon and chemical spills during all stages of the hydraulic fracturing water cycle. To support this discussion, a review of the EPA Draft and Final reports which investigated the impacts from the hydraulic fracturing water cycle on drinking water resources in the United States is included, as well as an analysis of the environmental compliance violations in Susquehanna County, PA. The analysis reviewed 5-years of data (2013-2017) from this adjacent county undergoing prolific development as an indicator of potential development incidents for the APE. There are ~1,431 unconventional wells operating in Susquehanna County of which 781 have been drilled and hydraulically fractured from 2013-2017. The data revealed 82 incidents related to potential surface- or ground-water impacts: 76 spills, 2 leaks, 2 lack of erosion control, and 2 well integrity issues with migrating gas. Of these 82 incidents involving the release of materials, only six were cited for a 401 violation indicating that the discharged substance resulted in impacts to the Waters of the Commonwealth. These six events account for 0.42% of the total operating unconventional wells, 0.77% of the drilled wells in 2013-2017, and 8.45% of the locations with incidents. Applying these percentages to the projected development rate for the DRB indicates that 3.63 (9.09% of 40 wells) release events might occur per year and there is less than a 0.5% chance that one of those events would result in impacts to the Waters of the Commonwealth.

To quantify the potential surface disturbances from projected HVHF development on the available unrestricted surface of the APE area (201 sq. miles), the likely placement of well pads and the number of wells on each pad was considered. The development scenario suggests wells would be drilled at a rate of ~5 wells per year per county with the exception of Wayne County where ~15 wells per year are estimated. It was also expected that operators would take a cautious approach to

development in this thermally mature region and develop multi-well pads with at least five wells per pad initially. Using this approach it was determined that from slightly less than 40 to a maximum of 80 well pads would be developed over the 10-year period depending on the number of wells per pad. The landscape or surface disturbances associated with these pads was calculated to be 1,200 acres for the 5-well per pad scenario and 600 acres for the 10-wells per pad scenario over the whole 10 years or about 120 to 60 acres per year. Factoring in restoration activities and mitigation measures reduced the residual altered acreage for the two scenarios to 400 acres and 200 acres respectively.

An economic analysis based on the estimated development rate (40 well/year) was conducted to identify future significant energy and economic benefits. Based on 2017 data, each well drilled in the APE is estimated to produce a total of 14.3 Bcf of natural gas over the first ten years of production. Using a range of plausible wellhead gas prices, that 14.3 Bcf would be worth from \$27 million to \$57 million. Using our estimate of 40 wells drilled per year, the production from those 40 wells would be valued at between \$1.1 billion and \$2.2 billion over ten years. Royalties collected by landowners annually from those 40 wells would be from \$143 million to \$458 million. State income taxes on those royalties would range from \$4 million to \$14 million per year. Drilling permit fees collected by the state for 40 wells per year would amount to \$156,000, or \$1.5 million over ten years. Lease bonus payments are difficult to estimate because they require a variety of assumptions, but they could conservatively range from \$6 million to \$64 million on land that is not restricted from development.

Finally, a review of existing water treatment technologies was conducted to capture the current technology and consider what might be available for use in the DRB. The review determined that a multitude of technologies exist that are designed to remove a variety of constituents from produced water, and that can treat a wide range of produced water quality. The product of these treatment technologies can range from clean water that meets drinking water standards to brines that can be recycled for various uses, including for fracturing additional wells, to solids that can be disposed of or recycled easily. Recycling the flowback\* and produced water has a number of benefits, including offsetting new source water demand for scarce fresh water resources, preserving that water for other uses, and reducing the volume of waste that must be disposed. Wastes from these treatment technologies are relatively low volume and can be disposed of safely. Flowback and produced water can also be recycled for agricultural and industrial uses, replacing volumes of fresh water that would otherwise be used in those sectors. In areas where any discharge of produced or treated water is a major concern, options that result in zero discharge of water, such as evaporation ponds and crystallization, can allow hydraulic fracturing to take place while addressing those concerns.

In conclusion, the development of hydrocarbon resources in the APE of the DRB would be limited to a six county area in the Upper Region where thermally mature Marcellus and Utica shales would most likely produce dry gas; there are an estimate 201 square miles or 128,640 acres available for development under the old Article 7 rules without restriction; the reasonably expected development rate would be approximately 40 wells per year; current hydrologic conditions in the

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\* The oil & gas industry generally does not use the term “flowback water” to refer to fluids generated from a well. Rather the term “flowback” is used to refer to a process and all fluids generated from a well are recognized as “produced water.” However, the DRBC uses this term in its materials and therefore we echo that usage in this report in order to maintain consistency and make it clear for the DRBC and other reviewers.

Upper Region of the DRB have been strained due to reduced annual precipitation over the past few years; the water withdrawn for HVHF in the APE is estimated at ~447 Mgals annually or 1.22 Mgal/d representing only 2.23% of the current estimated USGS daily withdrawal for the APE or only 0.81% of the DRBC reported withdrawals for the Upper Region; the compliance violations in Susquehanna County over the past 5-years indicate that 3.63 release events might occur per year in the APE and there is less than a 0.5% chance that one of those events would potentially reach the Waters of the Commonwealth; the landscape disturbances associated with pad development would range from 400 to 200 acres (0.625-0.3125 sq. miles) over the 10-year development period following restoration activities; state and private revenues generated by the development of natural gas would be significant with estimates ranging from \$148 million to \$475 million annually; and water treatment technologies are available that would reduce withdrawals, recycle produced water, and eliminate discharges.

The analysis presented in this report demonstrates that the potential risks to the environment posed by unconventional gas development are controllable and negligible and are offset by considerable potential benefits, and that a prohibition of HVHF in the DRB is not justified. The reasonable rate of development estimated, the focus on dry gas, the anticipated small surface footprint, the comparatively minor amount of water that would be withdrawn, the advances in pad containment and spill management that industry has made, and the projected economic benefits of unconventional gas development, all lead to this logical conclusion. Furthermore, given the exceptionally low number of violations in nearby Susquehanna County over a period that saw nearly four times as much drilling activity as is anticipated for the APE, as well as the water treatment technologies available for recycling and zero discharge that are protective of the environment, the DRBC should reconsider its proposed regulations regarding oil and gas development in order to better balance the risks and benefits of such development in accordance with the DRBC Comprehensive Plan.

# 1 Introduction

The Delaware River Basin Commission (DRBC) published proposed rules on November 30, 2017, which would prohibit high volume hydraulic fracturing (HVHF\*) within the Delaware River Basin (DRB). These rules would also modify DRBC policies to discourage importation of wastewater and exportation of<sup>1</sup> water, and include rules regarding the inter-basin transfer of water and wastewater related to hydraulic fracturing. The draft rules also include requirements for treatment and disposal of produced water from hydraulic fracturing, which does not impair or conflict with the preservation of the waters of the basin for uses in accordance with the DRBC Comprehensive Plan.

This report contains the results of the analysis of the risks and benefits related to DRBC’s proposed rule, as well as an updated analysis of potential environmental impacts and regulatory restrictions on oil and natural gas development within the portion of the DRBC that is within the State of Pennsylvania. The portions of the DRBC that contain hydrocarbon-bearing deposits in New York State are not addressed due to the hydraulic fracturing moratorium issued by New York State. The report addresses the following four major topic areas:

- **Proposed Rules Effects on Water and Land Use:** The proposed rules as issued November 30, 2017, prohibit HVHF in hydrocarbon-bearing formations; require DRBC approval to transfer water outside the DRB for use in hydraulic fracturing or to transfer produced water or centralized waste treatment (CWT) wastewater into the basin; and set policy that there be no measurable change in existing water quality. In light of the proposed prohibitions and policies, the previous impact and restriction analyses ALL Consulting prepared (April 2011) were updated to compare new reasonably foreseeable development levels with the previous (Article 7) DRBC setback and siting restriction guidelines versus no development at all. The new reasonably foreseeable development levels are based on updated thermal maturation data for the Marcellus and Utica shales within the DRB as well as the advanced drilling and fracturing techniques currently being employed in Pennsylvania.
- **Economic Analysis:** This analysis is based on the revised rate of development, the annual number of exploration, development and operational jobs and wages as well as the projected gas production and income projected for lease and royalty payments, which would be anticipated for that exploration and production within the DRB. The revenue from fees paid by the oil and gas industry have also been identified, based on the projected development within the DRB. Additionally, the substantial indirect financial impact the oil and gas industry has on other industries from the quantity of goods and services purchased from these firms is discussed.
- **Landscape Alterations:** Oil and gas development coupled with hydraulic fracturing has raised concerns that the activity and resulting disturbances would alter landscapes and pose unacceptable risks to high value water resources by impacting the drainage areas of Special

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\* The industry generally does not use the term “high volume hydraulic fracturing,” preferring to call the process merely “hydraulic fracturing.” However, the DRBC uses this term in its material and therefore we echo that usage in this report in order to maintain consistency and make it clear to the DRBC and other reviewers.



Protection Waters (SPW). These concerns are sometimes put forth prior to rigorous scientific evaluation of cause-and-effect relationships or the consideration of best management practices, technological improvements, and required mitigation measures being enforced. Advances in horizontal drilling and hydraulic fracturing have been identified and correlated so the average anticipated environmental disturbances could be evaluated in light of the projected development rate for affected counties within DRB and SPW.

- **Produced Water Treatment Technologies:** Produced water handling methodology depends on the composition of produced (influent) water, location, quantity and the availability of resources. This analysis reviewed current produced water technologies, including those that would be applicable for use in the eastern United States. In addition, the analysis took into account the technologies advantages and disadvantages, including their applicability for different kinds of produced water, achievement of targeted output criteria, the quantity and toxicity of the waste stream, and infrastructure considerations. No-discharge technologies were also reviewed as preventing or eliminating discharges to the basin's waters would satisfy the DRBC's goals to conserve, protect, maintain and improve the quality of the basin's waters. Recycling and the use of treated water in applications outside of the oil and gas industry is also discussed.

## 2 Proposed Rules Effects on Water and Land Use

The DRBC proposes to amend their *Special Regulations* by adding a section on hydraulic fracturing that would prohibit HVHF in hydrocarbon-bearing formations. The DRBC indicated that the prohibition is necessary “to effectuate the Comprehensive Plan for the immediate and long term development and use of the water resources of the Basin, and to conserve, preserve and protect the quality and quantity of the Basin’s water resources for uses in accordance with the Comprehensive Plan.”<sup>2</sup> Over the past half-century the DRBC has managed the DRB water resources through the Comprehensive Plan by issuing policies and regulations that established in-stream water quality standards throughout the Basin, prohibiting degradation of groundwater, and providing special protection to the non-tidal segment of the Delaware River to preserve its high water quality and water supply values. The DRBC took these measures to meet public and private needs for drinking water, recreation, power generation, and industrial activities. Therefore, to understand if HVHF poses a threat to these established needs and activities it is necessary to gauge the level of development that is being prohibited and the resulting water and land use that might occur if oil and gas development were to proceed. This being the case, the following analysis estimates the reasonable foreseeable development level and rate of development for the Marcellus and Utica shale within the DRB, as well as the water and land use needs of the projected development. These levels, rates, and quantities have been compared to existing water and land use for the domestic and industrial activities within the same area overlying the Marcellus and Utica shales in the DRB.

It should be noted that the State of Pennsylvania, in addition to many other states, has regulations that control the responsible development of shale gas resources, including those that would be developed within the DRB. It is generally recognized that the costs and risks as well as benefits of

HVHF primarily fall on a state, and the states with a history of oil and gas regulatory experience are better equipped to regulate HVHF. Many of the states, including PA, have adopted regulatory systems that fit current conditions and have a track record to prove it.<sup>3</sup> The Commonwealth of PA via their PA DEP has successfully managed Marcellus and Utica shale development in the Ohio River Basin (ORB), Susquehanna River Basin (SRB) and can do so in the DRB. Additionally, the PA DEP has multiple layers of permitting, inspection and enforcement plus industry has multiple layers of Best Management Practices (BMP). Given the rapid and increasing development of shale gas over the past decade PA has done an admirable job balancing the environmental and public safety issues with its responsibility to allow development of its shale hydrocarbon resource.<sup>4</sup>

## 2.1 Land

### 2.1.1 Potential Development Area

Since the previous analysis (April 2011) and associated reasonable foreseeable development rates were estimated, much has been discovered about the Marcellus and Utica shales within the DRB. The U.S. Energy Information Administration (EIA) has added and updated geologic information and maps of the Marcellus and Utica shale plays.<sup>5,6</sup> The categorization and appraising of the geologic features by the EIA since 2011 for the Marcellus and Utica shales include delineated thicknesses (isopach), contoured elevations of the formation tops (structure), paleogeography alignments, and tectonic structures (regional faults and folds, etc.), as well as play boundaries, well location, and initial wellhead yields, oil-to-gas and gas-to-oil ratios (GOR), of Marcellus and Utica wells producing from January 2000 and January 2004 through December 2016 respectively.

The play boundaries and high productivity areas are controlled by key geologic criteria that include thermal maturity, total organic carbon (TOC) content, formation thickness, porosity, depth, pressure, and the ability of the formations to be hydraulically fractured. Chief among these geologic criteria is thermal maturity as crude oil and natural gas are produced by heating the organic materials (i.e., kerogen) found in organic-rich rocks, usually shales. When these rocks are exposed to increasing temperatures and pressures over long periods of time, the organic materials in them are transformed by the heat into a waxy substance, i.e., kerogen. As the temperature rises progressively, the kerogen becomes oil, oil becomes wet gas, and wet gas becomes dry gas. The extent that the organic material has been converted can be measured by the thermal maturity.

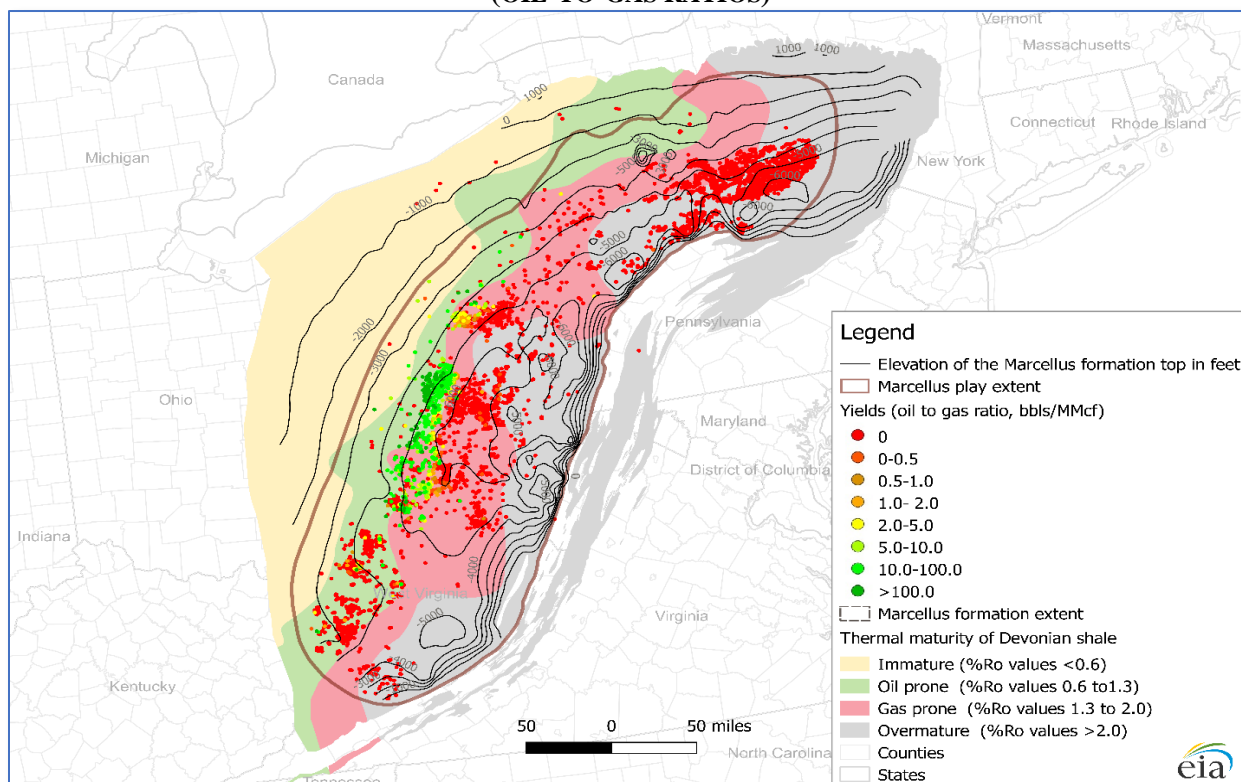
To estimate thermal maturity in shales, core samples are taken and the vitrinite reflectance (%R<sub>0</sub>) is measured. Vitrinite reflectance is a measure of the percentage of light reflected from the vitrinite maceral in a sedimentary rock.<sup>7</sup> Oil and gas zone boundaries are often established using vitrinite reflectance data; however, the boundaries are approximate and can vary according to kerogen type. The temperature arrays favorable to transforming organic material to oil and natural gas are denoted as the oil window and the gas window, respectively. The average %R<sub>0</sub> values for the different hydrocarbon windows in Marcellus and Utica shales are presented in **Exhibit 1**.<sup>8,9</sup>

**EXHIBIT 1: AVERAGE PERCENT VITRINITE REFLECTANCE IN MARCELLUS / UTICA SHALES**

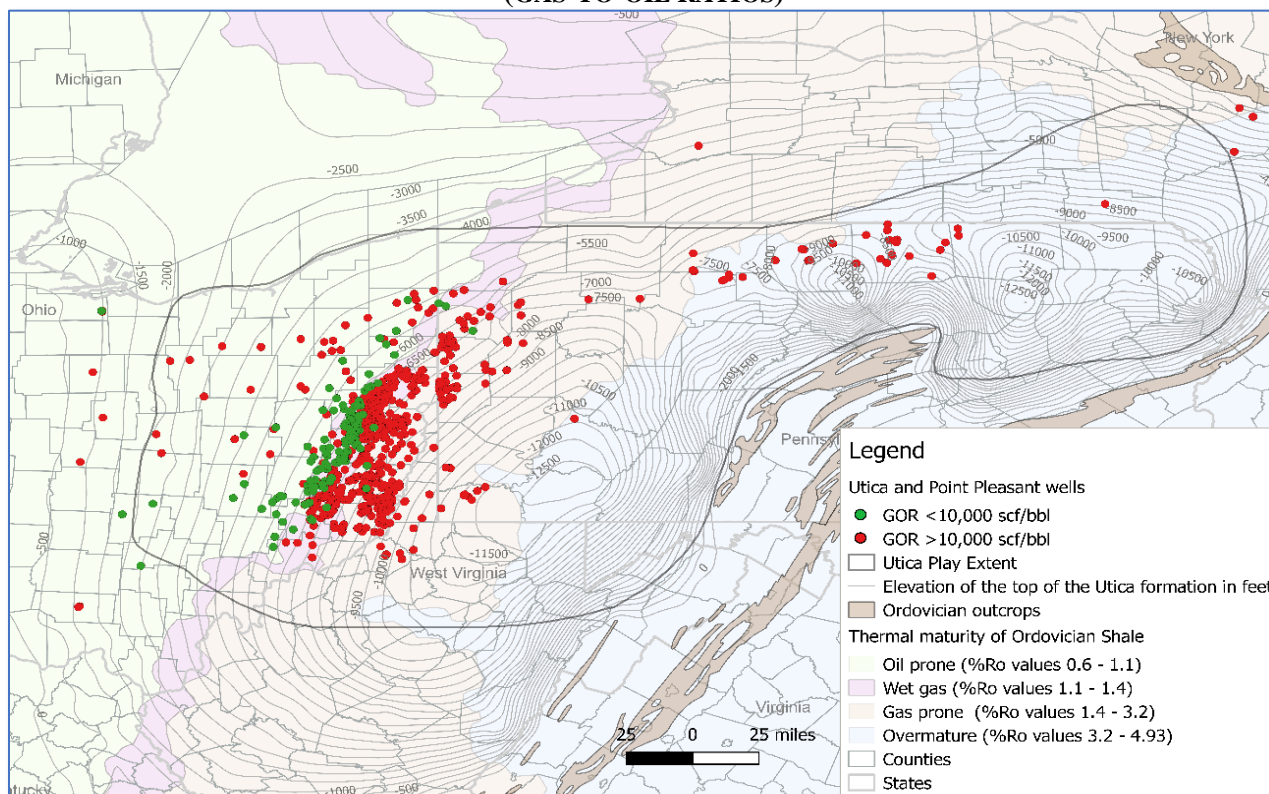
Hydrocarbon Windows	Marcellus	Utica
Immature	%R <sub>0</sub> <0.6	%R <sub>0</sub> <0.6
Oil Prone	%R <sub>0</sub> 0.6 – 1.3	%R <sub>0</sub> 0.6 – 1.1
Wet Gas Prone	%R <sub>0</sub> 1.3 -2.0*	%R <sub>0</sub> 1.1 -1.4
Gas Prone		%R <sub>0</sub> 1.4 – 3.2
Over Mature	%R <sub>0</sub> > 2.0	%R <sub>0</sub> 3.2 – 4.93

In the Marcellus Shale the %R<sub>0</sub> generally increase in a southeastern direction, ranging from 0.5% R<sub>0</sub> to more than 3.5% across the Appalachian basin (see **Exhibit 2**). In the Utica, the play becomes over mature with %R<sub>0</sub> values up to 4.93 as the production trends indicate in the eastern portion of the play (see **Exhibit 3**). Both **Exhibits 2** and **3** also show the distribution of production across the plays in terms of initial yields. Yields represent the ratio of either oil-to-gas (**Exhibit 2**) or GOR (**Exhibit 3**) produced from a well. The distribution of oil and natural gas in a formation is mainly controlled by the thermal maturity of a rock, which is an indication of potential hydrocarbon generation.

**EXHIBIT 2: THERMAL MATURITY OF MARCELLUS SHALE AND INITIAL YIELDS (OIL-TO-GAS RATIOS)**



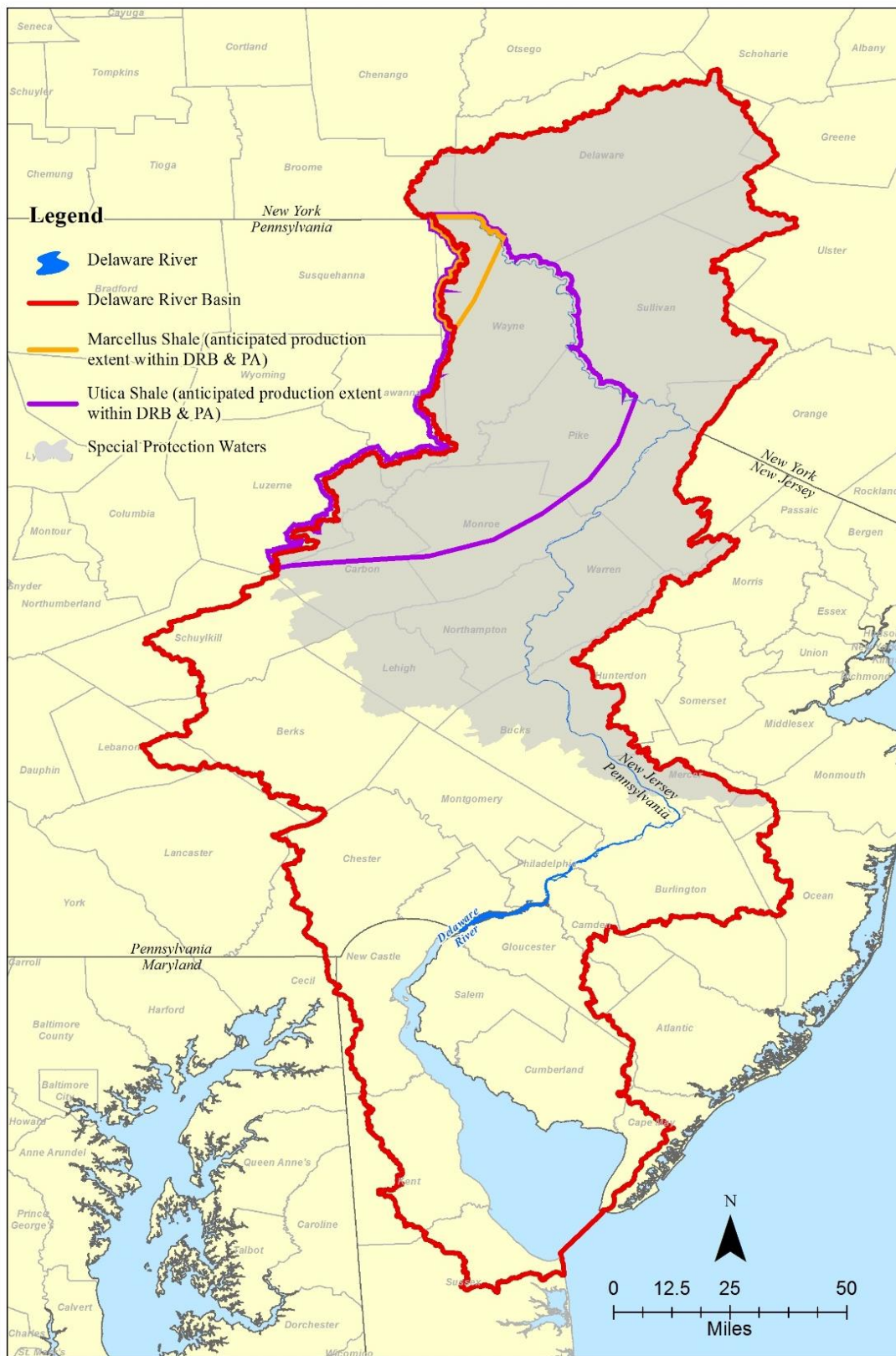
### EXHIBIT 3: THERMAL MATURITY OF THE UTICA SHALE AND INITIAL YIELDS (GAS-TO-OIL RATIOS)



Considering this thermal maturation data coupled with the existing production wells in nearby counties to the DRB, an anticipated production area for the Marcellus and Utica shales within Pennsylvania and within the DRB has been developed. **Exhibit 4** depicts the anticipated production extent (APE) of both the Marcellus and Utica shales.

Based on this information, a geographical information system (GIS) analysis was conducted to identify the amount of land surface overlying the shale plays in each county within the DRB that is in Pennsylvania. This land surface amount represents the available surface area for likely development. The acreage identified in each county that is within the APE totals an estimated 1,113,681 acres or approximately 47.1% of the total acreage in the six counties of interest (Carbon, Lackawanna, Luzerne, Monroe, Pike, Wayne). A summary of the acreage quantities overlying shales in the counties of interest is shown in **Exhibit 5**.

### EXHIBIT 4: ANTICIPATED PRODUCTION EXTENT OF MARCELLUS AND UTICA SHALE WITHIN PENNSYLVANIA



**EXHIBIT 5: PERCENT OF COUNTY WITHIN ANTICIPATED PRODUCTION EXTENT (APE) IN DRB**

County	~Total Acreage	~Acreage overlying Shale in APE of DRB	~Percent of County Overlying Shale in APE of DRB
Carbon	247,968.00	77,429.90	31.23%
Lackawanna	297,427.20	45,144.75	15.18%
Luzerne	580,364.80	83,317.72	14.36%
Monroe	395,116.80	218,137.96	55.21%
Pike	362,502.40	247,905.36	68.39%
Wayne	480,364.80	441,745.04*	91.96%
Total	2,363,744.00	1,113,680.73	47.12%

**2.1.2 Available Surface**

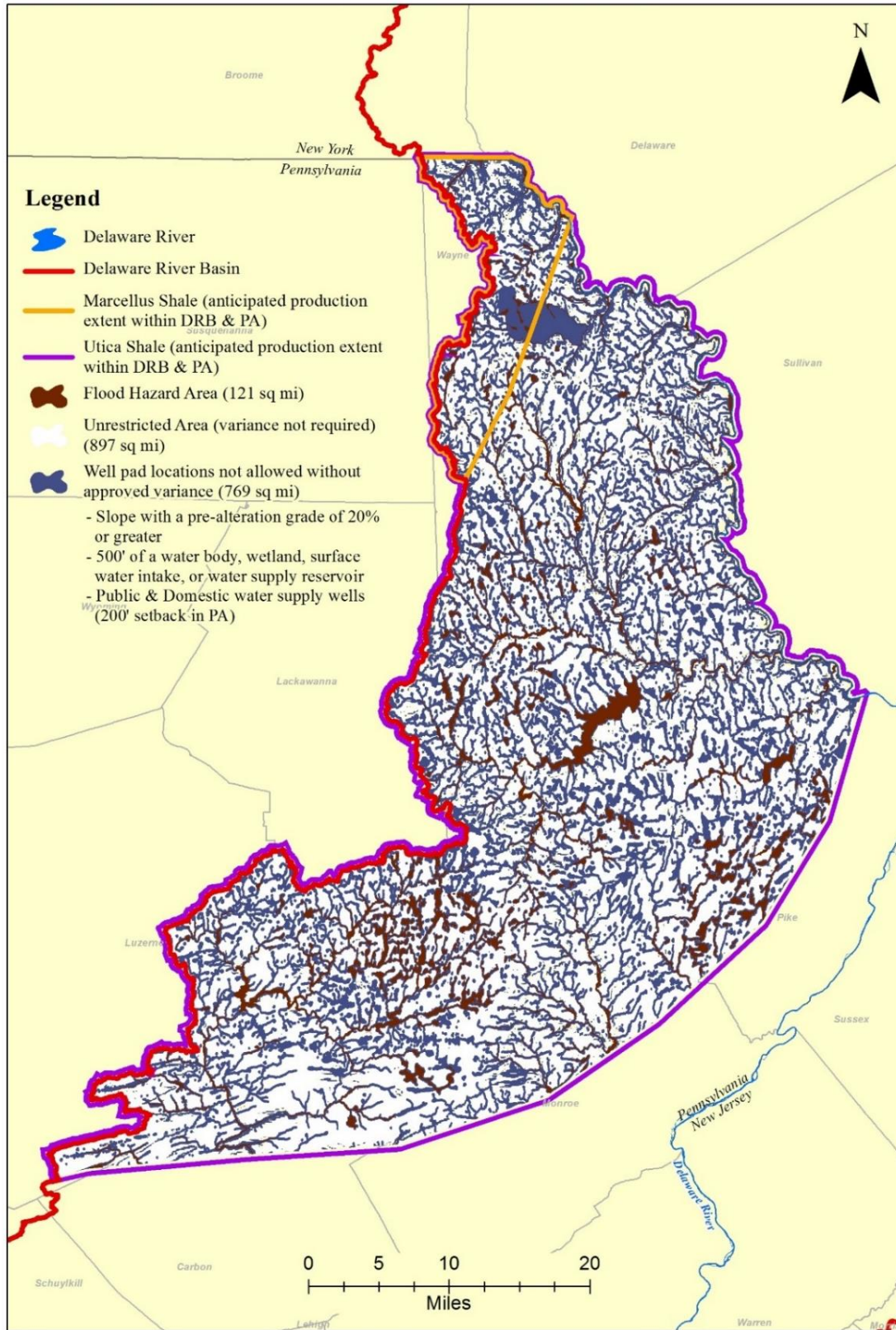
In order to analyze the impact of the proposed prohibition of HVHF, the available surface for shale development infrastructure within the DRB was estimated under the previous proposed (Article 7) regulations as proposed in 2010. These previously proposed regulations were applied to the APE boundary to identify the likely remaining acreage available for development under the latest anticipated development scenario and to demonstrate that the anticipated development could be conducted in a reasonable manner over a restricted area with minimal disturbance. ALL performed a GIS analysis of the APE area within the DRB that overlies the Marcellus and Utica shales. The surface acreage available for well pad placement, access roads, and utility rights-of-way (ROWS) was derived after siting restrictions, setbacks, and approval-by-rule criteria were applied as GIS layers. Note, this analysis should not be construed as an endorsement or agreement with the previously proposed Article 7 regulations, it is merely a case study using previously proposed and publicly commented on restrictions to determine if the anticipated gas development could be conducted with restrictions in place that are protective of the DRB versus the complete prohibition of any development, thus indicating that other options could be considered.

The analysis used representative polygons of the various Article 7 restrictions, setbacks, and Approval-by-Rule (ABR) criteria so that the areas in the APE of the Marcellus and Utica shales within the DRB could be queried and summary acreages for each criterion generated. The results of GIS analysis show that there are approximately 1,787 sq. miles of the DRB that overlay the APE of the Marcellus and Utica shales. Within the APE there are ~121 sq. miles of Flood Hazard Area (100-year flood plain), which would be restricted from development. An additional ~769 sq. miles would be restricted where a variance would be required for well pad placement due to slope or setback requirements. A remaining ~897 sq. miles would be available for well pad placement without a variance (approval for well pad placement would be either by docket or ABR with an approved Natural Gas Development Plan [NGDP]) (See **Exhibit 6**). The provisions of the ABR process without an approved NGDP would restrict ~725 square miles from well pad placement. A total of ~898 sq. miles would be available for well pad placement under the ABR process; however, ~697 sq. miles of that would be subject to forested site constraints, leaving only ~201 sq. miles for well pad placement without restrictions or constraints (see **Exhibit 7**). **Exhibit 8** provides a breakdown of the GIS layer analyses.

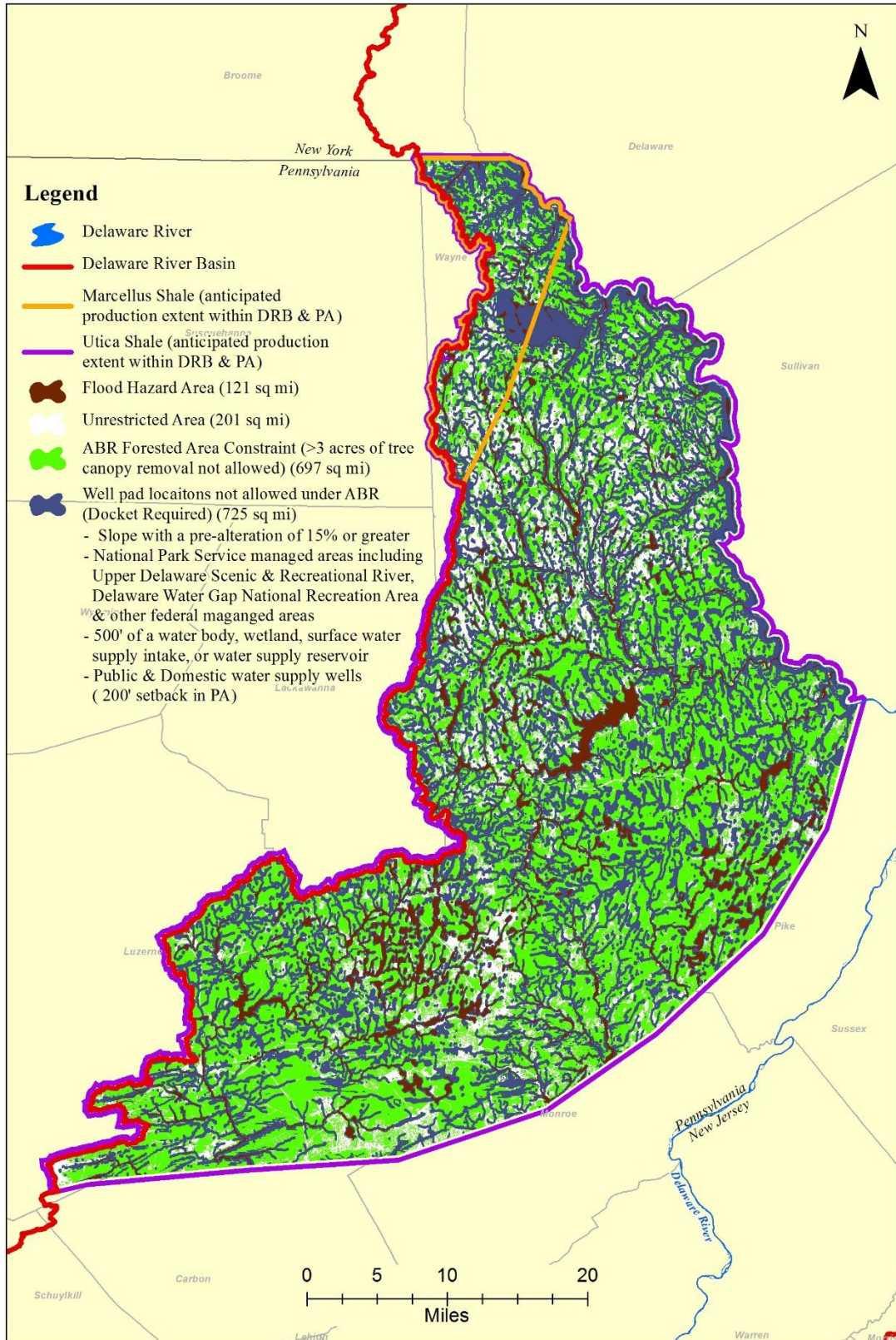
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\* The acreage overlying the shales in Wayne County is made up of approximately 371,707 acres, of which all of it is over the Utica, and an additional 70,038 acres over the Utica and Marcellus.

**EXHIBIT 6: SITING RESTRICTIONS AND SETBACKS – NATURAL GAS DEVELOPMENT PLAN**



**EXHIBIT 7: SITING RESTRICTIONS AND SETBACKS – APPROVAL BY RULE WITHOUT A NGDP**





**EXHIBIT 8: GIS LAYER ANALYSIS FOR ANTICIPATED PRODUCTION  
EXTENT WITHIN THE DRB**

GIS Layer Analysis		In APE of DRB Over Shale	% in APE of DRB Over Shale
Areas (ALL Quantities in Square Miles)			
1	Delaware River Basin Commission Area (13,611 miles <sup>2</sup> )	1,787	100%
2	Special Protection Waters (Entire Area 6,878 miles <sup>2</sup> )	1,787	100%
3	Upper Delaware Scenic and Recreational River (Entire Area 59 miles <sup>2</sup> )	25	1.40%
4	Southeastern Groundwater Protected Area (Entire Area 1,164 miles <sup>2</sup> )	0	0
5	Delaware River Water Gap National Recreation Area (Entire Area 107 miles <sup>2</sup> )	0	0
Restricted Areas			
6	Flood hazard Areas (100-year Floodplains)	121	6.77%
7	Slope Pre-alteration Grade 20% or Greater	95	5.32%
8	T&E Critical Habitat (Data not released by states, identify on project specific basis)	N/A	N/A
Setbacks			
9	DRBC Water Body Setback (500')	700	39.17%
10	DRBC Wetlands Setback (500')	628	35.14%
11	Public and Domestic Water Supply Wells (200') (Number of wells PA -1,280)	3	0.17%
12	Surface Water Supply Intake (500')(Assumed included within 500' setback for streams & waterbodies)	N/A	N/A
13	Occupied Homes (Host State) No Data	No Data	No Data
14	Public Buildings (Host State)	No Data	No Data
Approval by Rule Criteria			
15	Slope Greater than 15%	192	10.74%
16	Forested Areas	697	39.00%
17	Upper Delaware Scenic and Recreational River (UPDE)	25	1.40%
18	Delaware Water Gap National Recreational Area (DEWA)	0	0
19	Surface Area Affected by Restrictions and Setbacks	0	0
Analysis			
20	No well pad locations allowed (Restricted Area - Flood Hazard Areas)	121	6.77%
21	Well Pad Locations Not Allowed Without Approved Variance (Slope >20% and all setbacks)	769	43.03%
22	Well Pad Locations Allowed With Docket Approval (Variance not Required)	725	40.57%
23	Well Pad Locations Allowed Under ABR With Approval But Subject to Forest Site Constraints (>3 acres)	697	39.00%
24	Well Pad Locations Allowed Under ABR With Approval Not Subject to Forest Site Constraints	201	11.25%

Notes: APE - Anticipated Production Extent

**2.1.3 Oil & Gas Development Forecast**

The principal aspects motivating oil and gas exploration and development are supply and demand, energy commodity prices, technological innovations, and environmental impact potential. Deviations in any of these influences such as the recent slight rise in crude oil and natural gas prices<sup>10,11</sup> or the development of new horizontal drilling and hydraulic fracturing technology<sup>12,13</sup> can significantly alter economic parameters and influence decision making.

**2.1.3.1 *Natural Gas Resources in Appalachia***

The EIA estimates considerable development in natural gas and natural gas liquids (NGL) production in Appalachia over the coming decades. Natural gas production from the Marcellus/Utica region increased from 2.0 billion cubic feet per day (Bcf/d) in January 2010 to 24.2 Bcf/d in August 2017; this represents approximately one-third of all U.S. dry natural gas production. Natural gas production in the Appalachian region is projected to continue very steady

growth in the near and long term. Natural gas output is expected to be 8 trillion cubic feet (Tcf) in 2017 and estimated to increase 60% by 2020. Output in 2050 is projected at 18.7 Tcf.<sup>14</sup>

#### 2.1.3.2 Methodology for Estimating Future Oil and Gas Exploration and Development Activity

To estimate the future oil and gas exploration and development activities that can reasonably be expected to occur in the DRB over the next 10 years, an analysis of the Pennsylvania drilling permits issued and wells drilled between 2013 and 2017 by county and proximity to the DRB was conducted. Ten years was chosen as a practical duration for the current analysis. This forecast is based on the area's geology and historical and present activity, as well as factors such as economics, technological advances, access to oil and gas areas, transportation, and processing facilities. Projections of oil and gas activities are based upon present knowledge. Future changes in global oil and gas markets, infrastructure and transportation, or technological advancements may affect future oil and gas exploration and development activities within the state.

Estimated oil and gas activity does not necessarily correlate with geologic potential for the presence of hydrocarbons. Although the geology of an area may suggest the possibility of oil and gas resources, actual exploration and development may be restricted by high exploration costs, low oil and gas prices, or difficulty accessing the area due to lease stipulations or regulations. Thus a small area may have a high resource potential, yet have a low exploration and development potential due to severe restrictions on access. Conversely, technological advancements or an increase in oil and gas prices could result in oil and gas activities in areas regarded as having less or moderate potential for occurrence

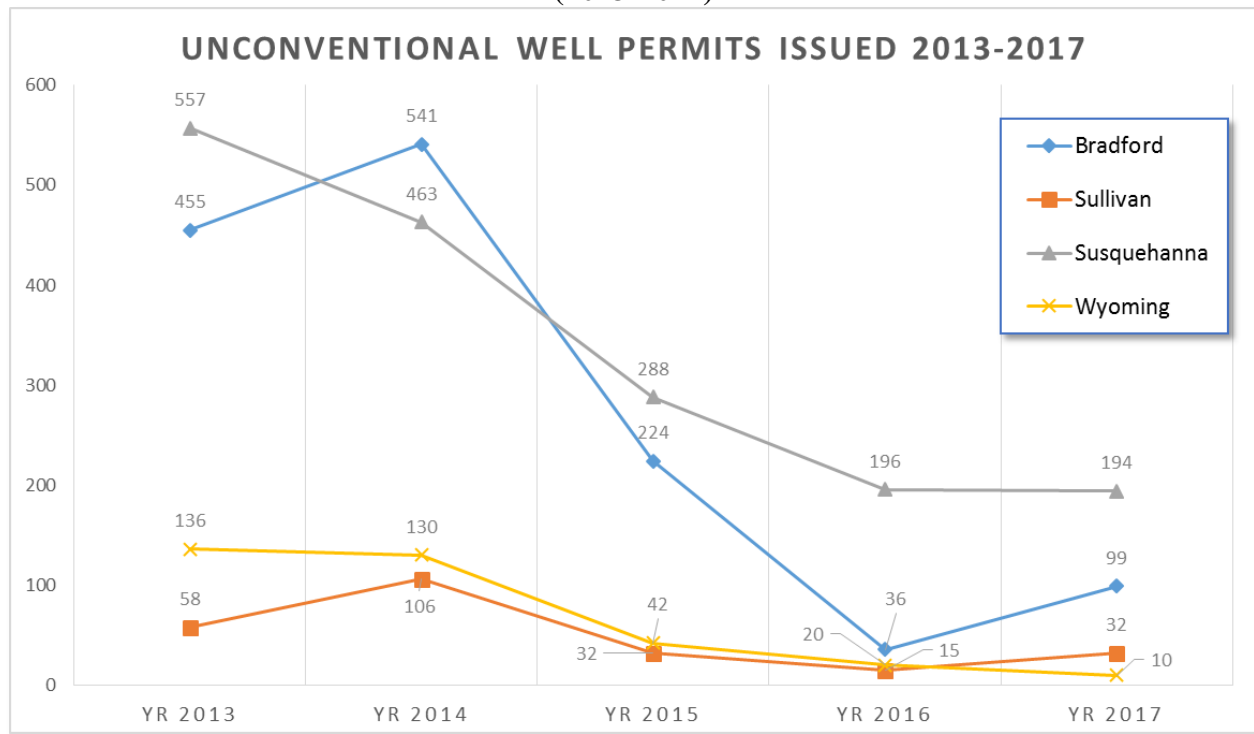
#### 2.1.3.3 Pennsylvania Well Permits Issued and Wells Drilled

A review of the Pennsylvania Department of Environmental Protection's (PA DEP) online Oil and Gas Reports reveals the number of permits issued for unconventional wells, as well as the number of unconventional wells drilled by county. Information regarding the permits issued for unconventional wells by county were obtained for years 2013-2017 using the PA DEP *Interactive Reports – Permits Issued Detail Report / Year to Date-Permits Issued by County and Well Type Report*. An analysis of the four producing counties (Bradford, Sullivan, Susquehanna, Wyoming) nearest the DRB anticipated production area indicates that the rate of permits issued has generally declined from 2013 to 2016 with a slight increase in 2017 for Bradford and Sullivan Counties. This information is depicted in **Exhibit 9**.<sup>15</sup>

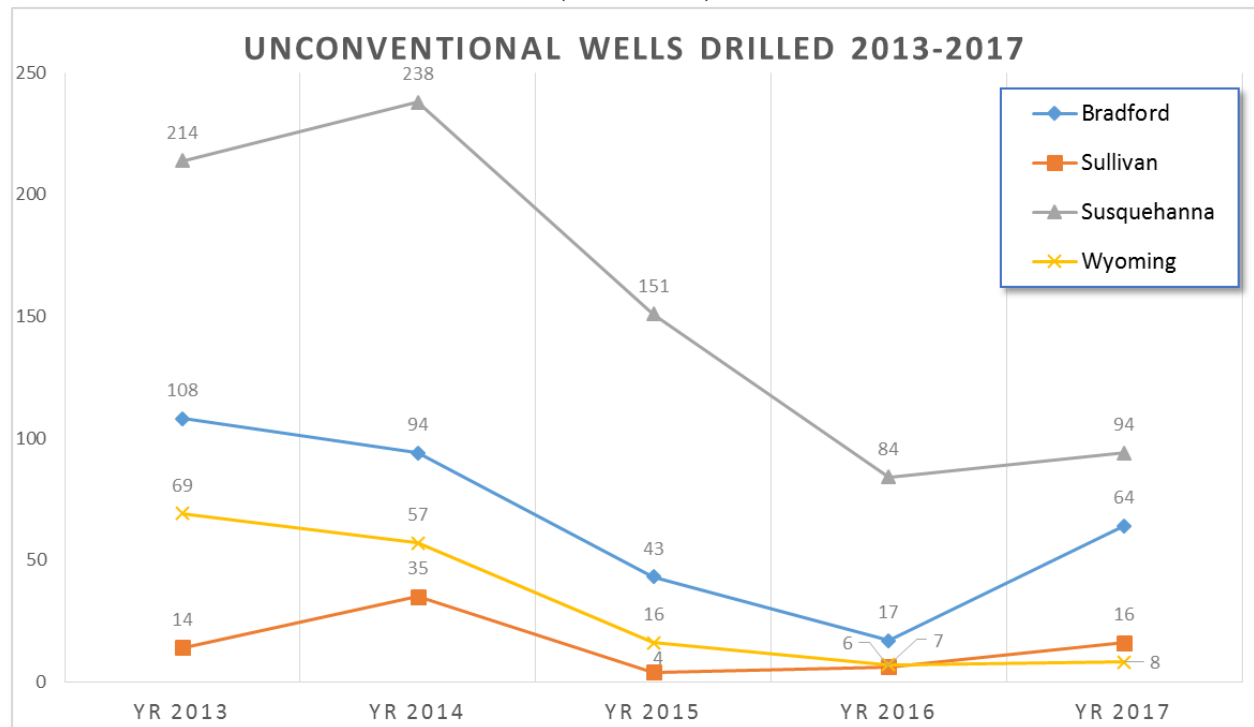
Information regarding the unconventional wells drilled by county was also obtained for years 2013-2017 using the PA DEP *Interactive Reports – SPUD Data Report / Wells Drilled By County*. An analysis of the same four nearby producing counties indicates that the rate of drilling followed a similar decline trend between 2013 and 2016 followed by a slight increase in 2017 for all four counties. This information is depicted in **Exhibit 10**.<sup>16</sup>

The Bureau of Land Management (BLM) Reasonable Foreseeable Development Scenario (RFDS) for Fluid Minerals in Pennsylvania, prepared in September 2011, was also evaluated for any insights with regards to development estimations.<sup>17</sup>

**EXHIBIT 9: UNCONVENTIONAL WELL PERMITS ISSUED IN COUNTIES NEAR THE DRB (2013-2017)**

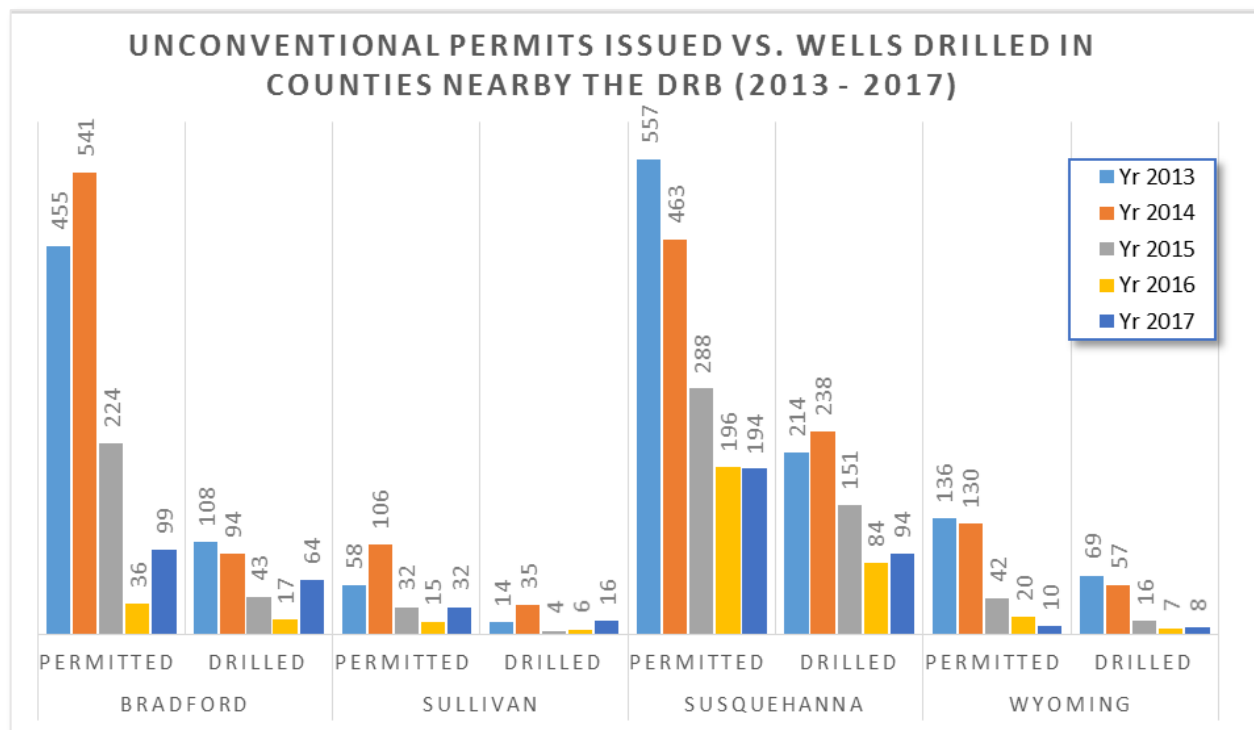


**EXHIBIT 10: UNCONVENTIONAL WELLS DRILLED IN COUNTIES NEARBY THE DRB (2013-2017)**



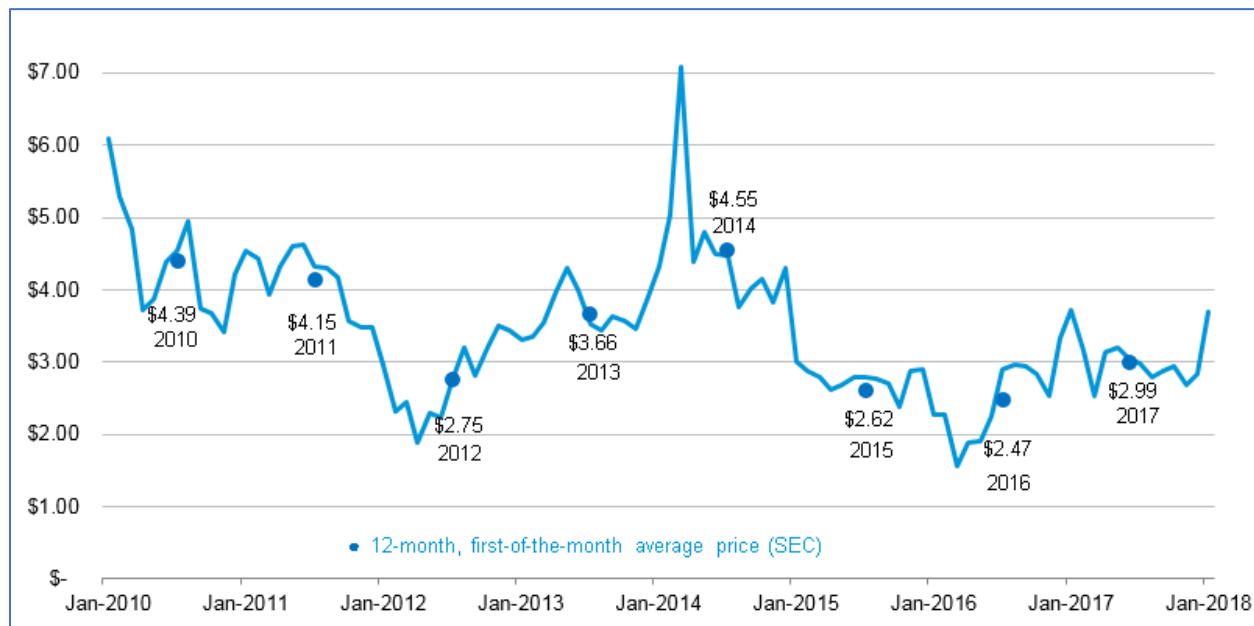
A comparison of the unconventional permits issued versus the unconventional wells drilled in these four nearby counties exposes the fact that generally less than half of the permits issued each year results in a well being drilled. This ratio reflects the numerous factors influencing drilling activity in Pennsylvania including price and demand fluctuations, drill rig availability, and pipeline capacity. **Exhibit 11** provides a side-by-side bar graph of the permits issued versus the wells drilled by nearby county.

**EXHIBIT 11: UNCONVENTIONAL WELL PERMITS ISSUED VS. WELLS DRILLED IN COUNTIES NEAR THE DRB (2013-2017)**



The BLM RFDS provided estimations for the federal minerals within the State on a county basis using data from 2003 to 2010 and addressed the earlier history of natural gas development in the Appalachian Basin with regard to natural gas prices. Of interest was the industry’s reaction to the price changes in 2008. It was a jump in natural gas prices that began in 2003 that helped stimulate interest in the Appalachian Basin. Exploration and development activities increased at a swift pace as the average monthly price rose to a high of \$12.69 per thousand cubic feet (Mcf) in June of 2008. By September 2009 the price for natural gas had dropped to \$2.99 per Mcf.<sup>18</sup> The decline in the natural gas price slowed the exploration and development pace of the Marcellus and Utica shales but it did not eliminate the interest in development. The following period of somewhat steady pricing (2010-2017, ~\$3.42 +/- \$1.20) has provided good data for evaluation with regard to development growth under tight economic conditions. During this period, operators developed and implemented additional cost-saving technology for drilling and production. See **Exhibit 12** for Henry Hub natural gas spot prices from 2010-2017.<sup>19</sup>

**EXHIBIT 12: HENRY HUB NATURAL GAS SPOT PRICE (FIRST-DAY-OF-THE-MONTH)  
2010-2017**



The EIA appraises the proven natural gas reserves in the Marcellus Play at 77.2 Tcf as of the end of 2015.<sup>20</sup> The EIA has not estimated the proven natural gas reserves for the Utica shale in Pennsylvania separately but recognizes the potential for dry gas in the area of the DRB. The now-proven recoverable reserves and the improved economic margins for the production of natural gas from the Marcellus and Utica shales should add to a solid foundation of cost control resulting in continued moderate growth of the Marcellus and Utica shales throughout the next 10-year period.

#### 2.1.3.4 Oil and Gas Development Potential in the DRB

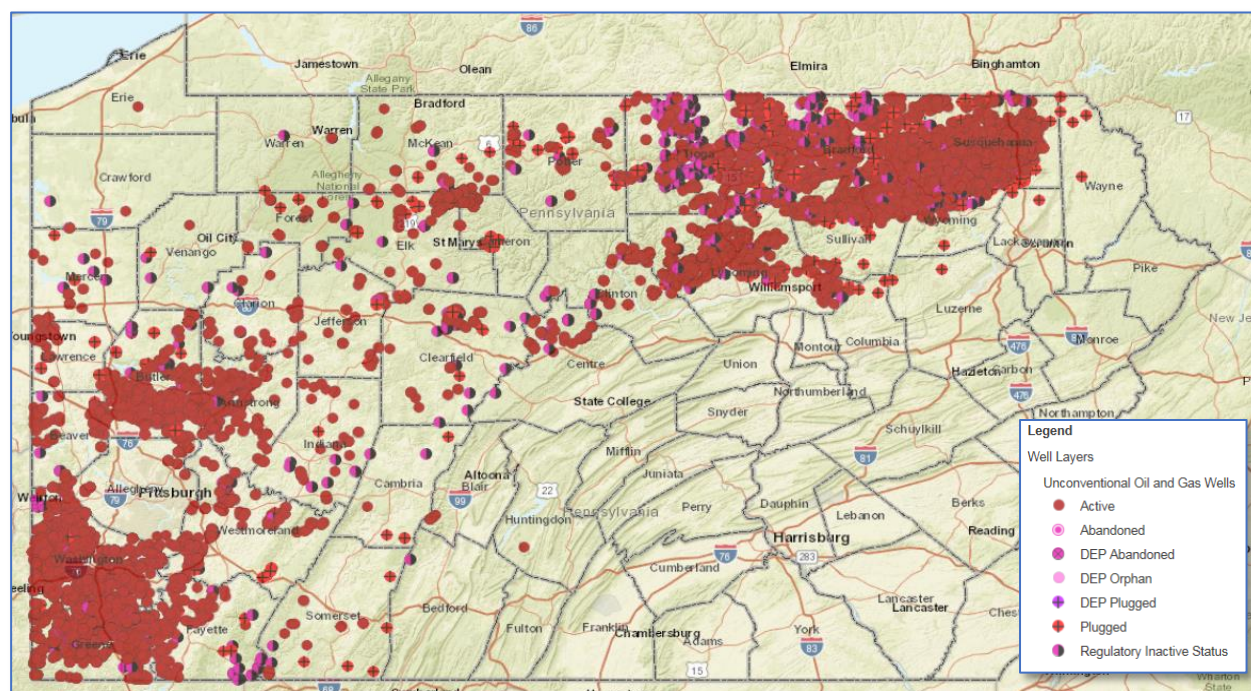
Since the first Marcellus gas wells were drilled in Pennsylvania in 2003, the state has seen relatively steady growth in exploration and production activity that is expected to continue for the foreseeable future. Given the information reviewed, each of the six counties in the DRB within Pennsylvania was assessed according to its individual potential for oil and gas development over the next 10 years. The data for each county were analyzed in relation to the county's relative position within the existing oil and gas regions of the state. Each county was assigned a value for potential oil and gas development and classified as having either High, Medium, or Low developmental potential over the next 10 years. This information coupled with the type of potential hydrocarbon present, the presence of potential productive formations, formation depths, thickness, thermal maturity, and other information provided previously in this report, was used as a basis for projecting the potential for oil and gas development. **Exhibit 13** presents the rankings according to the projected production potential and the forecast for annual wells. The low rankings for development potential reflect the thermal maturation of the shales in the eastern portion of the state and the lack of past activity as depicted in **Exhibit 14**. **Exhibit 14** is a map of the unconventional wells drilled into the Marcellus and Utica shales in Pennsylvania.<sup>21</sup> The PA DEP map shows few wells drilled in the counties of interest and seems to indicate a decline in operator activity from west to east in Susquehanna County, as well as a decline from north to south in Wyoming County.

As shown in the table, this analysis estimates a development potential of 40 wells drilled each year for the next ten years.

**EXHIBIT 13: HVHF WELL FORECAST FOR PENNSYLVANIA COUNTIES WITHIN THE DRB OVERLYING SHALES**

County	Type	Development Potential	Forecast Annual # of Wells	
			Gas Wells	Oil Wells
Carbon	Gas	Low	5.0	0.0
Lackawanna	Gas	Low	5.0	0.0
Luzerne	Gas	Low	5.0	0.0
Monroe	Gas	Low	5.0	0.0
Pike	Gas	Low	5.0	0.0
Wayne	Gas	Low	15.0	0.0
<b>Total</b>			<b>40.0</b>	<b>0.0</b>

**EXHIBIT 14: UNCONVENTIONAL WELLS DRILLED IN PENNSYLVANIA**



## 2.2 Water

### 2.2.1 Water Resources

The Water Resources Operations staff of the DRBC prepares annual Hydrologic Conditions in the Delaware River Basin reports.<sup>22</sup> A review of the latest report available (2016) indicates the following hydrologic highlights:

- The majority of the DRB counties saw below-normal precipitation during 2016. Only four southern counties out of the 38 total chronicled above-normal precipitation for the year. Annual precipitation in the anticipated production extent counties of interest were approximately 25% below normal as follows: Carbon -8.4”, Lackawanna -8.4”, Luzerne -8.0”, Monroe -12.1”, Pike -9.5”, and Wayne -6.5”.

- The mean streamflows along the main stem of the Delaware River and its two largest tributaries, the Lehigh and Schuylkill rivers, were normal to above normal from January through August; however, in September average monthly flows were generally below normal and remained that way for the remainder of 2016.
- The lower basin reservoir storage required releases totaling 9 billion gallons (Bgals) during 2016 to meet minimum flow objectives and to deter salinity in the Delaware Estuary. Late in the year (October/ November) the storage reservoirs were down and the drought warning was close to going into effect; however, before this happened, DRBC affirmed a basin-wide drought watch on November 23, 2016. Precipitation in late November and December increased storage volumes and the normal winter pool elevations were eventually reached and additional releases from this reservoir were no longer required through the end of 2016.
- The upper basin contains the three NYC Delaware reservoirs. These reservoirs are operated on a flexible flow management program. In the beginning of the year their combined storage was 2146 Bgals, which was 11 Bgals below the long-term median usable storage for that period. Precipitation raised the storage volume above the long-term median by early May, which was slightly (10 days) later than the normal refill date. Storage volumes severely dropped over the summer and fall months until in late November when the combined storage fell below the drought watch operation curve motivating the DRBC to issue the basin-wide drought watch. Again, late-year precipitation increased combined storage above the drought watch threshold, but not high enough to end the basin-wide drought watch. On New Year's Eve the reservoirs held 135.7 Bgals, just over half of their useable capacity but still 89 Bgals below the long-term median volume.
- Pennsylvania groundwater monitoring included measurements from Wayne County, which indicated that levels were generally within the normal range (25th to 75th percentile) for the first half of the year, although levels declined to below normal during the drier periods of April and May. By late May the trend was downward and by November levels were below the normal range. Again, increased precipitation during December caused the Wayne County water level to markedly increase to within the normal range by the end of the year.

A review of the previous three years of Hydrologic Conditions in the DRB reports (2013-2015) indicate a similar below-normal annual precipitation in the Upper Region with periodic reservoir releases conducted to augment late year streamflow lows and groundwater levels experiencing fluctuations below the 25th percentile for portions of the year. Reasons for the reduced precipitation are not discussed.

### **2.2.2 Water Use**

Water use in the DRB was evaluated using the data provided in the U.S. Geological Survey (USGS) "Estimated Use of Water in the United States in 2010,"<sup>23</sup> as downloaded for Pennsylvania and filtered by county for the DRB. The USGS National Water-Use Science Project compiles and disseminates the nation's water-use data every five years. The USGS works with local, State, and Federal environmental agencies to collect water-use data at the county level. USGS compiles data by domestic, industrial, irrigation, livestock, aquaculture, mining, and thermoelectric power generation. The USGS 2010 data is the latest data available in its entirety as the 2015 data has not

been released yet. The USGS data findings were compared to the DRBC’s *Draft Water Resources Program FT 2017-2019* Report for water use in the Upper Region.

Water withdrawal amounts as reported by the USGS in Million gallons per day (Mgal/d) were analyzed for the six counties of interest in the Upper Region of the DRB with anticipate shale production. The daily withdrawal amounts for the following groundwater and surface-water Use Sectors were totaled per county to provide a total daily withdrawal amount.

- Public Supply
- Domestic, self-supplied
- Industrial, self-supplied
- Irrigation-Crop
- Irrigation-Golf
- Livestock
- Aquaculture
- Mining
- Thermoelectric

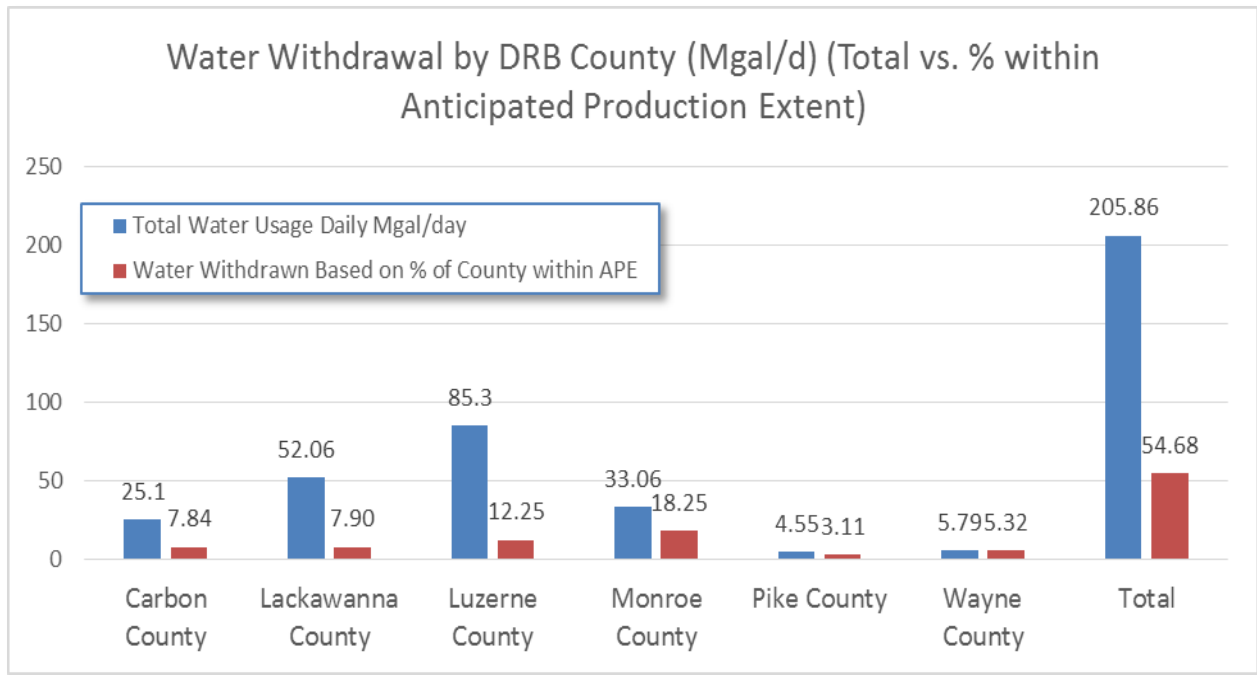
The data indicated that a total of 205.86 Mgal/d are being withdrawn from these six counties. The top three use sectors account for approximately 91.5% of total daily water withdrawals; these sectors are public supply (53.6%), thermoelectric (28.4%), and domestic self-supplied (9.6%). Also, two dominant counties account for ~66.7% of the total daily water withdrawals; these are Luzerne (41.4%) and Lackawanna (25.3%) Counties. However, when the percentage of the anticipated shale production extent per county (see **Exhibit 5**) within the DRB is applied to the total withdrawal quantities per county the total daily withdrawal is adjusted to 54.68 Mgal/d. The two dominant counties also changed when the anticipated production extent percentages were applied; these are Monroe (33.4%) and Luzerne (22.4%). **Exhibits 15, 16, and 17** show the sum of these water withdrawals by use sector and county totaled and with percentages of county within the anticipate production extent applied.

**EXHIBIT 15: USGS REPORTED WATER WITHDRAWALS BY USE SECTOR WITHIN DRB  
COUNTIES OF INTEREST**

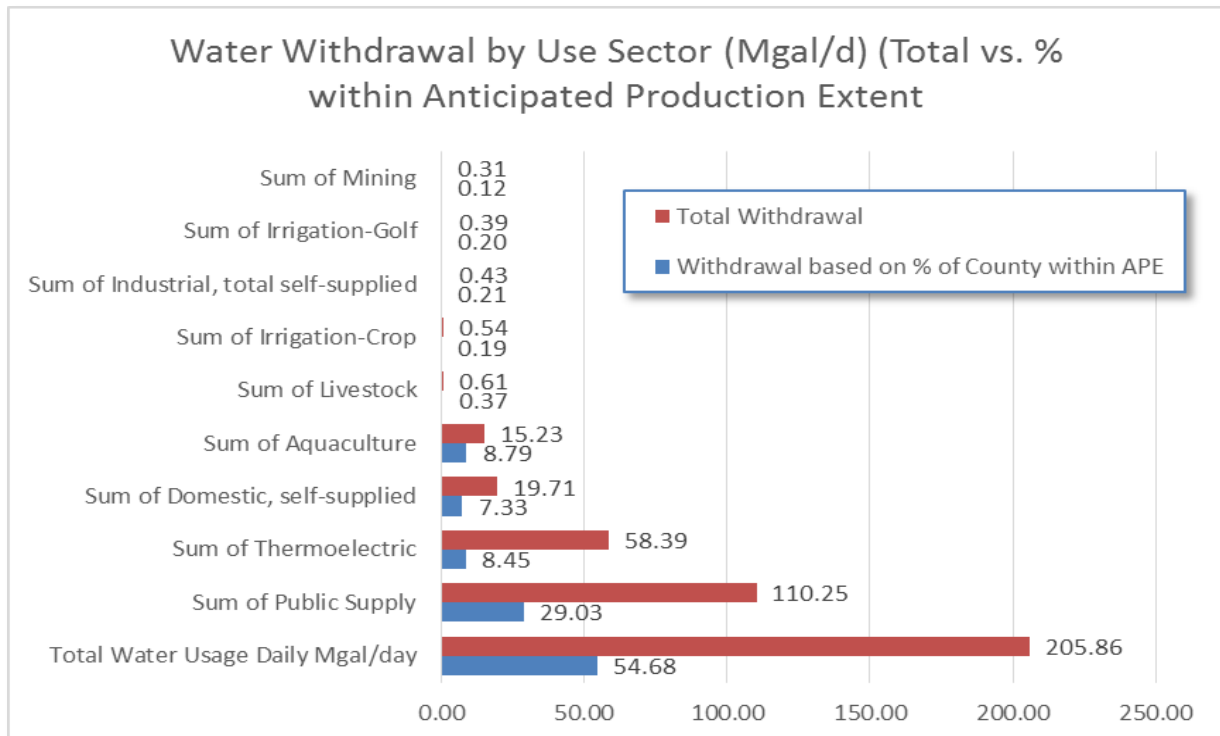
Total Water Withdrawals	Carbon County	Lackawanna County	Luzerne County	Monroe County	Pike County	Wayne County	Total
Sum of Public Supply, total groundwater withdrawals	2.88	1.76	4.28	6.24	2.83	2.51	20.5
Sum of Public Supply, total surface-water withdrawals	20	45.51	17.09	7.15	0	0	89.75
Sum of Domestic, self-supplied groundwater withdrawals, fresh	1.4	4.14	5.83	5.54	0.89	1.91	19.71
Sum of Domestic, self-supplied surface-water withdrawals, fresh	0	0	0	0	0	0	0
Sum of Industrial, total self-supplied groundwater withdrawals	0.07	0	0.02	0	0	0	0.09
Sum of Industrial, total self-supplied surface-water withdrawals	0	0	0	0.34	0	0	0.34
Sum of Irrigation-Crop, groundwater withdrawals, fresh	0.02	0.03	0.04	0.01	0	0.02	0.12
Sum of Irrigation-Crop, surface-water withdrawals, fresh	0.06	0.09	0.15	0.03	0.01	0.08	0.42
Sum of Irrigation-Golf, groundwater withdrawals, fresh	0.05	0	0	0.12	0	0	0.17
Sum of Irrigation-Golf, surface-water withdrawals, fresh	0.04	0	0	0.14	0.04	0	0.22
Sum of Livestock, groundwater withdrawals, fresh	0.02	0.08	0.1	0.02	0.01	0.29	0.52
Sum of Livestock, surface-water withdrawals, fresh	0.01	0.01	0.02	0.01	0	0.04	0.09
Sum of Aquaculture, total groundwater withdrawals	0.16	0	0	1.06	0.45	0.17	1.84
Sum of Aquaculture, total surface-water withdrawals	0.04	0	0	12.33	0.3	0.72	13.39
Sum of Mining, total groundwater withdrawals	0	0.15	0.02	0.07	0.02	0.05	0.31
Sum of Mining, total surface-water withdrawals	0	0	0	0	0	0	0
Sum of Thermoelectric, total groundwater withdrawals	0.35	0	0	0	0	0	0.35
Sum of Thermoelectric, total surface-water withdrawals	0	0.29	57.75	0	0	0	58.04
<b>Total Water Usage Daily Mgal/day</b>	<b>25.1</b>	<b>52.06</b>	<b>85.3</b>	<b>33.06</b>	<b>4.55</b>	<b>5.79</b>	<b>205.86</b>
<i>Percentage of County within APE</i>	<i>31.23%</i>	<i>15.18%</i>	<i>14.36%</i>	<i>55.21%</i>	<i>68.39%</i>	<i>91.96%</i>	
<i>Water Withdrawn Based on % of County within APE</i>	<i>7.84</i>	<i>7.90</i>	<i>12.25</i>	<i>18.25</i>	<i>3.11</i>	<i>5.32</i>	<i>54.68</i>
<b>Percent of Total Withdrawn</b>	<b>12.2%</b>	<b>25.3%</b>	<b>41.4%</b>	<b>16.1%</b>	<b>2.2%</b>	<b>2.8%</b>	
<i>Percent Withdrawn within APE</i>	<i>14.3%</i>	<i>14.5%</i>	<i>22.4%</i>	<i>33.4%</i>	<i>5.7%</i>	<i>9.7%</i>	



**EXHIBIT 16: USGS REPORTED WATER WITHDRAWALS BY DRB COUNTY TOTAL VS. PERCENT WITHIN ANTICIPATED PRODUCTION EXTENT**

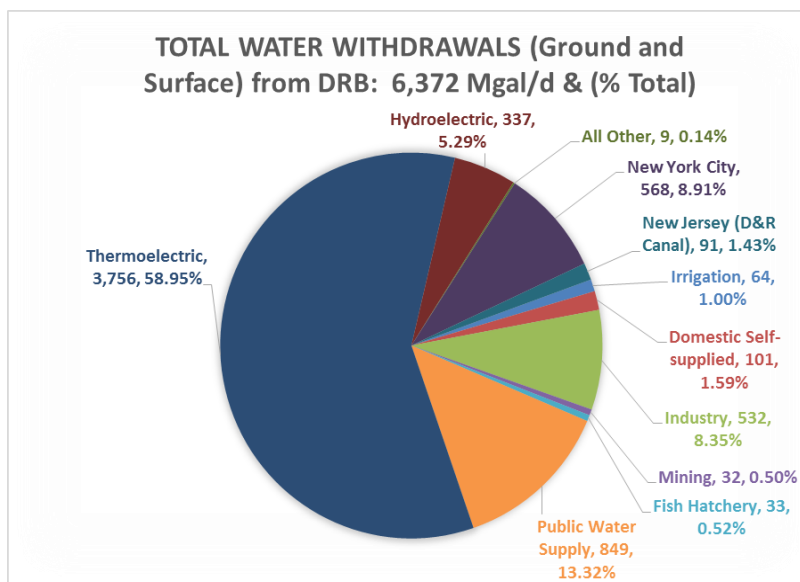


**EXHIBIT 17: USGS REPORTED WATER WITHDRAWALS BY USE SECTOR TOTAL VS. PERCENT WITHIN ANTICIPATED PRODUCTION EXTENT**



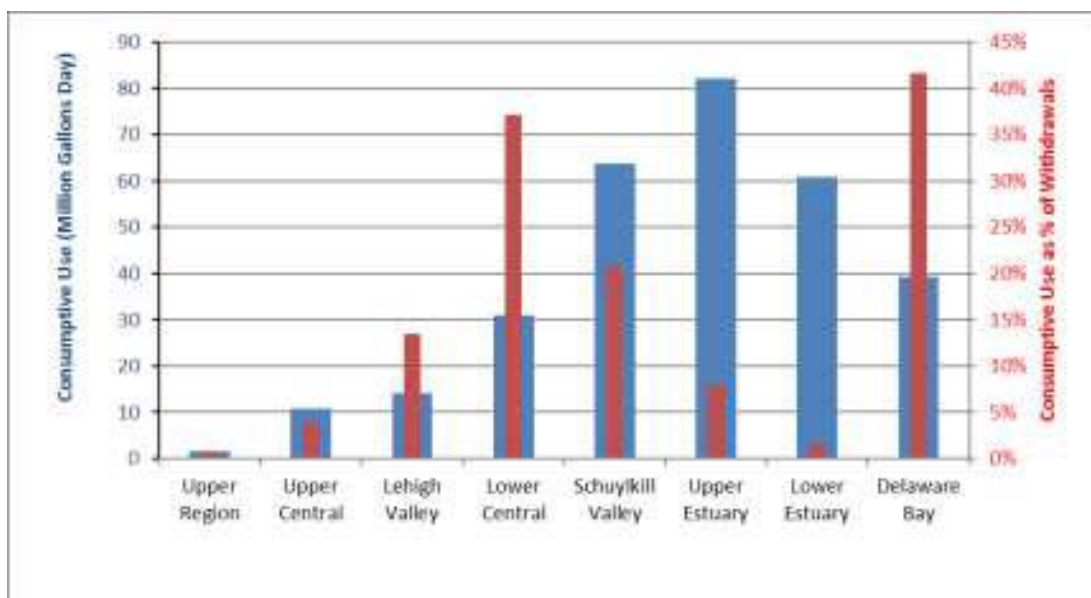
The USGS data reveals that all water withdrawals within the anticipated production extent of the counties of interest in the DRB currently totals 54.68 Mgal/d or approximately 19.97 Billion gallons annually. The DRBC tracks withdrawal and water use by similar use sectors and reports 6,372 Mgal/d withdrawn for the entire DRB.<sup>24</sup> **Exhibit 18** shows the DRBC use sectors and reported withdrawals based on 2014 data.

**EXHIBIT 18: TOTAL WATER WITHDRAWALS REPORTED BY DRBC**



The DRBC defines water not returned to the surface waters of the basin as consumptive use and as mentioned in their Additional Clarifying Amendments for the proposed rules they consider “most water used for HVHF is used “consumptively,” meaning it is not returned to the basin’s usable ground or surface waters.”<sup>25</sup> This does not take into account the “new” water produced from shales and the amount of produced water that is recycled and reused. Annual corporate sustainability reports routinely identify the large percentages or volumes of water being recycled / reused, e.g., Apache reuses nearly 50% of their produced water,<sup>26</sup> Hess Corporation has a track record of increasing their reuse percentage annually over the past four years,<sup>27</sup> and Chesapeake Energy recycled over 94 Mgals in 2016.<sup>28</sup> **Exhibit 19** (extracted from the DRBC Draft Water Resources Program, FY 2017 – 2019 [figure 8]) depicts the range of withdrawals by DRBC region and shows the consumptive use as a percentage of total withdrawals (excluding exports to NYC and

**EXHIBIT 19: DRBC REPORTED CONSUMPTIVE USE BY REGION**



**EXHIBIT 20: MAP OF DRBC REGIONS**



NJ). The anticipated production extent area is in the Upper Region as depicted on **Exhibit 20** (figure 9) also obtained from the DRBC Draft Water program document. Note, the image, although grainy, appears to indicate that the Upper Region withdrawals about 1.5 Mgal/d for consumptive use and that represents an estimated 1.0% of the withdrawals. Based on this data the daily withdrawal in the Upper Region would be approximately 150 Mgals/d. This is considerably larger than the amount withdrawn from the anticipated production extent based on USGS data for the counties of interest (54.86 Mgal/d). The DRBC reports an estimated 559 Mgal/d is consumed as authorized and another 171 Mgal/d are lost or consumed as a total based on 2014 DRBC water audit program. This 730 Mgal/d consumed or lost represents ~11.5% of the daily withdrawals.

**2.2.3 Water Availability**

Water is the major component needed for removing natural gas from underground shale rock formations. Pennsylvania's precipitation totals and surface and groundwater resources are considerably larger than those of most southwestern and northern plain states where other shale fields are in mature gas production.

While water is bountiful in Pennsylvania, a variety of use sectors place significant demands on the water resources in the Upper Region of the DRB. The total withdrawal of ground- and surface water in the anticipated production extent of the

DRB approaches 55 Mgals/d. Anticipated drilling and fracturing supply water may come from streams, ponds, lakes, rivers, and groundwater withdrawals, as well as from treated wastewater, acidic mine drainage, recycled production water, or spent process/cooling water from other nearby industries. Generally, water withdrawals exceeding 10,000 gallons per day (gals/d) for any rolling thirty-day period require registration with the PA DEP under authority of Act 220 of 2002, the Water Resources Planning Act, and implementing regulations at 25 Pa. Code Chapter 110.

Irrespective of the basin from which water is withdrawn, PA DEP requires an approved water management plan coupled with a well permit to cover the water volumes used for fracturing. A water management plan includes information about the sources of water to be used in the HVHF process, potential impacts of withdrawals on water resources, and proof of approval by the appropriate river basin commission, among other items.<sup>29</sup>

The DRBC has expressed concern about large-scale water withdrawals from small, remote, forested streams, often home to wild trout and other sensitive species, that can be very susceptible to damage from withdrawals. Withdrawals from small forested streams need to be carefully planned to minimize the possible ecological consequences.

Water-use plans can be designed to allow operators to continuously withdraw water from a stream in a small quantity that has minimal impact on stream flows, such as a quantity that cumulatively would not exceed about 10% of Q7-10\* low flows (called an uninterrupted withdrawal). Operators can also chose to withdraw larger amounts during times of high flow, usually in January and February in the Upper Region of the DRB, and store that water for use throughout the year. The Susquehanna River Basin Commission (SRBC) has granted some "passby flow determinations with interrupted withdrawal" that allow water withdrawal from smaller streams with the condition that withdrawal stop or decrease to a previously designated level when flows reach a preset minimum.<sup>30</sup>

Operators have also purchased water from municipal water systems and other permitted users. Within the Susquehanna River Basin (SRB) operators can purchase water, up to the total permitted amount, from users who have excess water. These sources may be used as long as they are registered under the applicable ABR for each drilling pad at which such sources would be used.<sup>31</sup> Water can also be withdrawn from private surface impoundments, provided operators have permission to access the water body, for which some landowners are charging an access fee. Withdrawals of water from ponds or lakes more than one acre in size may require additional approvals, such as a drawdown permit from the Pennsylvania Fish and Boat Commission.<sup>32</sup>

For purchases of water from a Public Water Supply Agencies (PWSA), the PA DEP considers the capability of the PWSA to sell water to the operator without threatening its ability to deliver drinking water to the public. In addition, the PA DEP considers the PWSA's own compliance with applicable laws, such as the Safe Drinking Water Act, the Water Rights Act and the Water Resources Planning Act.

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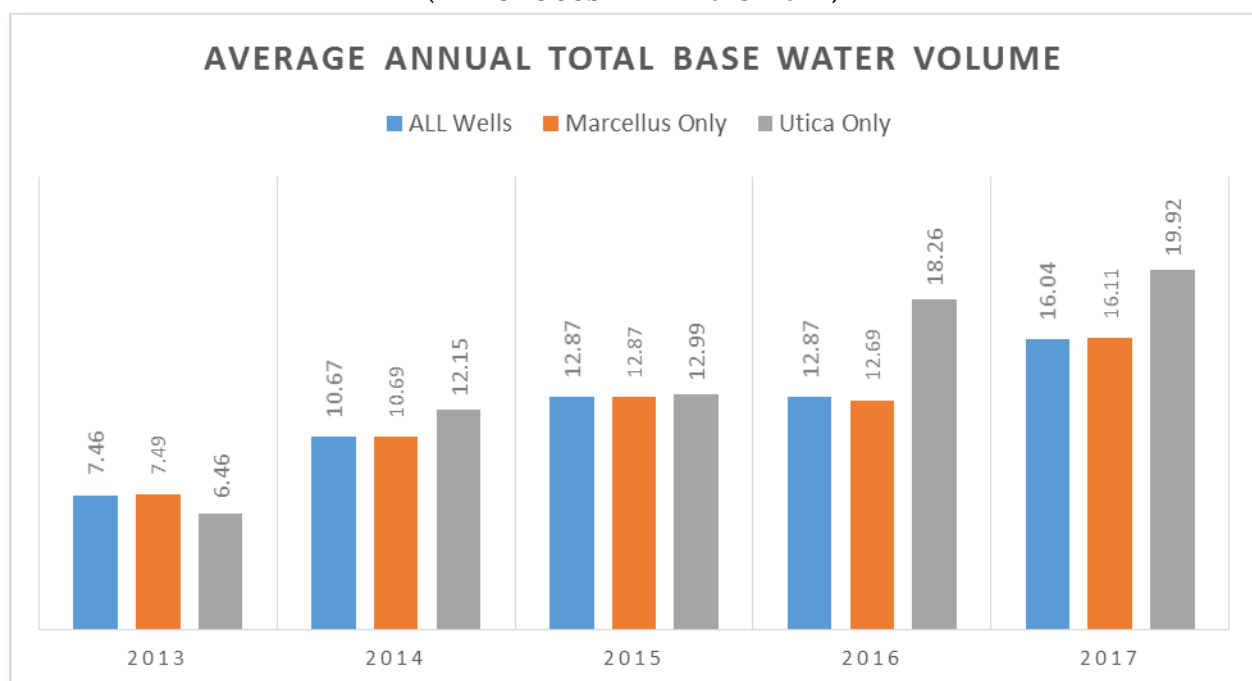
\* A 7-day low flow for a stream is the average flow measured during the 7 consecutive days of lowest flow during any given year. The 7-day 10-year low flow (Q7,10) is a statistical estimate of the lowest average flow that would be experienced during a consecutive 7-day period with an average recurrence interval of ten years.

Operators can also seek to withdraw groundwater, but the rules for determining the allowable withdrawal amounts can be cumbersome. Water that is on or under the land, such as accumulated snowmelt, stormwater runoff, or water from a spring-fed pond, can be sold as long as it has no impact on water on or under another property. Although landowners may be considered to have certain ownership rights in subsurface waters on their property, they can incur liability if their sale of water adversely affects a well or spring on another property. Generally, it will be difficult for landowners to sell water.

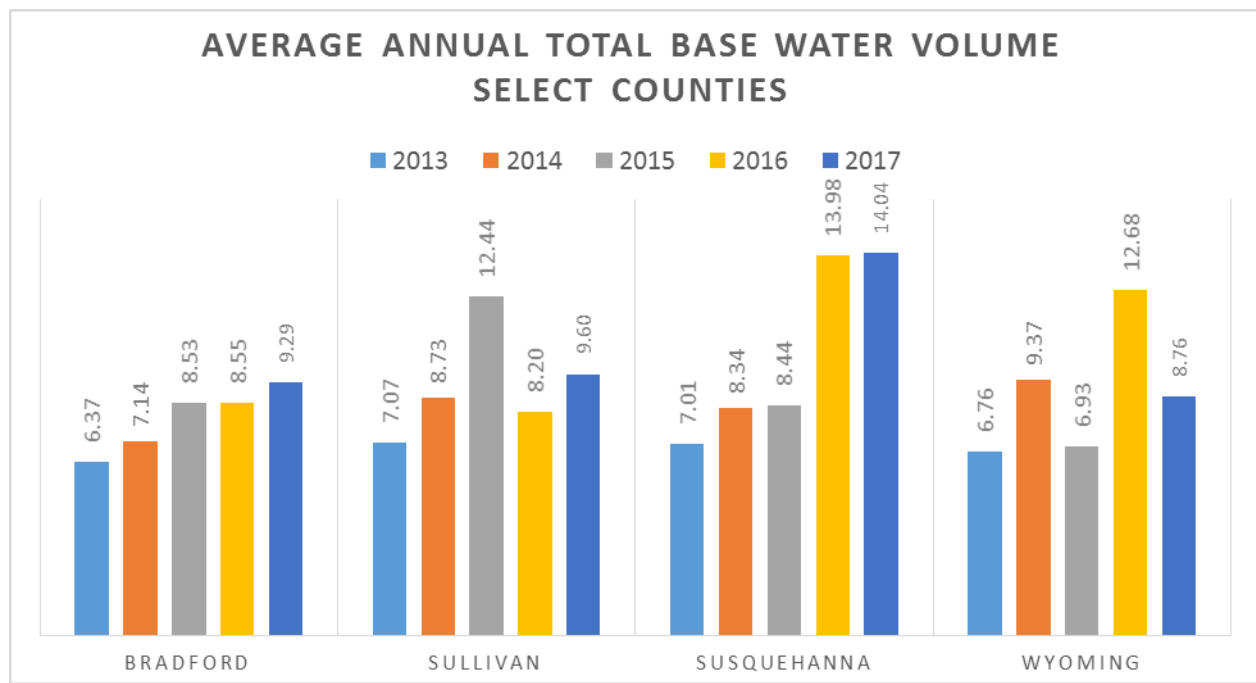
**2.2.4 Hydraulic Fracturing Water Quantity Update**

The average quantity of water being used as the base fluid in a HVHF treatments in Pennsylvania has increased since the previous analysis was conducted in 2011. An analysis of the base fluid volumes disclosed to FracFocus from Marcellus and Utica wells drilled in Pennsylvania was conducted to identify trends and volumes for the states as well as for adjacent counties to the DRB. Data was obtained from FracFocus for wells fractured in 2013 through 2017. The information obtained included 4,515 records containing the API number, county, year fractured, producing formation, and total base volume. The largest volume reported was a Marcellus well in Butler County, 86,534,700 gals, and the smallest volume was 4,200 gals, on a Marcellus well in McKean County. The 5-year average volume for all disclosures over this period is 11,172,772 gallons (gals), for Marcellus-only disclosures (4,301) 11,132,875 gals, and for Utica only disclosures (72) 13,145,825 gals. The average volume as analyzed is approximately 2.75 times larger than the median volume needed to fracture wells in the Susquehanna River Basin.<sup>33</sup> The increase in base fluid volume is likely a result of longer lateral wellbore lengths, greater depths drilled, optimization of multistage fractures, and new fracture methods being employed. Corporate sustainability reports cite the large percentages of water that are being recycled and reused for both drilling and hydraulic

**EXHIBIT 21: AVERAGE ANNUAL TOTAL BASE WATER VOLUME BY YEAR  
(FRACFOCUS DATA 2013-2017)**



**EXHIBIT 22: AVERAGE ANNUAL TOTAL BASE WATER VOLUME BY COUNTY  
(FRACFOCUS DATA 2013-2017)**



fracturing, reducing operator’s dependence on fresh and potable water sources.<sup>34,35,36</sup> **Exhibit 21** shows the annual average for total base volume for all unconventional wells fractured across the state, Marcellus only wells, and Utica only wells from 2013-2017. **Exhibit 22** provides the annual average total base volume for select counties near the DRB.

Using the 5-year average volume and the estimated development rate of 40 wells per year indicates that a total of ~447 Mgals or 1.22 Mgal/d would be withdrawn for natural gas development within the APE annually. The 1.22 Mgal/d represents 2.23% of the estimated USGS daily withdrawal for the APE and 0.81% of the DRBC reported withdrawals for the Upper Region. Since water for HVHF is considered a consumptive use the 1.22 Mgal/d would also represent an increase of 81.3% for consumptive water withdrawals in the Upper Region as compared to the current 1.5 Mgal/d being consumed as reported by the DRBC in Exhibit 19.

**2.2.5 Water Quality Concerns**

**2.2.5.1 Special Protection Waters**

Protecting water within the anticipated production extent of the DRB will involve the application of several best management practices (BMPs) suited to site specific conditions as the entire area is designated as Special Protection Waters (SPWs). Industry has a large assortment of BMPs that can be employed to address site specific situations and has done this successfully as demonstrated in both the ORB and SRB development efforts, see section 4.2 for a list of BMPs. Special Protection Waters are those that meet the water chemistry standards and the biological assessment qualifiers of Chapter 93 of the Pennsylvania Code Title 25, Sections 93.4b(a) [for High Quality Waters] and 93.4b(b) [for Exceptional Value Waters].<sup>37</sup> The PA DEP uses water quality to classify streams. The classifications consist of Exceptional Value (EV), High Quality (HQ) and Warm

Water Fisheries (WWF). The top classification constituting the highest level of protection is EV, the next classification down is HQ.

The Clean Water Act requires states to have protective uses for their surface waters. Once a protective use is established for a surface water, that use must be maintained and the surface water is not permitted to degrade.<sup>38</sup> Anti-degradation is a concept that has its roots in the federal Clean Water Act, and was promulgated by U.S. Environmental Protection Agency (EPA) for Pennsylvania 1996.<sup>39</sup> This PA DEP policy of anti-degradation promotes the maintenance and protection of existing instream water uses and the level of water quality in the state. The Pennsylvania Clean Streams Law reinforces the anti-degradation policy and was enacted to preserve and improve the quality of the Commonwealth's waters.

#### 2.2.5.2 Spill Prevention Control and Countermeasures

To develop hydrocarbon resources in the DRB and protect the SPWs, operators will need to comply with state regulations and continue to implement various BMPs where required to provide a measure of safety when drilling and operating wells. There are numerous BMPs that address site selection, pollution prevention measures, site preparation, erosion and sediment control, waste disposal, well operation procedures, and well plugging and site reclamation activities. The chief concern of the DRBC is the potential for impacts to surface and ground water from accidental chemical spills during all stages of the hydraulic fracturing water cycle, as evidenced in their notice of public hearing for the proposed rule.<sup>40</sup> With this in mind, the focus of the following discussion is on the protection of water quality by utilizing advances in spill protection, containment, and countermeasures that have been applied by the industry in other areas of special designation.

Spill prevention control and countermeasure (SPCC) plans are required for all non-transportation-related onshore oil and gas facilities that are reasonably expected to have a discharge into navigable waters of the United States.<sup>41</sup> Again, these requirements and plans are well understood by operators and developed based on site-specific criteria but generally only address the tanks that store oil or produced water, and are not required for equipment and other chemicals stored on site. To account for this operators have developed and implemented zero-discharge and controlled-collection well pad containments for use in sensitive environments, much like what might be experienced in the DRB. Examples are provided in the following two subsections.

##### 2.2.5.2.1 Zero Discharge Well Pad

The zero-discharge well pads include full pad liners with decking, perimeter berms, stormwater collection systems, gasketed cellars, and employee secondary containment for fracture tanks and chemical storage. **Exhibit 23** provides a series of photographs with captions that depict elements of a zero-discharge pad.<sup>42</sup> **Exhibit 24** provides a cellar containment design.

**EXHIBIT 23: ZERO-DISCHARGE WELL PAD**



**Well Pad Liner and Subbase Materials**



**Decking Placement**



**Well Pad Liner Berm**



**Perimeter Berm Liner and Geofabric**



**Cellar with Rubber Gasket**



**Grounding Rod Outside Containment**

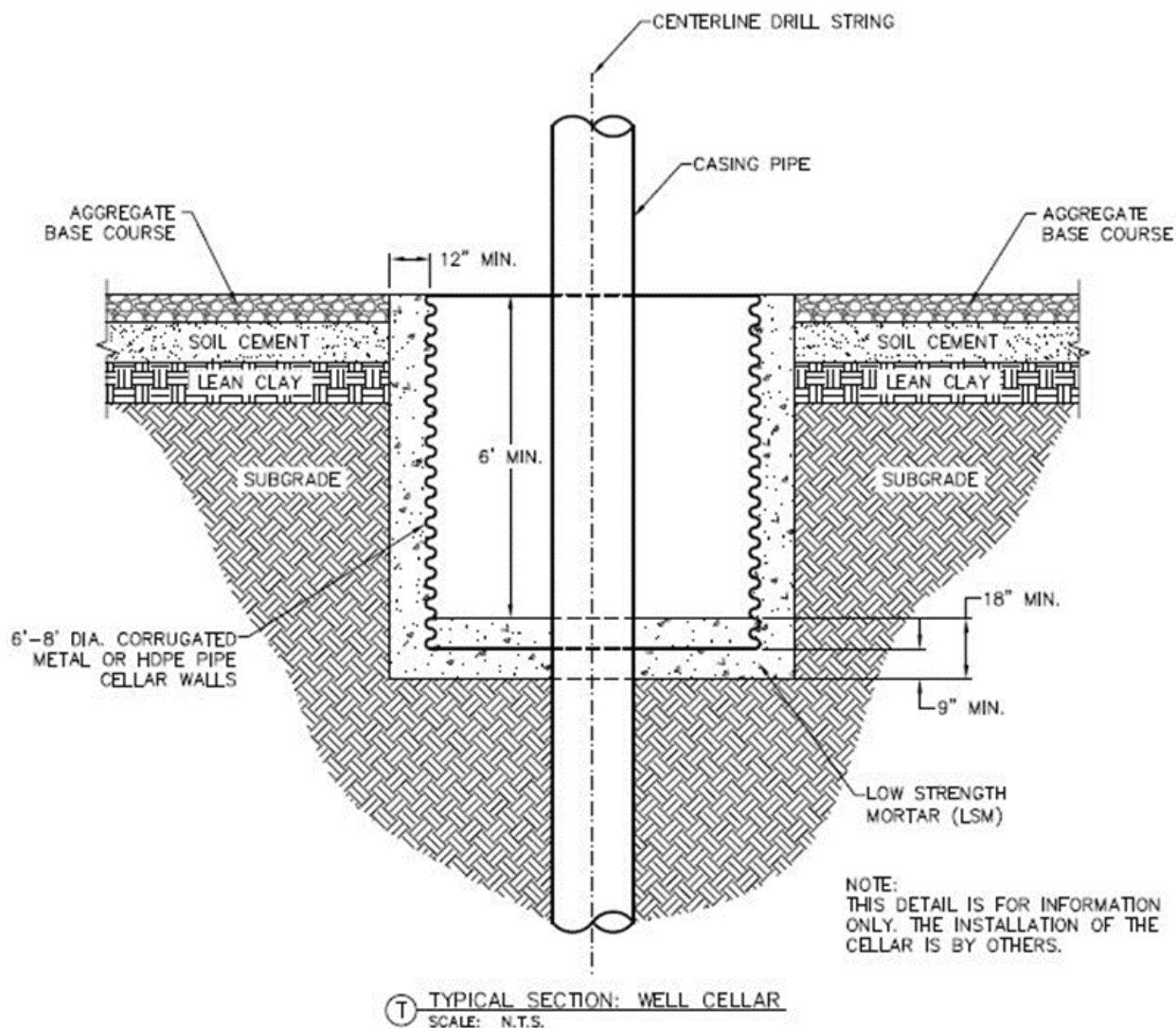


**Frac Tanks / Manifold in 2<sup>nd</sup> Containment**



**Frac Chemicals in 2<sup>nd</sup> Containment**



**EXHIBIT 24: CELLAR DESIGN AND COLLAR FOR ZERO-DISCHARGE WELL PAD**

The containment capacity of the zero-discharge well pads is based on the area within the perimeter berm times the berm height minus the anticipated 25-year, 24-hour precipitation amount. For a typical unconventional multi-well pad the area within the perimeter berm is ~5.5 acres and the berm is generally 18" in height. The capacity for a pad with these dimension could hold ~2.693 Mgals or ~64,120 barrels (bbls) before accounting for any rainfall. The Rainfall Frequency Atlas of the United States reports the Upper Region of the DRB between 5" and 6" for the 25-year, 24-hour rainfall amount.<sup>43</sup> Using the median amount of 5.5", the capacity of the secondary containment around the pad with said dimensions would hold ~1.87 Mgals or ~44,525 bbls, more than enough capacity to hold the volume of an accidental release during any single frac stage of a stimulation.

When these zero-discharge well pads are constructed there are several construction practices that are followed to prevent punctures during construction and operation activities. These practices include the following:

- Liners are installed smooth and wrinkle-free so when decking is placed there are no pinch-points which might result in potential tears.
- Liners are folded all the way over the perimeter berm and covered with soil on back side to lock them down.
- Liners have seams welded with heavy-duty plastic.
- Decking placement tools are modified so there are no sharp edges that contact liners.
- Interlocking rig mats or decking are used and damaged decking pieces are removed as they can puncture liners.
- Pad liner and perimeter berms have drive-over protection (ramps) installed to prevent crushing and to maintain the integrity of the containments.
- Access points are restricted to areas with proper ramp structures.
- The cellar is pre-set with conductor casing and embedded in low slump mortar (LSM) prior to the drill rig arrival.
- Cellars are monitored frequently to keep fluid levels pumped down.
- Grounding rods are placed outside containment so they do not penetrate the liner.
- Frac tanks, manifolds, chemicals, and diesel generators are placed in additional secondary containment (tertiary) to prevent accidental leaks from entering the environment.
- Spare equipment or materials are not stored against the perimeter liner as they could tear the liner.
- If a mouse hole is required because of the type of drilling rig used at the bottom of the tinnhorn is embedded in the LSM preventing the escape of fluids.

#### 2.2.5.2.2 Controlled-Collection Well Pads

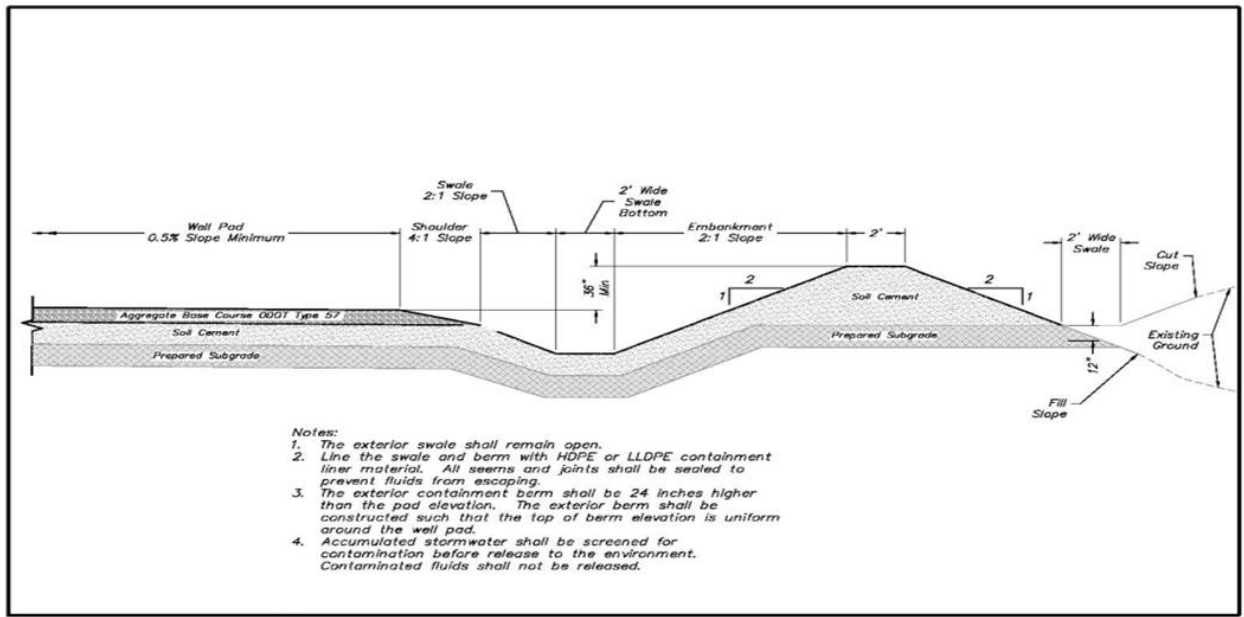
Controlled-collection well pads differ from zero-discharge pads in so much that they do not use full surface liners with decking but rather employ an engineered surface that utilizes a soil cement and aggregate base surrounded by a compacted clay soil berm and a drainage collection trench or swale. Secondary containment for tanks, equipment, and chemicals is still used on these pad surfaces. These types of well pads designs can prevent off-pad releases of spilled liquids. The collection systems are designed to slow and control spills for recovery efforts. If part of a spill avoidance and cleanup program, these controlled-collection systems can help with regulatory acceptance of spill prevention and mitigation planning. **Exhibits 25** and **26** provide typical section designs for controlled-collection exterior berms with perimeter drains and with swales. **Exhibit 27** shows an interior perimeter drain installation.

The perimeter drain requires less space and does not have an open trench, but has only ~2/3 the fluid collection capacity of the swale design and runs the risk of the drain pipe and aggregate being fouled. The swale and berm design has a large holding capacity and allows for regular visual inspections, but requires more space, is susceptible to freezing and can be damaged by vehicles.

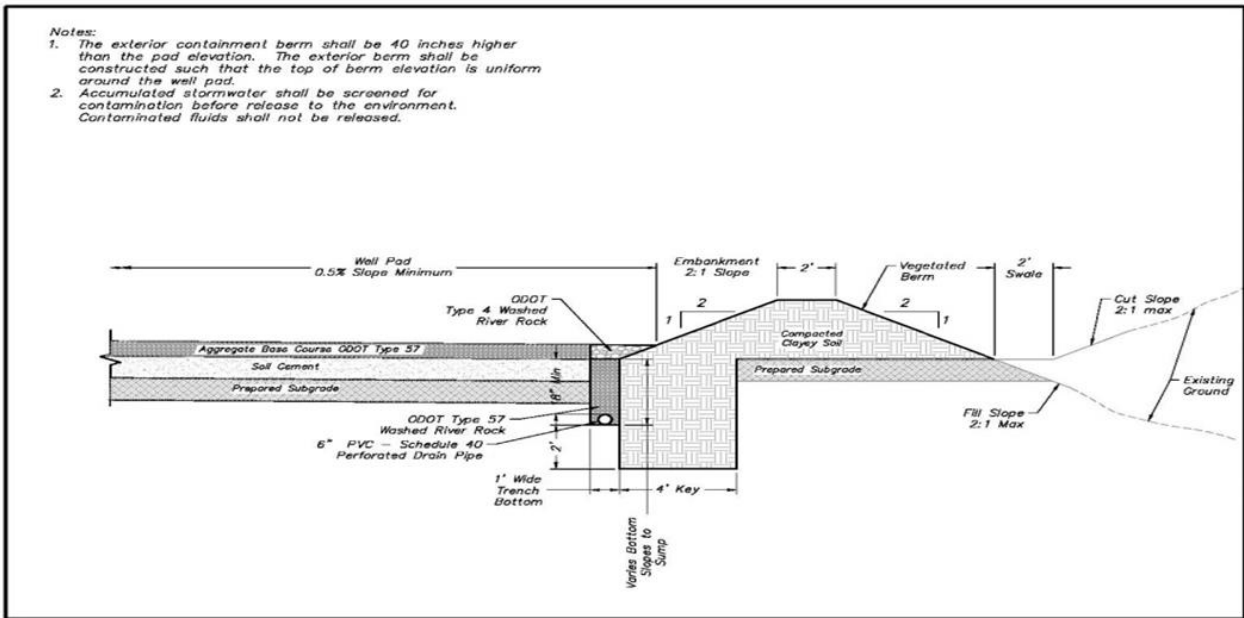
The perimeter drain design uses collection sumps that are installed in the corners of the well pads. The sumps receive runoff or other liquids from buried perforated drain pipes around the perimeter. Accumulated stormwater is sampled and those samples are sent for laboratory analysis. If analytical results indicate that impurities are present, the collected water is removed by a vacuum

truck and disposed of properly. If analytical results are acceptable, the collected water is released from the sump to the surface through a valve flow line at the base of the sump.

**EXHIBIT 25: EXTERIOR BERM AND SWALE TYPICAL SECTION**



**EXHIBIT 26: EXTERIOR BERM AND PERIMETER DRAIN TYPICAL SECTION**



**EXHIBIT 27: CORNER CATCH BASIN INSTALLATION (PERIMETER DRAIN)**



**Perimeter Drain with Perforated Pipe Trench**



**Bentonite Being Placed around Anti-Seep Collars**



**Catch Basin Installed before Backfill**



**Compacting Backfill around Catch Basin**



**Rip Rap Apron around Catch Basin**



**Perimeter Catch Basin**

**2.2.5.3 *EPA Study of Hydraulic Fracturing and Potential Drinking Water Impacts***

It has been just over a year since the EPA released their final report regarding the potential impacts of hydraulic fracturing on drinking water resources.<sup>44</sup> The final report acknowledges and incorporates many of the critiques identified during the peer review conducted by the EPA’s independent Science Advisory Board (SAB); however, the oil and gas industry has questioned

how the EPA derived its findings.<sup>45</sup> The study was initially understood to be an assessment limited to the actual process of hydraulic fracturing and its potential effect on drinking water. It later became a wider review of the "life cycle" of water during drilling and completion operations. The study evaluated hydraulic fracturing water cycle activities, including water acquisition, chemical additive storage and on-site mixing, hydraulic fracturing stimulations (i.e., the actual injecting of the fluid to fracture the production formation), handling of the produced water returned to the surface after fracturing and during production, and the ultimate disposal or treatment and reuse of the returned produced water. Each of the water cycle activities is addressed individually in the report.

Initially, the EPA concluded in their draft report that they did not find evidence that the mechanisms\* involved in hydraulic fracturing activities “have led to widespread, systemic impacts on drinking water resources in the United States.”<sup>46</sup> The EPA did, however, identify specific instances where individual mechanisms have led to drinking water resource impacts, including drinking water well impacts. They also acknowledged that the ratio of identified impact cases to the number of wells hydraulically fractured is very small. The EPA further explained that this finding may be the result of insufficient pre- and post-fracturing data on the quality of drinking water resources; the scarcity of long-term systematic studies; the proximity of other sources of contamination preventing a definitive link between hydraulic fracturing mechanisms and an impact; and the inaccessibility of some information on hydraulic fracturing activities and potential impacts.

This conclusion and recognition of the findings’ limitations did not alleviate concerns raised by the SAB peer review regarding the clarity and adequacy of the support behind these findings. The SAB expressed their concern, stating that they found them to be ambiguous and inconsistent with the data, observations, and levels of uncertainty discussed in the draft report. Specifically, the SAB indicated that the EPA did not support its conclusion quantitatively regarding the lack of evidence for widespread, systemic impacts of hydraulic fracturing on drinking water resources, and did not present the local or regional scale of impacts, define the terms “systemic” and “widespread,” nor clearly describe the system(s) of interest (e.g., groundwater, surface water). This critique of the draft findings prompted the EPA to revise their findings in the final report. The EPA indicated in their response to the SAB that they agreed that the concluding sentence could not be quantitatively supported given the existing data gaps and uncertainties. Additionally, the EPA recognized that the conclusion sentence in the draft report was understood by various readers in many different ways, thus signifying that it did not express the findings of the draft report clearly. Consequently, the sentence was removed from the final report.<sup>47</sup>

In the final report the EPA expressed that hydraulic fracturing activities can impact drinking water resources under certain circumstances.<sup>48</sup> The report identifies certain situations where impacts from hydraulic fracturing water cycle activities can be severe or recurrent:

- Water withdrawals during times or in areas with low water availability, principally where diminishing groundwater resources exist;

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\* These mechanisms include water withdrawals in times of, or in areas with, low water availability; spills of hydraulic fracturing fluids and produced water; fracturing directly into underground drinking water resources; below ground migration of liquids and gases; and inadequate treatment and discharge of produced water.

- Large-volume spills of hydraulic fracturing fluids, additive chemicals, or produced water that result in high concentrations of chemicals reaching groundwater resources;
- Fracture stimulations on wells with insufficient mechanical integrity, letting gases or liquids migrate to groundwater resources;
- Injection of fracturing fluids directly into groundwater resources;
- Discharge of undertreated produced water to surface water; and
- Disposal or storage of produced water into unlined pits.

The EPA again included an explanation of the findings that recognized gaps in the data and uncertainties restricted their complete understanding of the potential local and national impacts on drinking water resources; therefore, they could not characterize the severity of impacts, nor estimate the potential frequency of impacts on drinking water resources.

The EPA's revision of the conclusions motivated the three members of the SAB with industry experience to co-author a subsequent report summarizing the study and their experience serving on the SAB.<sup>49,50,51</sup> This summary identifies a series of factors that the authors assert affected EPA's study process. Foremost was the lack of oil and gas industry knowledge and consultation, data gaps, data interpretation issues, and pre-existing negative perceptions of hydraulic fracturing and the oil and gas industry.<sup>52</sup>

It was also observed that that the SAB members spent considerable time discussing fracture height growth, and if subsurface migration of fluids could access pathways and reach drinking water. It was explained that a study by Kevin Fisher and Norm Warpinski describing the natural limitations of fracture height growth was brought up multiple times, but this study did not make it into the report.

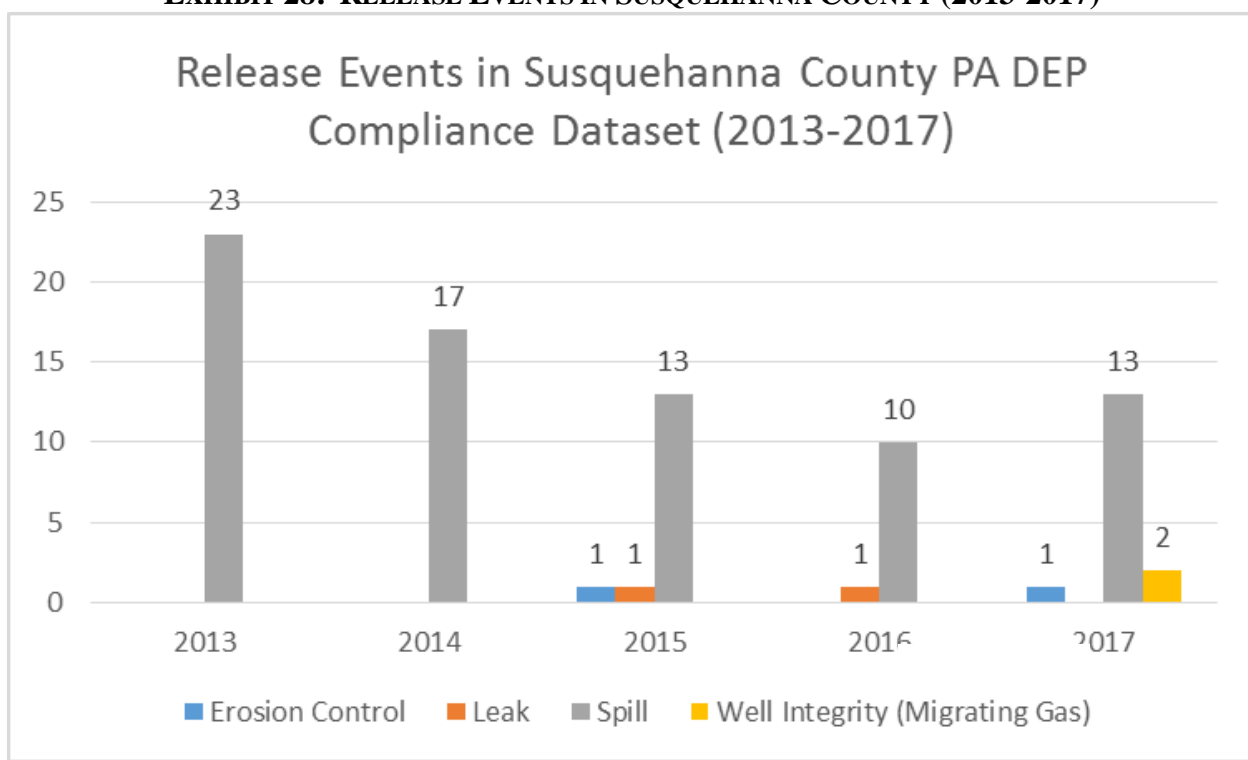
In the end, the industry members expressed their disappointment in the EPA study because it did not include any information about industry best practices to prevent spills, did not quantify risk or provide severity information, and did not include any substantive discussion of how hydraulic fracturing is regulated by states. The co-authors supported the conclusion of the original draft report and characterized it as "accurate, clear, concise, unambiguous, and supportive of the facts the EPA had reviewed."<sup>53</sup>

#### *2.2.5.4 PA DEP Violations – Susquehanna County*

To better understand the risk associated with the hydraulic fracturing water cycle mechanisms in Pennsylvania near the DRB, compliance data from Susquehanna County for years 2013-2017 was download from the PA DEP website.<sup>54</sup> We originally intended to analyze a larger sample of PA DEP compliance data but the data is presented without immediate violation identifiers so that it can be easily configured to identify spills with material type, quantity, cause, severity, etc. The data instead requires one to read the inspectors notes to extract the spill data of interest if recorded. This would be impractical for the entire state or multiple counties. Therefore, five years of data from the adjacent county with prolific development can serve as an indicator of potential development incidents for the DRB anticipated production extent. There are ~1,431 unconventional wells operating in Susquehanna County of which 781 have been drilled and hydraulically fractured from 2013-2017.

The results of this data request identified inspections\* of 112 wells at 89 pads. The inspections produced 310 violations and 61 enforcements actions. There were 82 incidents related to potential surface- or ground-water impacts identified, 76 spills, two leaks, two lack of erosion control, and two well integrity issues. Of these 82 incidents involving the release on materials only six were cited for a 401 violation indicating that the discharged substance may have reached the Waters of the Commonwealth. The six incidents included three produced water spill in 2013, and two well integrity and one lack of erosion control incidents in 2017. The amount of sediment or natural gas that may have reached the Waters of the Commonwealth in 2017 were not quantified in the dataset but these events were identified early and short lived. The three produced water spills in 2013 involved one bbl (42 gals), 75 bbls (3,150 gals) and an unreported amount. **Exhibit 28** shows these incidents by year, **Exhibit 29** identifies the materials release by year and the max volume in gallons of any single release per year, and **Exhibit 30** shows the incidents by material type released per year.

**EXHIBIT 28: RELEASE EVENTS IN SUSQUEHANNA COUNTY (2013-2017)**



\* Spills greater than 5 gallons are required to be reported to the PA DEP and these reports lead to site inspections, however not all inspections are a result of a reported spill, land owner complaint, spot, and unannounced inspections are also conducted.

**EXHIBIT 29: MAXIMUM QUANTITY PER MATERIAL TYPE RELEASED BY YEAR  
(SUSQUEHANNA COUNTY)**

Material Type (gals)	2013	2014	2015	2016	2017	
Antifreeze					10	1
Diesel Fuel	300	40		20	750	150
Ethylene Glycol	105					
Ferric Sulfate	200					
Frac Fluid (Water & Additives)	7560			1680		500.5
Frac Water (Fresh & Recycled)				10	200	
Glycol		210				
HCL Acid			7			
Hydraulic Fluid			2	21	15	
Lubricant	2.5					
Mineral Oil	840					
Oil Based Mud	5.5	420		84	3000	42
Produced Water	3150	3780		68	1000.5	126.5
Rigwash						500
Sediment						0
Unknown	5	0		0		
Water Base Mud	4200					

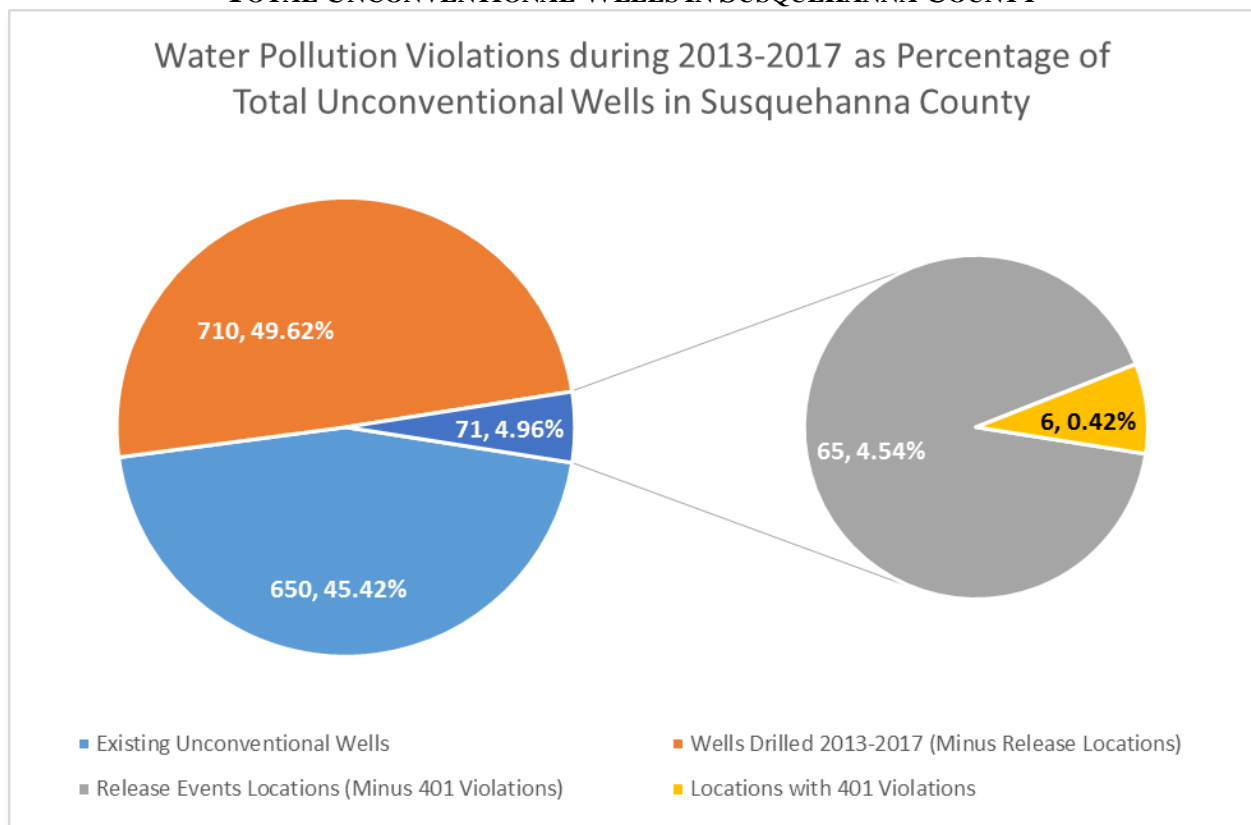
**EXHIBIT 30: NUMBER OF INCIDENTS BY MATERIAL TYPE PER YEAR  
(SUSQUEHANNA COUNTY)**

Material Type	2013	2014	2015	2016	2017	Total
Antifreeze				1	1	2
Diesel Fuel	2	1	1	1	2	7
Ethylene Glycol	1					1
Ferric Sulfate	1					1
Frac Fluid (Water & Additives)	2		2		1	5
Frac Water (Fresh & Recycled)			1	2		3
Gas					2	2
Glycol		1				1
HCL Acid		1				1
Hydraulic Fluid		1	1	1		3
Lubricant	1					1
Mineral Oil	1					1
Oil Based Mud	1	5	2	1	1	10
Produced Water	10	5	5	5	6	31
Rigwash					2	2
Sediment			1		1	1
Unknown	3	3	2			8
Water Base Mud	1					1
<b>Total</b>	<b>23</b>	<b>17</b>	<b>15</b>	<b>11</b>	<b>16</b>	<b>82</b>



It is also important to recognize that these 82 release events occurred at only 71 locations whereas there were 1,431 unconventional wells operating as of the end of 2017 and 781 new wells had been drilled over the five-year compliance review period. As a percentage, the locations with incidents account for 4.96% of the total operating unconventional wells and only 9.09% of the wells drilled during the period of 2013-2017 in Susquehanna County. The six events that were issued 401 violations for potentially reaching the Waters of the Commonwealth account for 0.42% of the total operating unconventional wells, 0.77% of the drilled wells in 2013-2017, and 8.45% of the locations with incidents. **Exhibit 31** graphically depicts the water violation events as a percentage of the total unconventional wells in Susquehanna County. Applying these percentages to the projected development rate for the DRB indicates that 3.63 (9.09% of 40 wells) release events would occur per year and there is less than a 0.5% chance that one of those events would potentially reach the Waters of the Commonwealth. It is understood that this analysis cannot completely forecast future events as there are numerous other factors to consider, such as: operator history, frequency of inspections, inspector due diligence, site location, operator environmental reverence, etc., but this does show that the mechanisms involved in hydraulic fracturing activities have not led to widespread, systemic impacts on drinking water resources in Susquehanna County.

**EXHIBIT 31: WATER VIOLATIONS DURING 2013-2017 AS PERCENTAGE OF TOTAL UNCONVENTIONAL WELLS IN SUSQUEHANNA COUNTY**



### 3 Economic Analysis

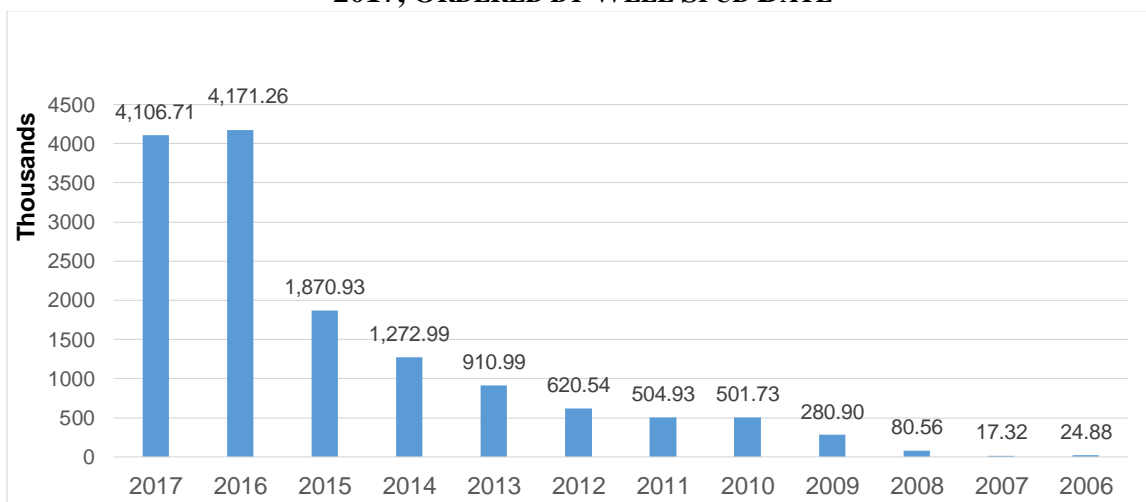
#### 3.1 Drilling and Production

As described in section 2, ALL estimates that 40 wells per year would be drilled in the six DRBC counties combined if there is no HVHF ban (see **Exhibit 13**). This drilling rate is based on resource potential and historic drilling data.

In order to estimate the economic impact of this drilling, an estimate of production from these wells must be made. ALL looked at production data from a representative nearby county, Susquehanna County, which is just west of the DRBC area in question, and which has experienced shale drilling and production over the last several years. Production volumes for 2017 for wells in the county were downloaded from the PA DEP website and then ordered by spud date, so that the age of each well could be determined.<sup>55</sup> The 2017 production for wells spudded in each year were averaged.

**Exhibit 32** shows the resulting decline curve averaged over the producing wells in the county. Production remains high for the first two years and then decreases. Average total production for the first ten years is ~14.3 billion cubic feet (Bcf).

**EXHIBIT 32: AVERAGE SUSQUEHANNA COUNTY NATURAL GAS PRODUCTION PER WELL IN 2017, ORDERED BY WELL SPUD DATE**



The wellhead price of natural gas will determine the value of this production, which determines the royalties that will be paid to landowners, and which is also correlated with the number of jobs that are generated by these wells. The EIA forecasts the future price of natural gas (but not the local or statewide price). EIA estimates that the Henry Hub price will average \$3.06 in 2018, rising to 4.07 in 2025 and \$4.17 in 2027, in 2017 dollars.<sup>56</sup>

Historically, the wellhead price of gas in the Marcellus region is lower than the Henry Hub price. The reason is that oversupply in the basin has saturated the Northeast gas market and new pipeline capacity has been blocked by protests and lawsuits. However, the differential between the wellhead price in the Marcellus play and the Henry Hub price has been narrowing as new pipeline capacity

is added. That differential has decreased from over \$1.50 per Mcf to around 90 cents per Mcf. As more pipelines are built and operating, that gap is expected to decrease even more.<sup>57,58</sup>

It is informative, therefore, to look at the value of the production from the representative well described above at different prices that may be received for the gas produced in the region, and in the six DRB counties in Pennsylvania, in the future. **Exhibit 33** shows the value of that production at \$2, \$3, and \$4 per Mcf, for a single well with the decline curve shown above and for the 40 wells that are forecast to be drilled annually.

**EXHIBIT 33: VALUE OF PRODUCTION FROM A REPRESENTATIVE PENNSYLVANIA MARCELLUS/UTICA SHALE WELL AND FROM 40 WELLS THAT WOULD BE DRILLED ANNUALLY**

Wellhead Price (\$/Mcf)	Value of ten years of production (\$millions)	
	Single Well	40 Wells
2.00	\$28.6	\$1,146
3.00	\$43.0	\$1,719
4.00	\$57.3	\$2,291

There are number of economic impact studies that estimate jobs resulting from shale gas development. Some use input-output models to analyze the flow of investment and expenditures throughout the local economy. They can then use this analysis to develop simple multipliers. For example, Considine, et al., from Pennsylvania State University, using the IMPLAN model, find that each Marcellus Shale well in Pennsylvania generates \$6.2 million in economic impact in the state.<sup>59</sup> Therefore, 40 wells per year would generate nearly \$250 million of economic impact annually.

The same study concludes that every \$1 million of gross output generated by Marcellus gas wells results in 6.8 direct and indirect jobs in Pennsylvania. Using the values of the natural gas production shown in **Exhibit 33**, this translates to a range of approximately 780 to 1,560 jobs created annually for every 40 wells drilled each year in DRB counties.

Alternatively, DeLeire, et al., estimate that each well generates between 4.7 and 5.8 new jobs two years out from spudding the well.<sup>60</sup> For 40 new wells per year, this comes to 188 to 232 jobs per year. Note that these are only the direct jobs generated in the mining and oil and gas sector.

The jobs directly associated with these wells are generally high-paying ones. As the shale gas industry was taking hold in the Marcellus region, the U.S. Bureau of Labor Statistics reported increasing pay for oil field workers in Pennsylvania, growing to almost \$85,000 per year in 2012.<sup>61</sup> In January 2018, the website salary.com reported salaries for Oil and Gas Supervisors in Pennsylvania between \$83,000 and \$102,000 per year.<sup>62</sup>

In addition to oil and gas field workers, there are many other industry support jobs and jobs in associated sectors. Many people, such as landmen and attorneys, are required to identify prospective properties for leasing, write leases, and conduct related legal and regulatory work. Seismic surveys also require manpower, and create demand for local business services. Once a drilling site is located, site preparation and construction and drilling begins and with it the need for services, labor, and other locally supplied activities. If natural gas is found in commercial

quantities, infrastructure such as well production equipment and pipelines are installed, which further stimulates local business activity.

Finally, as production flows from the well, royalties are paid to landowners. These expenditures stimulate the local economy and provide additional resources for community services, such as health care, education, and charities. The workers in the industry earn wages, which increase household incomes, which then stimulates spending on local goods and services. These impacts associated with household spending are called induced impacts. The total economic impacts are the sum of the direct, indirect, and induced spending, which are the result of the investment by shale gas producers. The total amount of these expenditures and their distribution across various industries and sectors can be estimated using input-output models which contain data on the flows among those sectors that result from investments. However, the extent of that kind of analysis is beyond the scope of this report.

### 3.2 Lease and Royalty Income

Leasing and production of natural gas resources generates revenue for the landowner in the form of lease bonus payments and royalties. Lease bonus payments are upfront payments by the producer to the landowner in exchange for the execution of a lease to produce oil and gas from the subsurface. The size of these payments are a function of the perceived resource potential (for example, payments may be higher if there are nearby producing wells), competition for leases, and the negotiating ability of the parties involved. They are usually paid on a per-acre basis.

While there will undoubtedly be lease bonuses paid in the six DRBC counties in the absence of a HVHF ban, the amount of those payments is very difficult to forecast. It is not determined only by the number of wells that are expected to be drilled. Many areas are leased, and bonuses paid, on speculation without ever drilling a well on the acreage. This may be due to nearby drilling experience that did not pan out commercially, to lack of capital to drill, to regulatory restrictions that make it impractical to drill, or for other reasons. Also, we do not know how much of the available resource has already been leased in these counties.

The amount of payments can vary widely and are especially uncertain in an area that does not have much drilling experience, as in these counties. There is anecdotal information on the size of bonus payments in the Pennsylvania Marcellus area. They may range from a few hundred dollars per acre to \$2,500 an acre and possibly more.<sup>63,64</sup>

To get an idea of the magnitude of payments that might be made in the six counties in question, assume that 10%-20% of the accessible acreage, as shown in section 2, is leased with bonus payments ranging from \$500 to \$2,500 an acre. The accessible, unrestricted area is approximately 201 square miles (see **Exhibit 7**) or 128,640 acres. The range of lease bonus payments on 10% (12,864 acres) to 20% (25,728 acres) of this unrestricted acreage is shown in the following table.

**EXHIBIT 34: SAMPLE LEASE BONUS TOTALS IN THE SIX DRBC COUNTIES**

Bonus Payment per Acre	10% of unrestricted land	20% of unrestricted land
\$500	\$6,432,000	\$12,864,000
\$1000	\$12,864,000	\$25,728,000
\$2500	\$32,160,000	\$64,320,000

This acreage may be a very conservative estimate of the amount of future leasing. While the accessible surface area is restricted by regulatory setbacks, flood zones, and forested areas, oil and gas leases address the amount of subsurface acreage to be accessed. Horizontal drilling may reach two or three miles from the surface location of the wellhead and therefore can access many times the area that is unrestricted at the surface. Lease bonuses would pay for the subsurface acreage to be produced rather than the surface footprint.

Once wells are drilled and gas is produced, the landowner collects a royalty on the value of the production. Pennsylvania has a statutory minimum of 12.5% royalty on that revenue, but it can often be higher. In one recent example, Chief Oil and Gas signed a lease with the Pennsylvania Game Commission for a royalty in excess of 20%.<sup>65</sup> The following table shows the amount of royalties that would be paid on the first ten years of revenue from 40 gas wells (one year's estimated drilling) (see **Exhibit 35**) at three wellhead prices and two royalty levels.

**EXHIBIT 35: ROYALTY TOTALS FOR TEN YEARS OF PRODUCTION FOR 40 WELLS THAT WOULD BE DRILLED ANNUALLY**

Wellhead Price (\$/Mcf)	Royalties for 10 years production, 40 wells (\$millions)	
	12.5%	20.0%
2.00	\$143	\$229
3.00	\$215	\$344
4.00	\$286	\$458

### 3.3 State Taxes and Fees

#### 3.3.1 Unconventional Gas Impact Fee

The wells that are projected to be drilled in the gas shales in the DRBC counties will generate revenue for state and local governments in the form of taxes and fees. This revenue would not be realized if there is a ban on HVHF. The state imposes an impact fee on unconventional gas wells and there are permit fees charged by the PA DEP for drilling permits. In addition, landowners, employees, and producers would pay income tax on lease payments, royalties, wages, and profits.

Pennsylvania is the only major gas-producing state that does not impose a severance tax on gas production. Rather, the state charges an impact fee on unconventional gas wells.<sup>66</sup> This fee is charged for each new gas well, starting in the year the well is spudded, and continuing for 15 years in decreasing amounts. The fee is set by the Pennsylvania Public Utility Commission and is based on the price of natural gas. It is also adjusted for inflation. In 2017, the fee for the first year, i.e., the year the well is spudded, is \$50,700. It decreases to \$10,200 in year 15. This is based on a gas price of \$3.11 per Mcf. The fee would increase if the price of gas exceeds \$5.00 per Mcf and would decrease if the price falls below \$3.00 per Mcf.<sup>67</sup> Based on the EIA price projections cited above, it is expected that this fee would remain stable, adjusted for inflation, over the next ten years.

Under the current fee schedule, each unconventional natural gas well drilled in the Pennsylvania DRB counties would pay \$314,700 over 15 years. Therefore, 40 wells drilled annually would pay \$12,588,000. The projected 400 wells that would be drilled over the next ten years would pay a total of \$125,880,000 in impact fees over their producing lives.

This revenue is distributed to state agencies, counties, and municipalities according to a complex formula that is specified in the law. In general, the first \$25.5 million collected each year is

distributed to a series of state agencies. Of the remainder collected, 60% goes to counties and municipalities that have unconventional gas wells, and 40% is distributed to all counties in the states as well as a fund for infrastructure improvements and environmental stewardship.<sup>68</sup> Thus, these wells will directly benefit state and local agencies and governments across Pennsylvania through distribution of the impact fee.

### 3.3.2 Drilling Permit Fees

The PA DEP charges a fee for the drilling permit needed to drill a gas well. This fee is based on the length of the wellbore, including both the vertical and horizontal sections. Therefore, in order to calculate the fee, we have to make assumptions about the wells that will be drilled.

The Utica Shale underlies most of the DRB area in question (see **Exhibit 4**). This formation ranges between 7,000 and 9,500 feet in depth in this area.<sup>69</sup> We will assume an average depth of 9,000 feet for the future wells in these counties. The lengths of the laterals for horizontally drilled wells has been increasing over time as technology and experience improve. A lateral length of 10,000 feet is reasonable, giving a total wellbore length of 19,000 feet. The PA DEP permit fee for a well of this length is \$4,400.<sup>70</sup>

The Marcellus Shale is somewhat shallower than the Utica, about 6,000 feet in this area.<sup>71</sup> It lies under a small portion of Wayne County, and is underlain by the Utica Shale. Therefore, any Marcellus well here could also be drilled into the Utica as well. If limited to 6,000 feet in depth, and with a 10,000 foot lateral, the permit fee would be \$3,900, just \$500 less than the fee for a Utica well.

Assuming that 40 wells per year are drilled into the Utica Shale, the combined permit fees per year collected by the PA DEP would total \$156,000\*. Over ten years, the amount collected would be \$1,560,000.

### 3.3.3 Income Taxes

Pennsylvania would collect state income taxes from individuals and corporations as a result of the increased economic activity from drilling unconventional gas wells in the DRB counties. These taxes would be collected on royalty and lease bonus income, wages, and corporate profits.

Individual income tax on royalty payments would be charged at the state's individual tax rate of 3.07%.<sup>72</sup> Based on the royalty amounts shown in **Exhibit 35** above, and applying this income tax rate, the amount of taxes collected for royalties received from 40 wells over 10 years of production would be as shown below in **Exhibit 36**. The table shows the amounts that would be collected depending on natural gas wellhead price and royalty rate that is agreed to between the landowner and the producer. For ten years' worth of drilling, i.e., 400 wells, the taxes collected would be ten times the amounts shown, between \$44 million and \$141 million. It should be noted that these amounts are only estimates in that each landowner's tax situation may be different, depending on other income and deductions, as well as tax structure. Some landowners may arrange other tax structures, such as limited liability corporations or partnerships, to receive the royalty income and therefore may pay taxes at different effective rates.

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\* The PA DEP is considering raising the permit fee in fiscal year 2019 so these amounts will potentially increase.

**EXHIBIT 36: INDIVIDUAL INCOME TAXES ON ROYALTY INCOME FOR TEN YEARS OF PRODUCTION FOR 40 WELLS THAT WOULD BE DRILLED ANNUALLY**

Wellhead Price (\$/Mcf)	Taxes on Royalties for 10 years production, 40 wells (\$millions)	
	12.5%	20.0%
2.00	\$4.4	7.0
3.00	\$6.6	\$10.6
4.00	\$8.8	\$14.1

As described in the previous section, the amounts of lease bonus payments in the future is very uncertain. However, **Exhibit 36** gives an idea of the magnitude of such payments to landowners given certain assumptions. Of course, these landowners would pay state income taxes on that income. The table in **Exhibit 37** below applies the state income tax rate to those amounts.

**EXHIBIT 37: STATE INCOME TAXES ON LEASE BONUS PAYMENTS UNDER DIFFERENT BONUS LEVELS AND ACREAGES LEASED**

Bonus Payment per Acre	10% of unrestricted land	20% of unrestricted land
\$500	\$197,462	\$394,925
\$1000	\$394,925	\$789,850
\$2500	\$987,312	\$1,974,624

Other income taxes would be paid by wage earners employed by the gas producers, by companies that support those producers, and by associated sectors, such as hotels and restaurants used by those workers. In addition, the income earned by those workers would be spent on the local economy and further increase wages in the area, leading to increased income taxes. The flow of those wages is complex and is modeled by input-output models in a number of studies of economic impact.<sup>73</sup> Such an analysis is beyond the scope of this report. In addition, there is uncertainty about what those workers would be doing in the absence of this drilling activity. Some may travel to Pennsylvania from other regions. Their wages would be a true increase in the income of the local area. The same would be true for unemployed workers who are hired due to gas development. Some may be working locally in other sectors and choose to work in the gas fields because of higher pay. In those cases, only the taxes on the incremental wages should be counted as an increase in state revenues. Those assumptions and analysis likewise are beyond the scope here. There would certainly be income to the state from additional personal income taxes.

Similarly, state corporate income taxes will be assessed on profits realized by the gas producers, which are determined by the cost of the wells, operating expenses, and revenues. Once again, there will also be increased economic activity in other sectors of the economy as a result of the drilling and production of new wells, and input-output analysis is needed to track the flows of those dollars and resulting profits and taxes.

## 4 Landscape Alterations

It has been asserted that hydraulic fracturing alters the landscape and poses risks to high value water resources in the DRB and that the development and subsequent disturbances would impact the drainage area of Special Protection Waters.<sup>74</sup> This section attempts to quantify landscape alterations that might affect water quality during HVHF activities in the DRB.

### 4.1 Quantity of Potential Disturbances

Advances in horizontal drilling and hydraulic fracturing have led operators to be able to drill longer lateral wellbores, multi-lateral wells, and batch drilling or developing more than one well on a pad.<sup>75</sup> A study from the Fall of 2014 states there are an average of five wells per pad in the Marcellus, however, a couple of recent articles indicate the industry's trend is to go large with companies now placing 10 to 20 wells per pad with plans to go even bigger, as much as 40 wells per pad.<sup>76,77 78</sup> These larger sites means fewer well pads in total and a 10-acre surface area can theoretically extract natural gas from underneath an area nearly the size of a city (35,000 acres).<sup>79</sup> Operators have discovered that drilling as many wells, and as long a lateral as technology or land constraints will allow, is the most efficient and economical way to develop the resources. Other benefits include consistent well development, less truck traffic, smaller overall footprint, less access roads and right-of-ways, contained water management, and improved compliance. The dimensions of the pad are determined based on the total number of wells and the associated surface equipment. Companies plot and plan how rigs will be configured on the pad, drill order of wells, where completions equipment is placed on site, and how the permanent production facility will function. Planning each pad allows optimal use of space. **Exhibit 38** shows the EQT Corporation's Cogar pad, a 10-acre pad in Amwell Township, PA that holds 22 unconventional horizontal shale wells.<sup>80</sup> **Exhibit 39** shows an aerial view of a 2013 Cabot Oil & Gas pad with 10-wells in PA.<sup>81</sup>

With regards to lateral lengths, it was reported that Range Resources is averaging 6,000-foot laterals, CONSOL on the other hand is reaching 8,000-foot laterals, and EQT Corp. reported the current "economic and technological limit" is 21,000 feet, or 4 miles in the Marcellus. Considering how much the industry has changed in the past five years in Pennsylvania alone, it is safe to say all development quantities are subject to frequent and rapid changes.

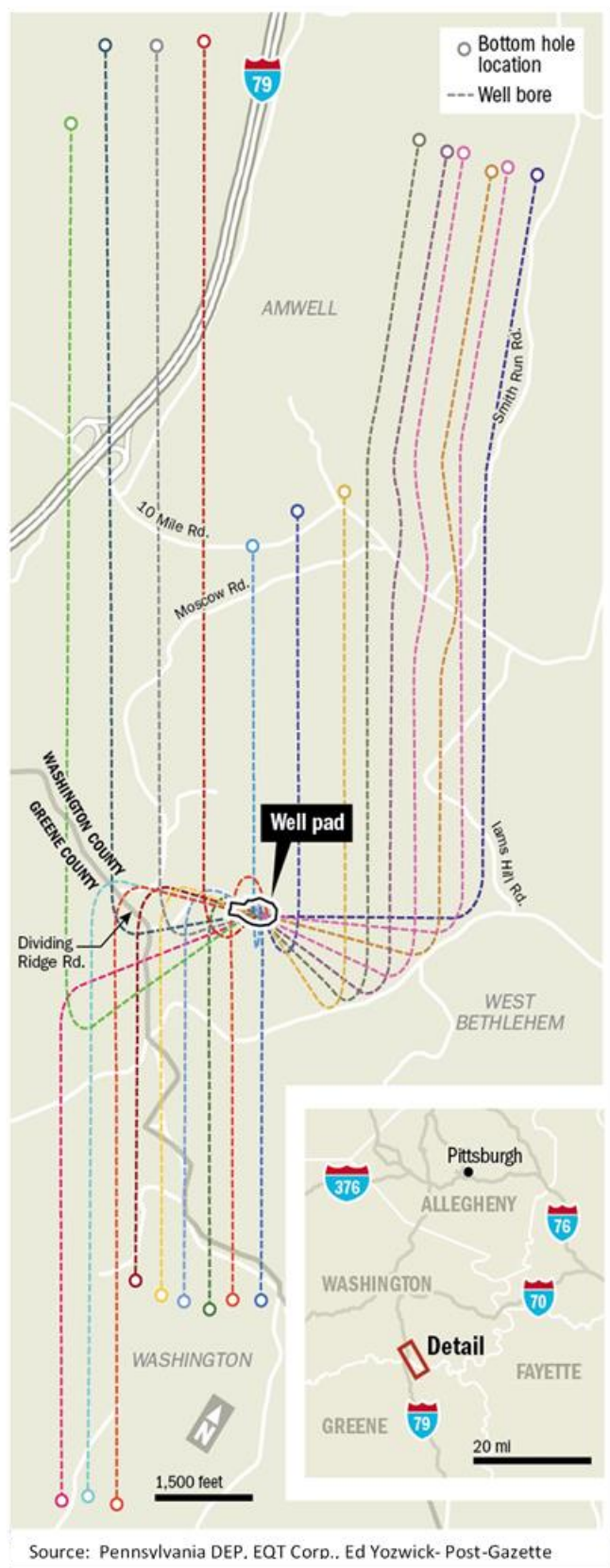
To quantify the potential surface disturbances from projected HVHF development in the DRB within the available surface of the anticipated production extent (APE) area one needs to consider the annual rate of development and the likely placement of well pads and the number of wells on each pad. The rate of development as projected (Exhibit 13) suggests that approximately 40 wells per year could be development in the APE of the DRB if the commission were to impose similar restrictions and setbacks as outlined in Article 7\* (2010) versus the complete prohibition of HVHF as is currently proposed. A deeper look at the estimate affirms that the wells would be spread out over the five counties at approximately 5 wells per year per county with the exception of Wayne County where both the Marcellus and Utica shales are present and 15 wells per year are estimated.

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\* Note, the Article 7 analysis should not be construed as an endorsement or agreement with the previously proposed regulations it is merely a case study to determine if the anticipated gas development could be conducted with restrictions in place that are protective of the DRB versus the complete prohibition of any development, thus indicating that other options are practical.



**EXHIBIT 38: EQT CORP. – COGAR WELL PAD**



Wells per year does not correlate directly to well pads per year as the economics of developing hydrocarbons, optimum well spacing, and technical challenges, coupled with the constraints of drilling in the in the DRB would affect quantity and placement of wells. Therefore, we think existing operators would take a cautious approach to development in this thermally mature region of the Marcellus and Utica and develop multi-well pads with at least five wells per pad initially. This would allow operators to maximize productivity and efficiency as well as take advantage of the limited surface available without docket or approval requirements in the DRB. This approach suggests that only one well pad would be developed per county per year, except for Wayne County which would experience three pads annually. This means the number of pads developed the first year drilling is allowed would be eight and subsequent years could see eight pads each or existing pads could be expanded to hold 10 or more wells thereby reducing the number of new pads annually. The 10-year development estimate called for a total of 400 wells therefore the number of pads over this duration would range from slightly less than 40 to a maximum of 80.

The average surface area impacted as a result of constructing a multi-pad with road and utility access, and processing and water management areas is approximately 11.5 to 15 acres.<sup>82,83</sup> Applying the average acreages altered per well pad to the number of well pads anticipated to be developed each year under the 5-wells per pad or 10+ wells per pad scenarios generates an anticipated annual acres altered per year estimate. (see **Exhibit 40**). Under the 5-wells per pad scenario there would be eight pads developed annually altering an estimate 120 acres annually (8 pads x 15 acres each)

**EXHIBIT 39: 2013 CABOT OIL & GAS PAD WITH 10 WELLS**

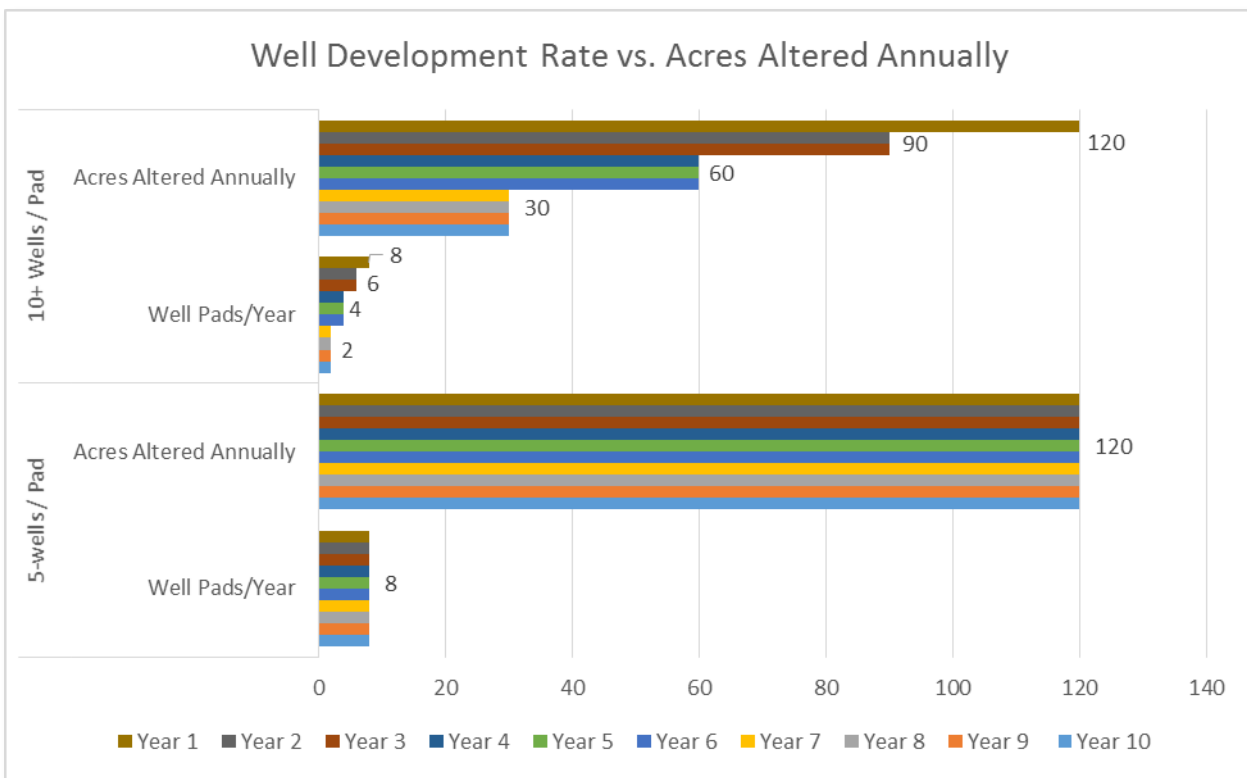
Source: Cabot Oil & Gas, Siemens - The Vault

resulting in a total of 1,200 acres (1.87 sq. miles) altered over the 10-year development period. Under the 10+ wells per pad scenario there would be eight pads the first year but as wells are added to existing pads the number of new pads per year would drop over the subsequent years resulting in only 40 pads and half the altered acreage at 600 acres (0.94 sq. miles).

As a well transitions from the drilling and completion phase to the production phase, land disturbance is reduced as a result of restoration activities for the well pad and associated facilities. Additionally, BMPs can be employed to effectively address erosion and sedimentation control during both the construction and operational phases of a natural gas development project.

It should be noted that these altered acre totals do not account for restoration activities once the initial drilling and fracturing operations are complete. Restoration typically includes revegetation, reversing compacted soils, contour adjustments, etc. At the completion of restoration activities approximately 3.5 to 5 acres per pad site remain altered depending of road lengths and processing equipment remaining on site.<sup>84,85</sup>

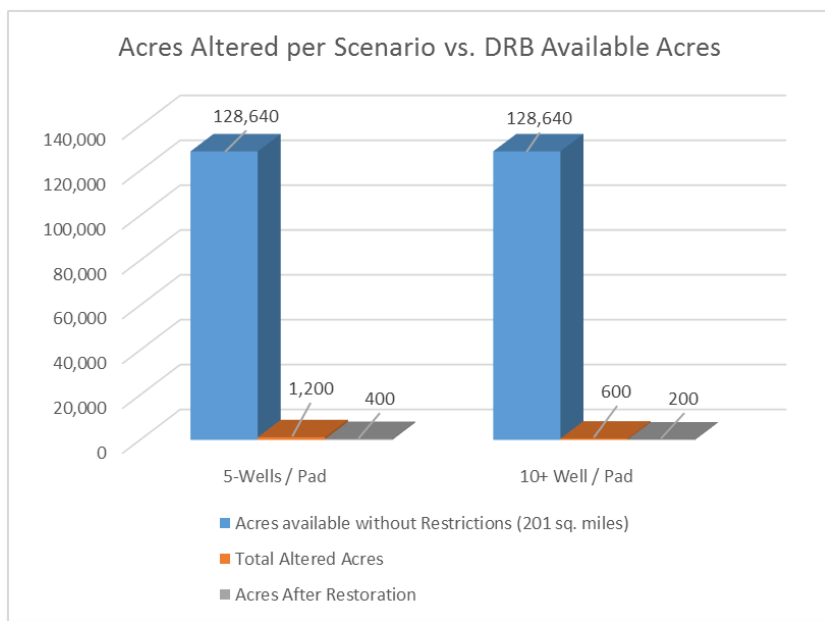
**EXHIBIT 40: ESTIMATED ACRES ALTERED PER YEAR BY DEVELOPMENT SCENARIO**



The remaining altered acreage after restoration efforts over the development period for the two scenarios results in 400 acres for the 5-well per pad scenario and only 200 acres for the 10+ wells per pad scenario. **Exhibit 41** depicts the altered acreage by scenario as compared to the surface available without restriction as identified in **Exhibit 7**.

Land use requirements for natural gas development are a factor to be considered with respect to construction practices and controlling sedimentation and erosion to maintain basin water quality, the overall footprint would be relatively small and temporary. The percentage of land remaining altered under each scenario as compared to the acreage available without restriction is miniscule at 0.311% and 0.155% respectively. The percentage of land remaining altered as compared to the total acreage within the anticipate

**EXHIBIT 41: ALTERED ACREAGE PER SCENARIO**



production extent (1,787 sq. miles or 1,143,680 acres) of the DRB is infinitesimal at 0.0350% and 0.0175% respectively.

## 4.2 Quality Impacts

The freshwater quality at any location in the DRB echoes the cumulative effects of numerous influences along waters path. Anthropogenic undertakings on landscape scales can affect both water quality and quantity. Changes in the land cover and land management practices have been recognized as crucial factors influencing the hydrological system, via changes in runoff as well as water quality. There have been several waves of research that tried to reveal the effects of land use and land cover changes on the quality of surface water.<sup>86</sup> Impact of human landscape alterations and management decisions such as controversial agricultural practices, large residential developments, and industrial uses was studied by the EPA in the late 1990's to generate and develop models and tools to evaluate alternative scenarios and compare potential impacts.<sup>87</sup> This EPA study generated numerous papers and presentation but of interest are the models that were developed and can be used to evaluate the projected development scenario in the anticipated production extent of the DRB to provide a more definitive assessment of the potential impacts. A water quality model, SWAT (Soil and Water Assessment Tool) which has been used to evaluate watersheds with regards to alternative futures was developed under this study and is available for use with ArcView applications (GIS analysis).

Results of the SWAT model applied to the agricultural development scenarios, as well as the current landscape and a landscape representing the historic past, of the study area under investigation indicated that substantial decreases in nutrient and sediment export from agricultural watersheds could be achieved if practices involving input reductions and increases in perennial cover were employed over extensive areas of the agricultural landscape. Fortunately for the DRB the footprint for natural gas development as estimated for the 40 or 80 well pads is tiny and would be constructed in locations most likely without tree cover and only affect perennial covered areas for a relatively short duration (<1years per pad site) before restoration activities were instituted. This development pattern within the DRB unrestricted surface cover would emphasize the application of BMPs for sedimentation and erosion control as well and spill control to avoid even minor events that might affect water quality.

Well field-related erosion is typically a result of pad site construction, access road development, widening of existing roads, installation of pipelines, and placement of production facilities. These activities can be controlled with the use of various BMPs such as:

- Protecting bare soils from the wearing effects of water and wind.
- Reducing or preventing soils from being transported offsite to a stream, surface water body, or wetland.
- Conducting routine inspections of erosion and sediment controls after each rain event.
- Implement sediment controls with erosion controls.
- Divert drainage from off-site to reduce stormwater run-on.
- Eliminate direct discharge to surface water.
- Construct a stabilized entrance or wheel wash to reduce mud on streets/ roads from vehicle drag out.

- Stabilize roads with crushed rock.
- Stabilize embankments.
- Minimize area of disturbance.
- Limit activities during rainfall.
- Rock construction entrance.
- Establish buffers for sensitive areas.
- Water bars or broad based dip in roadways
- Permanently stabilize ditches and drainage with grass or rock.
- Culvert pipe rock apron (inlet/outlet protection).
- Erosion control batting/mat.
- Riprap (armoring).
- Geotextiles (separator fabric).
- Level spreaders.
- Surface roughening.
- Terracing.
- Watering for dust (wind).
- Temporary and permanent seeding.
- Mulching.
- Hydro seeding.
- Re-establish vegetation cover promptly.
- Silt fence or super silt fence.
- Silt sock or compost filter sock (wattles).
- Straw or hay bale barrier.
- Gravel or stone filter berm.
- Sediment trap or filter bag.
- Ditch check (silt sock or rock).
- Brush pile sediment barrier.
- Vegetative filter strip.

There is a myriad of information available about each of the BMPs, however most critical might be the development of an Erosion and Sediment Control Plan as required by the PA DEP. Integral to these plans are the inclusion of a well site layout with grading and boundary, well pad grading plan, plan and profile of access road, location and size of erosion and sediment control devices, drainage area map, locations of wetland/ponds or stream nearby, soils map, temporary and permanent stabilization measures, construction details and specifications, construction sequencing, emergency containment map, and a maintenance plan/schedule. These measures combined with good oversight should reduce the chance of any development efforts regardless of size affecting the water quality long-term while conducting hydraulic fracturing water cycle mechanisms.

## 5 Water Treatment Technologies

While flowback\* and produced water is commonly injected underground using Underground Injection Wells regulated under the Federal Safe Drinking Water Act, not all areas have suitable geology for such wells. In addition, that water can represent a valuable resource that can substitute for fresh water. A common solution is to recycle the water for use in fracturing other wells.

The objective when treating water to recycle it for hydraulic fracturing is to produce clean brine that is compatible with the fracture fluid chemistry being used, and to do so economically. Depending on the fracturing chemistry used, a water treatment process must be able to remove hydrocarbons, gelling agents, metals, hydrogen sulfide, iron sulfide, boron, and suspended solids. It has to be able to handle variable quantities and qualities of inlet water. In order for the economics to work, the water treatment must compete favorably with the acquisition of fresh water and disposal of produced wastewater. The goal for reuse of the produced water is to apply enough water treatment to condition the water so that it does not impact the fracturing fluid formulation/effectiveness, proppant conductivity, or well productivity of the wells being fractured.

A multitude of technologies exist that are designed to remove specific constituents or a range of constituents from produced water. Generally, several technologies are used in combination. The number of process stages and technologies required for any specific project will be based on the type and concentration of constituents that must be reduced or removed to meet the water reuse specifications. Determining the most suitable treatment technology for re-use must take into consideration management alternatives, treatment drivers, economics, and regulatory requirements in addition to the chemical constituents present in the feed water.

Recycling the flowback and produced water in this way has a number of benefits. It directly offsets new source water demand for scarce fresh water resources, preserving that water for other uses. It reduces the volume of waste that must be disposed of and it economically produces clean brine water that can be used as a base for hydraulic fracturing of additional wells.

### 5.1 Water Compatibility for Use or Reuse in Hydraulic Fracturing

Reuse of flowback and produced water for additional hydraulic fracturing avoids putting that water back in the surface environment and has the additional benefit of reducing demand for fresh water. However, that water must be treated in order to be suitable for fracturing operations. The type of treatment needed depends on the geology where the well will be fractured as well as the characteristics of the water being recycled.

Produced water is also handled in a distinctly different manner in each of the shale plays. For example, in the Barnett Shale Play, a long history of production in the Fort Worth Basin area, coupled with favorable geologic conditions, has resulted in a relatively large injection disposal well network and available water floods. However, as water sourcing has become more complex, the water recycling market has increased in the Barnett Play. In the Fayetteville Shale, early water management was included in land farming of fluids; however, changes in regulation have

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\* The oil & gas industry generally does not use the term “flowback water” to refer to fluids generated from a well. Rather, the term “flowback” is used to refer to a process and all fluids generated from a well are recognized as “produced water.” However, the DRBC uses this term in its materials and therefore we echo that usage in this report in order to maintain consistency and make it clear for the DRBC and other reviewers.

eliminated land farming and now most produced water is hauled to other parts of the state or other states where injection disposal and water floods are available. The cost of hauling the water through these methods has resulted in the industry looking at recycling and re-use of produced water after treatment as a possible option. The Marcellus and Utica shales are similar to the Fayetteville with an overall lack of existing injection disposal infrastructure so disposal of produced water has involved a great deal of trucking of water. The size of the Marcellus and Utica play, the costs of source water, and limited disposal options have resulted in several operators moving to recycling using treatment technologies.

In addition, each of these shale gas plays has a distinct produced water character which, combined with the infrastructure differences, affects the management of this produced water. Water production profiles, water quality, and disposal options are also distinctly different for the major shale gas plays, requiring developers of this resource to adapt to each play in order to remain successful in developing these resources.

Treatment of source water for fracturing, whatever the source, nearly universally involves inhibition/removal of: (a) suspended solids, (b) micro-organisms, and (c) scaling ions. Reuse of flowback and produced water in subsequent operations can require removal of total dissolved solids (TDS) in addition to the removal of heavy metals and in some cases bacteria. Other treatment technologies, and sometimes multiple treatment technologies, must be implemented to reach the quality that is required for the selected management option.

Chemical additives typically used in the blended fluid to ensure its optimum fracturing properties include the following:

For total suspended solids control:

- Iron particulate inhibitors – to control scale formation with a neutral pH iron control agent, also preserving the activity of other scale inhibitors.
- Other scale inhibitors – for sulfates and carbonates, controlled by a blended scale control inhibitor.

For control of fracturing pressure and formation damage:

- Friction reducers (salt tolerant) – such as the nano-particle friction reducer (NFR) to maintain friction reduction enabling the high flow rate fracturing.
- Biocide controllers – control sulfate reducing bacteria, slime-forming bacteria, iron oxidizing bacteria, and more.
- Clay stabilizers – temporary (KCl) and longer-term inhibitors, now often low-toxicity clay stabilizers.

Numerous physical treatment options are available and applied to meet treatment goals of source waters for HVHF fluids. Commercial treatment processes and their applications for HVHF source waters are listed in **Exhibit 42**.

**EXHIBIT 42: WATER TREATMENT PROCESSES AND APPLICATIONS**

Water Treatment Processes	Methods	Applications
<b>Suspended Solids Removal</b>	<ul style="list-style-type: none"> <li>• Settling: Oxidation and Precipitation</li> <li>• Settling: Chemical Flocculation and Precipitation</li> <li>• Settling: Electro Coagulation Enhanced</li> <li>• Desanders and Hydrocyclones</li> <li>• Auto Flush Sand Filters</li> <li>• Membrane Filtration: Micro, Ultra, &amp; Nano Pores</li> </ul>	<ul style="list-style-type: none"> <li>• Precipitates iron and removes scale, polymers, bacteria</li> <li>• Removes dispersed solids including scale</li> <li>• Removes suspended solids and some ions</li> <li>• Removes particles to 50 microns</li> <li>• Removes particles to about 50 microns</li> <li>• Removes particulates to 1 micron</li> </ul>
<b>Oil and Grease Removal</b>	<ul style="list-style-type: none"> <li>• Separators / Skimmers</li> <li>• Flotation</li> <li>• Multi-media Filtration</li> <li>• Oxidation: Chloro Oxidants</li> </ul>	<ul style="list-style-type: none"> <li>• Oil removal</li> <li>• Remove fines and oil to less than 50 ppm</li> <li>• Adsorb some soluble organics, oily fines filtration</li> <li>• Destroy oil dissolved and as fine suspension</li> </ul>
<b>Scale Removal / Imbibition</b>	<ul style="list-style-type: none"> <li>• Scale Control with Chemical Addition</li> <li>• Oxidation</li> <li>• Settling and Filtering</li> <li>• Adsorption: Ion Exchange Resins, Activated Carbon</li> </ul>	<ul style="list-style-type: none"> <li>• Chemical packages; scale inhibitors to hinder particulate formation, chemicals used vary with salinity</li> <li>• Precipitates iron, kills bacteria and destroys polymers</li> <li>• Removes scale particles</li> <li>• Remove multi-valent ions and some soluble organics</li> </ul>
<b>Bacterial Imbibition / Removal</b>	<ul style="list-style-type: none"> <li>• Biocide Addition</li> <li>• UV Light Treatment</li> <li>• Oxidation: Ozone, Chloro compounds</li> </ul>	<ul style="list-style-type: none"> <li>• Inhibit, destroy sulfate reducers, etc., during treatment and down hole</li> <li>• Destroy bacteria after particulate removal</li> <li>• Kill bacteria, destroy polymers, oxidize iron</li> </ul>
<b>Desalination</b>	<ul style="list-style-type: none"> <li>• Ion Exchange</li> <li>• Reverse / Forward Osmosis</li> <li>• Thermal Treatment: Vapor Recompression</li> </ul>	<ul style="list-style-type: none"> <li>• Low salinities to 10,000 ppm, removes ions</li> <li>• Low salinities to 40,000 ppm, removes TDS, sensitive</li> <li>• High salinities (50,000 – 200,000 ppm), yields clean water</li> </ul>

The treatment technologies and processes listed above are in widespread commercial use by operators. Numerous other treatment technologies are in development, with limited application, or used in conjunction with the listed technologies. Detailed assessments of most treatment technologies commonly in use are provided in a study conducted by the Colorado School of Mines.<sup>88</sup>

The following is a brief description of some common water treatment processes. They can be used either by themselves or in combination with each other. Many vendors combine the processes in different ways to achieve the water quality desired.

## 5.2 Water Treatment Processes

### 5.2.1 Settling and Dilution

Settling and Dilution are the easiest and least expensive of the produced water treatment processes. Settling is the simple removal of suspended solids using gravity in a large, lined pit. The pit has to provide sufficient residence time for the solids to settle. Dilution can be done while pumping the produced water to the fracturing job by merging flow from a produced water source and a fresh water source. The salinity in the combined stream is controlled by the amount of fresh water added to the produced water.



### **5.2.2 Filtration**

There are many different types of filtration systems including sock, sand, carbon, glass and diatomaceous earth. For filtering fracturing water while it is being pumped, the sock filter is the most common. A 25-micron filter is used for most fracturing jobs. Most of these filter systems are highly mobile and can operate at 100 barrels per minute.

### **5.2.3 Thermal Evaporation/Distillation: Thermal Vapor Compression and Mechanical Vapor Recompression**

Distillation can be done with either small mobile units or large stationary units. The distillation process can be used with water up to 300,000 parts per million (ppm) TDS and can remove particles as small as one micron. The distillation process has the highest energy consumption of any of the water treatment technologies used. Distillation can process wastewater to meet or exceed environmental discharge water quality standards that are currently in place.

In general terms, distillation involves boiling water into steam, which is then passed through a cooling chamber and subsequently condensed into a purified form. This process is used to segregate water impurities from the purified product for collection and disposal. More modern approaches for the distillation process include the use of Thermal Vapor Recompression (TVR) and Mechanical Vapor Recompression (MVR). In principle, both technologies distill water in a similar overall process but differ in how increases to steam pressure and temperatures are applied.<sup>89</sup> With TVR, steam jet ejectors are used to raise the pressure and temperature of vapors, whereas, with MVR, a mechanical compressor is used instead of steam jet ejectors.

Thermal evaporation distillation is most effective at desalinating brine, and removing inorganic compounds such as heavy metals (iron, barium and lead) and nitrate, TDS, and hardness (calcium and magnesium). In some cases thermal evaporation distillation can be effective at the removal of organic material such as bacteria, through the boiling process. When using MVR, the treatment of raw water (or brine) with TDS concentrations of 60,000-80,000 milligrams per liter (mg/L) will result in fresh water recovery rates of approximately 70%-85%.<sup>90</sup> Evaporators are capable of treating produced water with higher TDS concentrations, but levels above 80,000 mg/L result in loss of water recovery (or increased brine concentrate) and an increase to treatment costs due to the additional energy required for treatment. In general, MVR systems are limited to treating water with TDS concentrations of 150,000 mg/L with a water recovery rate of approximately 50%.<sup>91</sup> Problems associated with this technology include fouling with organic deposits and corrosion within the heat exchanger that is caused by the recirculation of brine, which is used for heat recovery in the evaporator.

### **5.2.4 Chemical Treatment**

The addition of chemicals to promote agglomeration (flocculation) of polymers (friction reducers or scale inhibitors) and suspended solids is typically one of the early treatment steps before produced water is migrated to other treatment processes when, for instance, disposal or beneficial reuse options are being considered. In addition, water used for drilling or fracturing may come from several sources, including freshwater supply wells, chlorinated city water, rainwater, pond water, and lake water; each of which contain some bacterial content.<sup>92</sup> For example, chemical treatment of source or recycled water that is being used for fracturing purposes may require the

addition of biocides to reduce bacteria in drilling equipment, which if left untreated, may lead to fouling.

Flocculation (i.e., the adhesion of smaller particles to form large particles through aggregation) is used prior to evaporation or membrane treatment technologies to minimize the effects of scaling, or to reduce the build-up of polymers when the objectives of water treatment are for fracturing reuse. The process of flocculation allows particles to be more easily retained and removed as solids in the form of a “filter cake” or sludge. In general terms, the agglomeration of particles (flocs) facilitates separation of solid particles from their suspension liquid by means of sedimentation which in turn allows the solid phase to be removed in a minimal volume via filtration. The three main types of chemicals used in the flocculation process are inorganic electrolytes such as aluminum (aluminum sulphate), lime, ferric chloride, and ferrous sulfate; organic polymers; and synthetic polyelectrolytes with anionic or cationic functional groups. The water can then be run through a dissolved air filtration (DAF) unit or clarifier to remove the floating solids and those that sink to the bottom of the tank. The sludge recovered from the DAF or clarifier can then be dewatered, tested, and if compatible, disposed of in a land fill.<sup>93</sup>

In the oil and gas industry, it is common practice for untreated produced waters to be placed in open impoundments while awaiting use in the fracturing process. Microbes that can cause problems with equipment can grow under these conditions. Biocides are added to drilling and fracturing fluids to prevent micro-organism growth on associated equipment, as well as to reduce bio-fouling of fractures.

### **5.2.5 Electro Coagulation**

The electro coagulation process uses either steel or aluminum electrodes and an electric current to remove oil, suspended solids and heavy metals from produced water. It can treat water with up to 300,000 TDS. Electro coagulation has become a rapidly growing area of wastewater treatment due to its ability to remove contaminants that are generally more difficult to remove by filtration or chemical treatment systems, such as emulsified oil, total petroleum hydrocarbons, suspended solids, and heavy metals. As water passes through the electro coagulation cell, multiple reactions take place simultaneously. As the reactions continue, large flocs form that entrain suspended solids, heavy metals, emulsified oils and other contaminants. Finally, the flocs are removed from the water in downstream solids separation and filtration process steps.

### **5.2.6 Reverse Osmosis**

Reverse Osmosis (RO) is a water treatment technology using semipermeable membranes to remove salt and other constituents from water. Pretreatment of the water prior to the RO membrane is essential to minimize the effects of fouling which can greatly reduce the efficiency of the separation and prevent damage to the membrane. Types of pre-treatment are dependent on the quality of the water processed. Energy is the single largest cost to processing water using RO. One of the biggest drawbacks to using RO is the limited amount of useable water recovered. Depending on the salinity of the water being treated, 50% or more of the treated water could end up as heavy brine. In many cases, the heavy brine is a waste product and has to be disposed of.

When two solutions of different concentrations are placed between semi-permeable membranes, the solvent will pass from the less concentrated to the more concentrated solution. This flow

produces a pressure difference which is referred to as osmotic pressure. If these pressures are reversed by applying energy from a pump, pure water is forced from the more concentrated solution through the membrane into the less concentrated solution. As the pressure increases, the concentration of solution passing along the membrane is also increased. The subsequent buildup of dissolved solids along the membrane requires continual increases in energy (between 140 and 400 pounds per square inch [psi]) to pass the pure water through the membrane.

RO is subject to fouling if pretreatment methods are not used. Pretreatment requirements include the removal of suspended solids to prevent colloidal and bio-fouling, as well as the removal of dissolved solids to prevent scaling and chemical attack. Pretreatment can include media filters to remove suspended particles, ion exchange softening or anti-scalant to remove hardness, temperature and pH adjustment to lower chemical solubilities to prevent scaling, activated carbon or bisulfite to remove chlorides, and cartridge (micro) filters to remove some dissolved particles and any remaining suspended particles. In addition, RO water treatment systems may utilize a crossflow process to keep the membrane clear. In the crossflow process flow of water is reversed momentarily to push sediment and scaling off the screen, or an acid wash may be used on thicker membranes.<sup>94</sup>

RO water treatment can be applied to convert brackish water, seawater or brine to drinking water; reclaim wastewater; and recover dissolved salts from various industrial processes. RO can treat water with TDS concentrations up to 40,000 mg/L but is not effective at treating non-ionized materials such as gases or large organic molecules that will not pass through the membrane. Relative to distillation, the RO treatment produces lower water recovery rates (approximately 65%) or a larger brine stream, which will increase disposal costs.<sup>95</sup> However, RO water treatment requires less energy than thermal distillation treatment, which may help to lower operating costs. In addition, an advantage of reverse osmosis over evaporation is that the lifecycle costs of RO are about half those of evaporators.

### **5.2.7 Ion Exchange**

Ion exchange involves the exchange or replacement of dissolved constituents by attachment to electrostatically charged ion exchange material, often consisting of a synthetic resin. The process uses an exchange of ions between a solid resin and the water. Prior to running through the ion exchange resin, the water must be pretreated to prevent fouling the resin. Ion exchange resins are classified as cation exchangers, which exchange positively charged ions, and anion exchangers, which exchange negatively charged ions. Ion exchange is a reversible chemical reaction wherein positively or negatively charged ions present in the water are replaced by similarly charged ions present on the surface of the resin. The resins are either naturally occurring inorganic zeolites or synthetically produced organic resins. When the replacement ions on the resin are exhausted, the resin must be recharged with more replacement ions. The ion exchange process relies on the natural tendency of water solutions to be electrically neutral. Therefore, ions in the resin bed are exchanged with ions of similar charge from the source water and as result of the exchange process, no reduction in ions is obtained.<sup>96</sup>

The process of ion exchange historically has been used to remove hardness ions such as calcium and magnesium by replacing them with sodium and chloride ions.<sup>97</sup> However, in the case of oil and gas produced water, ion exchange is typically used to preferentially remove sodium. For oil

and gas-produced water, ion exchange is used to deionize water by replacing ions, such as conductive salts (desalination), with H<sup>+</sup> and OH<sup>-</sup> when pure water is required.<sup>98</sup> However, ion exchange has limited applicability as a primary treatment method in the shale gas industry since the technology is limited to removing constituents in waters with TDS levels below approximately 5,000 mg/L, but is applicable as a pretreatment method to remove other water constituents such as heavy metals (i.e., barium, iron, strontium) and alkalinity or as a polishing treatment.<sup>99</sup>

### 5.2.8 Electrodialysis and Electrodialysis Reversal

Traditionally, electrodialysis treatment of water has been used to desalt brackish water to produce higher quality water. The basic principles of this treatment process are similar to ion exchange in that dissolved ions present in water have either a positive or negative charge and are attracted to electrodes with an opposite electric charge. In electrodialysis, membranes that allow either cations or anions (but not both) to pass are placed between a pair of electrodes. These membranes are arranged alternatively (cation and anion) to selectively collect charged ions and a spacer sheet that permits feed water to flow along the face of the membrane is placed between each pair of membranes. Positively charged ions (e.g., Na<sup>+</sup>) migrate to the cathode and negatively charged ions (e.g., Cl<sup>-</sup>) migrate to the anode. During migration the charged ions are rejected by similarly charged ion exchange membranes. As a result, water within one compartment is concentrated, leaving desalted water within another compartment of the electrodialysis unit.

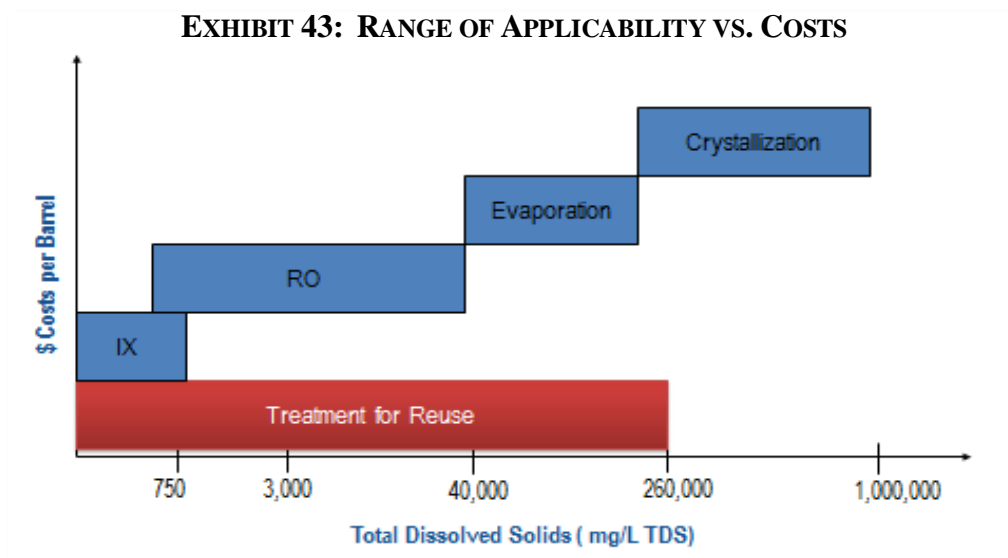
An improvement to electrodialysis, referred to as Electrodialysis Reversal (EDR), utilizes the same concept except that in EDR, there is periodic automatic reversal of polarity and cell function to reverse the flow of ions across the membrane. The reversal process is useful in breaking up and flushing scales, slimes, and other deposits in the cells before they build up and create flow problems across the cells. The flushing allows the unit to operate with fewer pretreatment chemicals, which helps to minimize membrane fouling.<sup>100</sup>

Electrodialysis and EDR differ from a normal ion exchange process by utilizing both cation and anion selective membranes to segregate charged ions extracted from a water solution.<sup>101</sup> Depending on the number of stages present within an electrodialysis unit, this treatment process can remove approximately 25% to 60% of TDS, with a resulting waste stream of approximately 15% to 30% of the raw water input. The number of stages required for the electrodialysis process is driven by feed water quality and the economics of achieving the desired outcome quality. Primary factors that impact feed water quality are hardness, alkalinity, TDS, temperature, and the presence of ions, such as iron and manganese. Electrodialysis is limited to treating TDS concentrations ranging from 4,000 mg/L to 15,000 mg/L.<sup>102</sup>

In general, electrodialysis is more expensive than RO but is more resistant to membrane fouling,<sup>103</sup> which in turn can reduce costs typically associated with membrane replacement or cleaning. The electrodialysis treatment process is applicable for removing and/or reducing aluminum, barium, bromide, cadmium, calcium, chloride, 97%-98% of copper, 90%-95% of cyanide, 94%-97% of potassium, TDS, and volatile organic compounds (VOCs). Electrodialysis does not remove bacteria, colloidal material, or silica. Electrodialysis and EDR do not remove small suspended material, so 5 to 25 micron polishing filters immediately before the feed inlet are necessary. Pretreatment is also necessary for electrodialysis to control scale build-up of calcium carbonate

(CaCO<sub>3</sub>) and magnesium hydroxide, as well as iron ions. Typically, these constituents are controlled either chemically by acid addition for pH adjustment and/or by cartridge filter.

The following graph in **Exhibit 43** is a qualitative representation of the relative costs of several of these treatment options along with the range of TDS in the water that can be treated by each technology.



### 5.3 Recycling Water for Non-Oil and Gas Uses

Produced water and flowback water can be recycled for other, non-oil and gas uses as well, after treatment. This again has the benefit of reducing the demand for fresh water in these applications.

#### 5.3.1 Agricultural Use

Produced water can be used for agricultural livestock and irrigation applications, depending on the quality of the water available for use. These applications are generally most desirable in arid regions. An increase in available water for agricultural livestock can result in increased cattle density, increased weight gain in cattle, and a subsequent increase in range utilization. Incorporating stock water use in a produced water management plan can be a viable component, but stock ponds should be limited by the volume of water the system can handle without creating overflow channels that could impact downstream properties. As a result, stock water is generally used in concert with additional management options. Produced water availability increases the opportunities for farming through irrigation, especially in areas with limited water resources. Regions historically limited to dry land farming could incorporate forms of irrigation to grow additional higher-water-needs crops. The suitability of produced water for irrigation purposes is limited by the water quality, and the physical and chemical properties of the soils to be irrigated. Furthermore, it is limited by landowner commitment to the additional management actions related to addressing the use of poorer water quality and potential regulatory constraints.

#### 5.3.2 Industrial Use

A variety of existing industries could benefit from the increased water supply from oil and gas produced water, including coal mines, animal feeding operations, cooling tower water for various

industrial applications, car wash facilities, commercial fisheries, enhanced oil recovery, and fire protection.

In coal operations, produced water is primarily useful for dust suppression operations and restoration efforts including recharging depleted groundwater aquifers and irrigation for surface revegetation. Use of produced water for coal operations could reduce the impact on both groundwater and surface water supplies that would otherwise be used to maintain operations. Coal mine use is limited primarily by timing, as water availability for restoration and recharge must coincide with water demand, and transportation.

Many industrial activities, such as chemical plants and power plants, require water as a cooling agent. Also, coal-fired power plants and coal-to-liquids plants require large volumes of water to sustain operations. Many proposed coal-to-liquids operations could become realities with the available produced water for potential use. Water quality is a hindering factor, as high TDS waters can cause mineral deposits in a closed system, reducing flow and heat exchange. Therefore, the water must be treated to the required quality.

Field and car wash facilities have become more prevalent as the awareness of noxious weed spreading increases. Spreading of noxious weeds can make any site restoration more complicated as well as negatively impacting ecosystems, farmland and grazing land. Using oil and gas produced water to wash equipment and vehicles before and after entering areas with high probability of transporting noxious weeds can significantly reduce the potential distribution to other areas. Field washing facilities are typically installed as part of restoration projects and, therefore, are short term. However, applicability is limited by produced water quality.

Enhanced Oil Recovery (EOR) is another common produced water management option which involves injecting produced water into a secondary or advanced recovery well into conventional oil-producing horizons. The injected fluid creates a waterflood that sweeps the oil towards production wells strategically located throughout a mature field. This process is fairly common in oil and gas operations and can be effectively implemented with varying degrees of water quality. Unlike other beneficial uses, water quality limits this option in the other direction; high-quality produced water would be better suited for other beneficial uses. This process is typically constrained by both transportation and water volumes available.

Produced water availability would have to be in the near vicinity of mature conventional oil development to make the beneficial use economically viable. Furthermore, large volumes of water are necessary to implement secondary or enhanced oil recovery operations, making the demand for water long term; in some situations, supplemental water sources may be necessary.

Fire protection and fighting fires does not require the high-quality water and produced water could supply both fire hydrants and sprinkler systems, reducing the strain on drinking quality water traditionally obtained from municipal supply systems.

## **5.4 Non-Discharge Options**

Where any discharge of produced or treated water is a major concern, options that result in zero discharge of water can allow hydraulic fracturing to take place while addressing those concerns.

### 5.4.1 Evaporation ponds

Evaporation ponds are designed to store water at the surface so that natural evaporative processes can move the water from the land to the atmosphere. As the evaporation process occurs, pure water is removed, leaving behind increased TDS water which over time can become concentrated brine. Evaporation pits are lined to prevent infiltration of the water. Use of evaporation ponds is most suited for arid areas with high natural evaporation rates. Reduced evaporation rates can occur as a result of landscape and topographical variations, landowner constraints, natural runoff or flooding, and seasonal variations. In areas of shale gas development, evaporation pits are not a likely beneficial use alternative primarily because high salinity waters, such as produced water, have low evaporation rates. Furthermore, in areas such as the Marcellus and Utica play, precipitation far exceeds the amount of evaporation that will occur.

### 5.4.2 Crystallization

Crystallization is an equilibrium-based separation technology that uses energy as the separating agent and is often comprised of a combination of treatment processes that are more energy efficient at removing water from lower TDS waters.<sup>104</sup> RO is commonly used for an initial pass through if TDS levels are sufficiently low. Crystallization processes can then be used to further concentrate the RO concentrate stream by extracting water from the brine solution. Total volume of the liquid concentrate is reduced while the associated TDS increases significantly. The water (extract phase) can be recirculated through the RO and concentrate (sludge-water) flows through evaporators. Water is evaporated with heat or pressure differential and the dissolved solids remain in sludge state. Handling and disposal of reduced volume of waste in slurry/sludge form is easier.

Salt is extracted from brine (salt solution) by evaporating away the water. Usually an industrial site for salt production would contain a series of evaporators through which the brine becomes progressively more concentrated. Each evaporator contains a large number of tubes through which the brine is circulated. The tubes are heated by steam and the large number of tubes gives a large surface area for heat transfer to the brine. As the brine boils, salt crystals begin to form and sink to the bottom of the evaporator. This produces a thick mixture of salt crystals and salt solution, which is fed into another evaporator to repeat the process and concentrate the salt further. The process can have several stages to concentrate the slurry. In commercial salt applications the slurry can be centrifuged to dry for industrial use or heat dried for human or food grade use.<sup>105</sup> For crystallization to occur from a solution it must be supersaturated; this means that the solution has to contain more solute entities (molecules or ions) dissolved than the solution would contain under the equilibrium (saturated solution) state. Supersaturation can be achieved by various methods. The most common ones in industrial practice are 1) solution cooling, 2) addition of a second solvent to reduce the solubility of the solute (technique known as antisolvent or drown-out), 3) chemical reaction, and 4) change in pH.

Crystallization is often used to process the concentrate from Reverse Osmosis and Electrodialysis from low TDS water. Evaporators can treat RO or Electrodialysis concentrates to a total solids (TS) concentration of 300,000 ppm, subject to some solubility limitations. The sludge or solid can then be used commercially, as in salt production, or disposed of properly resulting in a zero liquid discharge system.

**Exhibit 44** summarizes the input and output water quality and other characteristics of the water treatment technologies discussed above.<sup>106</sup>

**EXHIBIT 44: SELECTED FEATURES OF WATER TREATMENT TECHNOLOGIES**

Treatment Technology	Feed Water Quality	Output Water Quality	Infrastructure Considerations	Pretreatment Needs
<b>Settling and Dilution</b>	No restrictions	Depends on system design	Large footprint required	None
<b>Filtration</b>	All TDS levels	> 90% oil and grease removal	Requires a vessel to contain the media and pumps and plumbing to implement backwashes	None
<b>Thermal Distillation</b>	Applicable to a wide TDS range	Very high quality	Large physical plant size.	Feed water requires screens and rough filtration to remove large suspended solids
<b>Chemical Treatment</b>	Applicable to all TDS levels	Depends on the process	Depends on the process	None
<b>Reverse Osmosis</b>	Most applicable for TDS ranging from 20,000 to 47,000 mg/L	Typically, product water TDS ranges from 100 to 400 mg/L	Requires minimal operational footprints	Requires extensive pretreatment to mitigate harmful water quality constituents that will otherwise foul or scale the membrane
<b>Ion Exchange</b>	Average TDS application range is between 500 mg/L and 7,000 mg/L	Dependent on feed water salinity and operating conditions	Highly variable operational footprint depending on the application	Requires pretreatment options including suspended solids, oxidized metals, and scaling mineral removal
<b>Electrodialysis</b>	Cost effective to TDS < 8,000 mg/L	Product water quality depends on ED stages, can achieve over 90%	No special infrastructure requirement	Requires removal of particles and other scaling and fouling substances through filtration, pH adjustment, and addition of antiscalant
<b>Evaporation Ponds</b>	2,000 mg/L to high TDS >40,000 mg/L	N/A	Large land area required	None
<b>Crystallization</b>	Not sensitive to the level and type of brine	No product water	No special infrastructural requirement	May include settling and filtration to remove suspended solids and organic matter



## 6 Conclusions

In conclusion the development of hydrocarbon resources in the APE of the DRB would be limited to a six county area in the Upper Region where thermally mature Marcellus and Utica shales would most likely produce dry gas; there are an estimate 201 square miles or 128,640 acres available for development under the old Article 7 rules without restriction; the reasonably expected development rate would be approximately 40 wells per year; current hydrologic conditions in the Upper Region of the DRB have been strained due to reduced annual precipitation for the past few years; the water withdrawn for HVHF in the APE is estimated at ~447 Mgals annually or 1.22 Mgal/d representing only 2.23% of the current estimated USGS daily withdrawal for the APE or only 0.81% of the DRBC reported withdrawals for the Upper Region; the compliance violations in Susquehanna County over the past 5-years indicate that 3.63 release events might occur per year in the APE and there is less than a 0.5% chance that one of those events would potentially reach the Waters of the Commonwealth; the landscape disturbances associated with pad development would range from 400 to 200 acres (0.625 – 0.31 sq. miles) over the 10-year development period following restoration activities; state and private revenues generated by the development of natural gas would be significant with estimates ranging from \$148 million to \$475 million annually; and water treatment technologies are available that would reduce withdrawals, recycle produced water, and eliminate discharges.

The analysis presented in this report demonstrates that the potential risks to the environment posed by unconventional gas development are controllable and negligible and are offset by considerable potential benefits, and that a prohibition of HVHF in the DRB is not justified. The reasonable rate of development estimated, the focus on dry gas, the anticipated small surface footprint, the comparatively minor amount of water that would be withdrawn, the advances in pad containment and spill management that industry has made, and the projected economic benefits of unconventional gas development all lead to this logical conclusion. Furthermore, given the exceptionally low number of violations in nearby Susquehanna County over a period that saw nearly four times as much drilling activity as is anticipated for the APE, as well as the water treatment technologies available for recycling and zero discharge that are protective of the environment, the DRBC should reconsider its proposed regulations regarding oil and gas development in order to better balance the risks and benefits of such development in accordance with the DRBC Comprehensive Plan.

## 7 Endnotes

<sup>1</sup> ALL Consulting, “Analysis of Delaware River Basin Commission Proposed (Article 7) Natural Gas Development Regulations” (April 2011).

<sup>2</sup> Delaware River Basin Commission, Notice of Public Hearing on 18 CFR Parts 401 and 440, Proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities; Additional Clarifying Amendments (November 30, 2017), <http://www.nj.gov/drbc/library/documents/HydraulicFracturing/RulemakingNotice113017.pdf> (accessed February 20, 2018).

<sup>3</sup> Pennsylvania Department of Environmental Protection, “Marcellus Shale,” <http://www.dep.pa.gov/business/energy/oilandgasprograms/oilandgasmgmt/marcellus-shale/Pages/default.aspx> (accessed March 9, 2018).

<sup>4</sup> Pennsylvania Department of Health, “Unconventional Oil and Natural Gas Development” (March 2017), [http://www.health.pa.gov/My%20Health/Environmental%20Health/Documents/Mar2017\\_UONGD.pdf](http://www.health.pa.gov/My%20Health/Environmental%20Health/Documents/Mar2017_UONGD.pdf) (accessed March 12, 2018).

<sup>5</sup> U.S. Energy Information Administration, “Utica Shale Play: Geology Review” (April 2017), [https://www.eia.gov/maps/pdf/UticaShalePlayReport\\_April2017.pdf](https://www.eia.gov/maps/pdf/UticaShalePlayReport_April2017.pdf) (accessed February 19, 2018).

<sup>6</sup> U.S. Energy Information Administration, “Marcellus Shale Play: Geology Review” (January 2017), [https://www.eia.gov/maps/pdf/MarcellusPlayUpdate\\_Jan2017.pdf](https://www.eia.gov/maps/pdf/MarcellusPlayUpdate_Jan2017.pdf) (accessed February 19, 2018).

<sup>7</sup> Brian J. Cardott, “Introduction to Vitrinite Reflectance as a Thermal Maturity Indicator,” Search and Discovery Article #40928 (2012), [http://www.searchanddiscovery.com/pdfz/documents/2012/40928cardott/ndx\\_cardott.pdf.html](http://www.searchanddiscovery.com/pdfz/documents/2012/40928cardott/ndx_cardott.pdf.html) (accessed February 22, 2018).

<sup>8</sup> U.S. Energy Information Administration, “Utica Shale Play: Geology Review” (April 2017), [https://www.eia.gov/maps/pdf/UticaShalePlayReport\\_April2017.pdf](https://www.eia.gov/maps/pdf/UticaShalePlayReport_April2017.pdf) (accessed February 19, 2018).

<sup>9</sup> U.S. Energy Information Administration, “Marcellus Shale Play: Geology Review” (January 2017), [https://www.eia.gov/maps/pdf/MarcellusPlayUpdate\\_Jan2017.pdf](https://www.eia.gov/maps/pdf/MarcellusPlayUpdate_Jan2017.pdf) (accessed February 19, 2018).

<sup>10</sup> U.S. Energy Information Administration, Petroleum & Other Liquids, Monthly Spot Prices (released February 14, 2018), [https://www.eia.gov/dnav/pet/pet\\_pri\\_spt\\_s1\\_m.htm](https://www.eia.gov/dnav/pet/pet_pri_spt_s1_m.htm) (accessed February 20, 2018).

<sup>11</sup> U.S. Energy Information Administration, Natural Gas, Henry Hub Natural Gas Spot Price, Dollars per M Btu (released February 14, 2018), <https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm> (accessed February 22, 2018).

<sup>12</sup> Trent Jacobs, “Schlumberger: New Automated Hydraulic Fracturing Tech Trims Time and Workforce Requirements,” *Journal of Petroleum Technology* (April 6, 2017), <https://www.spe.org/en/jpt/jpt-article-detail/?art=2892> (accessed February 18, 2018).

<sup>13</sup> Stephen Rassenfoss, “They Are Not Drilling Shale Wells Like They Used To,” *Journal of Petroleum Technology* (January 25, 2018), <https://www.spe.org/en/jpt/jpt-article-detail/?art=3832> (accessed February 22, 2018).

<sup>14</sup> U.S. Department of Energy, *Natural Gas Liquids Primer: With a Focus on the Appalachian Region* (December 2017), <https://energy.gov/sites/prod/files/2017/12/f46/NGL%20Primer.pdf> (accessed February 16, 2017).

<sup>15</sup> Pennsylvania Department of Environmental Protection, Interactive Reports – Permits Issued Detail Report / Year to Date-Permits Issued by County and Well Type Report, [http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil\\_Gas/Permits\\_Issued\\_Count\\_by\\_Well\\_Type\\_YTD](http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Permits_Issued_Count_by_Well_Type_YTD) (accessed February 21, 2018).

<sup>16</sup> Pennsylvania Department of Environmental Protection, Interactive Reports - SPUD Data Report / Wells Drilled By County, [http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil\\_Gas/Wells\\_Drilled\\_By\\_County](http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/Wells_Drilled_By_County) (accessed February 21, 2018).

<sup>17</sup> U.S. Department of the Interior, Bureau of Land Management, Northeastern States Field Office, *Reasonable Foreseeable Development Scenario For Fluid Minerals, Pennsylvania* (September 2011).

<sup>18</sup> U.S. Energy Information Administration, Natural Gas, Henry Hub Natural Gas Spot Price, Dollars per M Btu (released February 14, 2018), <https://www.eia.gov/dnav/ng/hist/rngwhhdm.htm> (accessed February 22, 2018).

<sup>19</sup> U.S. Energy Information Administration, Natural Gas, “U.S. Crude Oil and Natural Gas Proved Reserves, Year-end 2016” (released February 13, 2018), <https://www.eia.gov/naturalgas/crudeoilreserves/> (accessed February 22, 2018).

- 
- <sup>20</sup> U.S. Energy Information Administration, “Marcellus Shale Play: Geology Review” (January 2017), [https://www.eia.gov/maps/pdf/MarcellusPlayUpdate\\_Jan2017.pdf](https://www.eia.gov/maps/pdf/MarcellusPlayUpdate_Jan2017.pdf) (accessed February 19, 2018).
- <sup>21</sup> Pennsylvania Department of Environmental Protection, PA Oil and Gas Mapping, Interactive website, <http://www.depgis.state.pa.us/PaOilAndGasMapping/OilGasWellsStrayGasMap.html> (accessed February 6, 2018).
- <sup>22</sup> Delaware River Basin Commission, Hydrologic Information – Annual Summaries, <http://www.nj.gov/drbc/hydrological/reports/annual-hydro-reports.html> (accessed February 15, 2018).
- <sup>23</sup> Molly A. Maupin, Joan F. Kenny, Susan S. Hutson, John K. Lovelace, Nancy L. Barber, and Kristin S. Linsey, “Estimated Use of Water in the United States in 2010,” U.S. Geological Survey Circular 1405 (2014), <https://pubs.usgs.gov/circ/1405/pdf/circ1405.pdf> (accessed February 22, 2018).
- <sup>24</sup> Delaware River Basin Commission, *Draft Water Resources Program, FY 2017 – 2019* (January 2017), <http://www.state.nj.us/drbc/library/documents/WRP2017-2019DRAFT.pdf> (accessed February 21, 2018).
- <sup>25</sup> Delaware River Basin Commission, Notice of Public Hearing on 18 CFR Parts 401 and 440, Proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities; Additional Clarifying Amendments (November 30, 2017), <http://www.nj.gov/drbc/library/documents/HydraulicFracturing/RulemakingNotice113017.pdf> (accessed February 20, 2018).
- <sup>26</sup> Apache Corporation, *Sustainability in a Changing Environment*, 2016 Sustainability Report (2016), [http://www.apachecorp.com/Resources/Upload/file/sustainability/APACHE-Sustainability\\_Report\\_2016.pdf](http://www.apachecorp.com/Resources/Upload/file/sustainability/APACHE-Sustainability_Report_2016.pdf) (accessed January 31, 2018).
- <sup>27</sup> Hess Corporation, *2016 Sustainability Report* (2016), <http://www.hess.com/sustainability/sustainability-reports/sustainability-report-2016#1> (accessed January 31, 2018).
- <sup>28</sup> Chesapeake Energy, *2016 Corporate Responsibility Highlights* (2017), 31, <http://www.chk.com/Documents/responsibility/2016-Highlights-Document.pdf> (accessed January 2018).
- <sup>29</sup> David B. Jostenski, “Water Management Plans,” Water Use Assessment Section, Pennsylvania Department of Environmental Protection, [http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/IndustryResources/TrainingWorkshops/MarcellusWMP\\_2010\\_05\\_04.pdf](http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/IndustryResources/TrainingWorkshops/MarcellusWMP_2010_05_04.pdf) (accessed February 8, 2018).
- <sup>30</sup> Susquehanna River Basin Commission, Low Flow Protection Policy Related to Withdrawal Approvals, Policy No. 2012-01 (December 14, 2012), [http://www.srbc.net/policies/docs/2012-01\\_Low\\_Flow\\_Protection\\_Policy\\_Related\\_to\\_Withdrawal\\_Approvals\\_12-14-12\\_fs170475.PDF](http://www.srbc.net/policies/docs/2012-01_Low_Flow_Protection_Policy_Related_to_Withdrawal_Approvals_12-14-12_fs170475.PDF) (accessed February 8, 2018).
- <sup>31</sup> Susquehanna River Basin Commission, “Frequently Asked Questions (FAQs): Questions About Surface Water and Groundwater Withdrawals” (no date), [https://www.srbc.net/programs/natural\\_gas\\_development\\_faq.htm](https://www.srbc.net/programs/natural_gas_development_faq.htm) (accessed February 8, 2018).
- <sup>32</sup> Charles Abdalla, “Water Withdrawals for Development of Marcellus Shale Gas in Pennsylvania,” PennState Extension (no date), <https://extension.psu.edu/water-withdrawals-for-development-of-marcellus-shale-gas-in-pennsylvania> (accessed February 8, 2018).
- <sup>33</sup> James L. Richenderfer et al., *Water Use Associated with Natural Gas Development: An Assessment of Activities Managed by the Susquehanna River Basin Commission, July 2008 through December 2013*, Pub. No. 299 (April 2016), 39, [http://www.srbc.net/pubinfo/techdocs/NaturalGasReport/docs/SRBC\\_Full\\_Gas\\_Report\\_fs306397v1\\_20160408.pdf](http://www.srbc.net/pubinfo/techdocs/NaturalGasReport/docs/SRBC_Full_Gas_Report_fs306397v1_20160408.pdf) (accessed February 19, 2018).
- <sup>34</sup> Hess Corporation, *2016 Sustainability Report* (2016), <http://www.hess.com/sustainability/sustainability-reports/sustainability-report-2016#1> (accessed January 31, 2018).
- <sup>35</sup> Chesapeake Energy, *2016 Corporate Responsibility Highlights* (2017), 31, <http://www.chk.com/Documents/responsibility/2016-Highlights-Document.pdf> (accessed January 2018).
- <sup>36</sup> Apache Corporation, *Sustainability in a Changing Environment*, 2016 Sustainability Report (2016), [http://www.apachecorp.com/Resources/Upload/file/sustainability/APACHE-Sustainability\\_Report\\_2016.pdf](http://www.apachecorp.com/Resources/Upload/file/sustainability/APACHE-Sustainability_Report_2016.pdf) (accessed January 31, 2018).
- <sup>37</sup> Pennsylvania Code Title 25, Chapter 93. Water Quality Standards, Sections 93.4b(a) [for High Quality Waters] and 93.4b(b) [for Exceptional Value Waters], <https://www.pacode.com/secure/data/025/chapter93/s93.4b.html> (accessed February 9, 2018).
- <sup>38</sup> Pennsylvania Code Title 25, Chapter 93. Water Quality Standards, Sections 93.4a [Antidegradation], <https://www.pacode.com/secure/data/025/chapter93/s93.4a.html> (accessed February 9, 2018).
- <sup>39</sup> Pennsylvania Department of Environmental Protection, Bureau of Water Supply and Wastewater Management, *Water Quality Antidegradation Implementation Guidance*, Document no. 391-0300-002 (effective November 29, 2003), <https://waynecountypa.gov/DocumentCenter/View/693> (accessed February 9, 2018).

<sup>40</sup> Delaware River Basin Commission, Notice of Public Hearing on 18 CFR Parts 401 and 440, Proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities; Additional Clarifying Amendments (November 30, 2017), <http://www.nj.gov/drbc/library/documents/HydraulicFracturing/RulemakingNotice113017.pdf> (accessed January 8, 2018).

<sup>41</sup> 40 CFR 112, Protection of Environment, Oil Pollution Prevention, [https://www.ecfr.gov/cgi-bin/text-idx?SID=a7168c1de6ea9340e75681b8f8b23c59&mc=true&node=se40.24.112\\_11&rgn=div8](https://www.ecfr.gov/cgi-bin/text-idx?SID=a7168c1de6ea9340e75681b8f8b23c59&mc=true&node=se40.24.112_11&rgn=div8) (accessed on February 12, 2018).

<sup>42</sup> ALL Consulting, “Well Site Development Environmental Protection, Spill Prevention and Containment,” presented at the American Society of Civil Engineers: Knowledge and Learning Seminar, Fort Worth, Texas (November 19 & 20, 2015).

<sup>43</sup> David M. Hershfield, “Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years,” U.S. Department of Commerce, Weather Bureau, Technical Paper No. 40 (May 1961), [http://www.nws.noaa.gov/oh/hdsc/PF\\_documents/TechnicalPaper\\_No40.pdf](http://www.nws.noaa.gov/oh/hdsc/PF_documents/TechnicalPaper_No40.pdf) (accessed February 13, 2018).

<sup>44</sup> U.S. Environmental Protection Agency, *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States*, Final Report, EPA/600/R-16/236F (December 2016), <https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990> (accessed February 1, 2018).

<sup>45</sup> U.S. Environmental Protection Agency, *Response to the U.S. Environmental Protection Agency’s Science Advisory Board Review of the Draft Report Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* (January 2017), <https://www.epa.gov/hfstudy/sab-peer-review-hydraulic-fracturing-assessment-report> (accessed February 1, 2018).

<sup>46</sup> U.S. Environmental Protection Agency, *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, External Review Draft, EPA/600/R-15/047 (2015), <https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651> (accessed February 1, 2018).

<sup>47</sup> U.S. Environmental Protection Agency, *Response to the U.S. Environmental Protection Agency’s Science Advisory Board Review of the Draft Report Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* (January 2017), <https://www.epa.gov/hfstudy/sab-peer-review-hydraulic-fracturing-assessment-report> (accessed February 1, 2018).

<sup>48</sup> U.S. Environmental Protection Agency, *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States*, Final Report, EPA/600/R-16/236F (December 2016), <https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=332990> (accessed February 1, 2018).

<sup>49</sup> Matt Zborowski, “Official: Lack of Industry Knowledge Hampered EPA Study on Hydraulic Fracturing and Drinking Water,” *Journal of Petroleum Technology* (January 26, 2018), <https://www.spe.org/en/jpt/jpt-article-detail/?art=3841> (accessed February 2, 2018).

<sup>50</sup> U.S. Environmental Protection Agency, *Response to the U.S. Environmental Protection Agency’s Science Advisory Board Review of the Draft Report Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* (January 2017), <https://www.epa.gov/hfstudy/sab-peer-review-hydraulic-fracturing-assessment-report> (accessed February 1, 2018).

<sup>51</sup> S. Dunn-Norman, W. Hufford, and S.W. Almond, “A Summary of the US Environmental Protection Agency’s Multiyear Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources,” SPE-189873-MS, presented at the SPE Hydraulic Fracturing Technology Conference and Exhibition, 23-25 January, The Woodlands, Texas (January 23-25, 2018).

<sup>52</sup> Dunn-Norman, W. Hufford, and S.W. Almond, “A Summary of the US Environmental Protection Agency’s Multiyear Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources,” SPE-189873-MS, presented at the SPE Hydraulic Fracturing Technology Conference and Exhibition, 23-25 January, The Woodlands, Texas (January 23-25, 2018).

<sup>53</sup> Matt Zborowski, “Official: Lack of Industry Knowledge Hampered EPA Study on Hydraulic Fracturing and Drinking Water,” *Journal of Petroleum Technology* (January 26, 2018), <https://www.spe.org/en/jpt/jpt-article-detail/?art=3841> (accessed February 2, 2018).

<sup>54</sup> Pennsylvania Department of Environmental Protection, Interactive Reports – Oil and Gas Compliance Report, County: 58 - Susquehanna; Municipality: All; Region: All; Operator: All; Unconventional Only: Yes, Resolved Violations Only: No; Inspections With Violations Only: Yes; Inspection Category: All, Inspections from

1/1/2013 to 12/31/2017, [http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil\\_Gas/OG\\_Compliance](http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance) (accessed February 19, 2018).

<sup>55</sup> Pennsylvania Department of Environmental Protection, Oil and Gas Reporting Website, [http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?%2fOil\\_Gas%2fOil\\_Gas\\_Well\\_Production](http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?%2fOil_Gas%2fOil_Gas_Well_Production) (accessed February 21, 2018).

<sup>56</sup> U.S. Energy Information Administration, “Total Energy: Production: Crude Oil and Lease Condensate,” in *Annual Energy Outlook 2018*, #AEO2018 (February 6, 2018), <https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-AEO2018&cases=ref2018&sourcekey=0> (accessed February 20, 2018).

<sup>57</sup> U.S. Energy Information Administration, “Spread Between Henry Hub, Marcellus Natural Gas Prices Narrows as Pipeline Capacity Grows” (January 27, 2016), <https://www.eia.gov/todayinenergy/detail.php?id=24712> (accessed February 20, 2018).

<sup>58</sup> Art Berman, “Strong Natural Gas Prices And Tight Supply In 2017,” *Forbes* online (May 16, 2017), <https://www.forbes.com/sites/arthurberman/2017/05/16/strong-natural-gas-prices-and-tight-supply-in-2017/#3ede3135d29> (accessed February 20, 2018).

<sup>59</sup> Timothy Considine, Robert Wastson, and Seth Blumsack, *The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts, and Future Potential*, The Pennsylvania State University College of Earth and Mineral Sciences, Department of Energy and Mineral Engineering (July 20, 2011), <http://marcelluscoalition.org/wp-content/uploads/2011/07/Final-2011-PA-Marcellus-Economic-Impacts.pdf> (accessed February 20, 2018).

<sup>60</sup> Thomas DeLeire, Paul Eliason, Christopher Timmins, “Measuring the Employment Impacts of Shale Gas Development,” *McCourt School of Public Policy, Georgetown University* (August 2014).

<sup>61</sup> Jennifer Cruz, Peter Smith, and Sara Stanley, “The Marcellus Shale Gas Boom in Pennsylvania: Employment and Wage Trends,” *Monthly Labor Review*, U.S. Bureau of Labor Statistics (February 2014), <https://www.bls.gov/opub/mlr/2014/article/the-marcellus-shale-gas-boom-in-pennsylvania.htm> (accessed February 23, 2018).

<sup>62</sup> “Pennsylvania Oil and Gas Field Supervisor Salaries,” *salary.com* (updated January 30, 2018), <https://www1.salary.com/PA/Oil-and-Gas-Field-Supervisor-salary.html> (accessed February 19, 2018).

<sup>63</sup> Nestico Druby, “What You Should Be Paid For,” *GasLeaseAttorneys.com* (© 2018), <http://www.gasleaseattorneys.com/paid.asp> (accessed on February 19, 2018).

<sup>64</sup> Jamison Conklin, “Chief Oil Leases Nearly 6,000 Acres in Marcellus from Pennsylvania Game Commission,” *NGI’s Shale Daily* (February 17, 2016), <http://www.naturalgasintel.com/articles/105379-chief-oil-leases-nearly-6000-acres-in-marcellus-from-pennsylvania-game-commission> (accessed February 20, 2018).

<sup>65</sup> Jamison Conklin, “Chief Oil Leases Nearly 6,000 Acres in Marcellus from Pennsylvania Game Commission,” *NGI’s Shale Daily* (February 17, 2016), <http://www.naturalgasintel.com/articles/105379-chief-oil-leases-nearly-6000-acres-in-marcellus-from-pennsylvania-game-commission> (accessed February 20, 2018).

<sup>66</sup> Marcellus Shale Coalition, “Pennsylvania’s Impact Fee: Benefiting Communities All Across the Commonwealth” (no date), <http://marcelluscoalition.org/wp-content/uploads/2016/06/2017-Impact-Fee-Fact-Sheet-081717.pdf> (accessed February 21, 2018).

<sup>67</sup> Act 13 Public Utility Commission, Fee Schedule, <https://www.act13-reporting.puc.pa.gov/Modules/Disbursements/FeeSchedule.aspx> (accessed February 21, 2018).

<sup>68</sup> Pennsylvania Public Utility Commission, Impact Fee Distributions to State & Local Governments, [http://www.puc.state.pa.us/filing\\_resources/issues\\_laws\\_regulations/impact\\_fee\\_collection/impact\\_fee\\_distribution\\_state\\_local\\_gov.aspx](http://www.puc.state.pa.us/filing_resources/issues_laws_regulations/impact_fee_collection/impact_fee_distribution_state_local_gov.aspx) (accessed February 21, 2018).

<sup>69</sup> U.S. Energy Information Administration, “Utica Shale Play: Geology Review” (April 2017), [https://www.eia.gov/maps/pdf/UticaShalePlayReport\\_April2017.pdf](https://www.eia.gov/maps/pdf/UticaShalePlayReport_April2017.pdf) (accessed February 19, 2018).

<sup>70</sup> Pennsylvania Department of Environmental Protection, Application Fee Calculator, <http://www.dep.state.pa.us/dep/deputate/minres/oilgas/2011Permitcalculator.htm> (accessed February 21, 2018).

<sup>71</sup> U.S. Energy Information Administration, “Marcellus Shale Play: Geology Review” (January 2017), [https://www.eia.gov/maps/pdf/MarcellusPlayUpdate\\_Jan2017.pdf](https://www.eia.gov/maps/pdf/MarcellusPlayUpdate_Jan2017.pdf) (accessed February 19, 2018).

<sup>72</sup> Pennsylvania Department of Revenue, Current Tax Rates, <http://www.revenue.pa.gov/GeneralTaxInformation/Current%20Tax%20Rates/Pages/default.aspx> (accessed February 21, 2018).

<sup>73</sup> See, for example, Timothy Considine, Robert Wastson, and Seth Blumsack, *The Pennsylvania Marcellus Natural Gas Industry: Status, Economic Impacts, and Future Potential*, The Pennsylvania State University College of Earth and Mineral Sciences, Department of Energy and Mineral Engineering (July 20, 2011),

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<http://marcelluscoalition.org/wp-content/uploads/2011/07/Final-2011-PA-Marcellus-Economic-Impacts.pdf> (accessed February 20, 2018).

<sup>74</sup> Delaware River Basin Commission, Notice of Public Hearing on 18 CFR Parts 401 and 440, Proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities; Additional Clarifying Amendments (November 30, 2017), <http://www.nj.gov/drbc/library/documents/HydraulicFracturing/RulemakingNotice113017.pdf> (accessed February 20, 2018).

<sup>75</sup> Husain, T. M. et al., Penn State University, Economic Comparison of Multi-Lateral Drilling over Horizontal Drilling for Marcellus Shale Field Development, (January 2011), accessed on February 16, 2018, at [https://www.ems.psu.edu/~elsworth/courses/egee580/2011/Final%20Reports/fishbone\\_report.pdf](https://www.ems.psu.edu/~elsworth/courses/egee580/2011/Final%20Reports/fishbone_report.pdf).

<sup>76</sup> Manda AK, Heath JL, Klein WA, Griffin MT, Montz BE., Journal of Environmental Management, V 142, Pages-36-45, Evolution of multi-well pad development and influence of well pads on environmental violations and wastewater volumes in the Marcellus shale (USA), (September 2014),

<sup>77</sup> Pickett, Al., The American Oil & Gas Reporter, Pad Drilling: Leading Operators Improve Efficiency and Effectiveness of Multiwell Pad Operations, (April 2015), accessed on February 16, 2018, at <https://www.aogr.com/magazine/cover-story/leading-operators-improve-efficiency-and-effectiveness-of-multiwell-pad-ope>.

<sup>78</sup> Marcellus Drilling News, Supersize Me! Marcellus / Utica Well Pads Now Hoist Up to 40 Wells. (January, 16, 2018) accessed on February 16, 2018, at <https://marcellusdrilling.com/2018/01/supersize-me-marcellus-utica-well-pads-now-host-up-to-40-wells/>.

<sup>79</sup> Marcellus Drilling News, Supersize Me! Marcellus / Utica Well Pads Now Hoist Up to 40 Wells. (January, 16, 2018) accessed on February 16, 2018, at <https://marcellusdrilling.com/2018/01/supersize-me-marcellus-utica-well-pads-now-host-up-to-40-wells/>.

<sup>80</sup> Litvak, Anya., Pittsburgh Post-Gazette, These days, oil and gas companies are super-sizing their well pads, (January 15, 2018), accessed on February 16, 2018, at <http://www.post-gazette.com/powersource/companies/2018/01/15/These-days-oil-and-gas-companies-are-super-sizing-their-well-pads/stories/201801140023>.

<sup>81</sup> Jacinto, Joan., Siemens, The Vault, Automating the New Oil & Gas Value Chain, accessed on February 16, 2018, at <http://www.totallyintegratedautomation.com/2015/04/automating-the-new-oil-gas-value-chain/>.

<sup>82</sup> U.S. Department of the Interior, Bureau of Land Management, Northeastern States Field Office, Reasonable Foreseeable Development Scenario For Fluid Minerals, Pennsylvania (September 2011).

<sup>83</sup> Bonnell, Joe., The Ohio State University, Environmental Issues Associated with Oil and Natural Gas Extraction, Transport and processing in the Marcellus and Utica Shale Region of Ohio, accessed on February 16, 2018, at <http://slideplayer.com/slide/7362821/>.

<sup>84</sup> U.S. Department of the Interior, Bureau of Land Management, Northeastern States Field Office, Reasonable Foreseeable Development Scenario For Fluid Minerals, Pennsylvania (September 2011).

<sup>85</sup> Marcellus Shale Coalition, Recommended Practices: Site Planning, Development and Restoration, (MSC RP 2012-1 April 26, 2012) accessed on February 16, 2018, at [http://marcelluscoalition.org/wp-content/uploads/2013/03/RP\\_Site\\_Planning.pdf](http://marcelluscoalition.org/wp-content/uploads/2013/03/RP_Site_Planning.pdf).

<sup>86</sup> Huang, Juan., et. al., The Scientific World Journal, Evaluation of the Impacts of Land Use on Water Quality: A Case Study in The Chaohu Lake Basin, July 22, 2013, accessed on February 17, 2018, at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3736410/>.

<sup>87</sup> Santelmann, Mary., Oregon State University, Modeling Effects of Alternative Landscape Design and Management on Water Quality and Biodiversity in Midwest Agricultural Watersheds, December 2000, accessed on February 17, 2018, at [https://cfpub.epa.gov/ncer\\_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/47/report/F](https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/47/report/F).

<sup>88</sup> Colorado School of Mines, “An Integrated Framework for Treatment and Management of Produced Water,” RPSEA Project 07122-12 (November 2009).

<sup>89</sup> U.S. DOE, “Use Vapor Recompression to Recover Low-Pressure Waste Steam,” DOE/GO-102012-3415 (January 2012), [https://energy.gov/sites/prod/files/2014/05/f16/steam11\\_waste\\_steam.pdf](https://energy.gov/sites/prod/files/2014/05/f16/steam11_waste_steam.pdf) (accessed February 18, 2018).

<sup>90</sup> A.W. Gaudlip and L.O. Paugh, “Marcellus Shale Water Management Challenges in Pennsylvania,” SPE 119898 (2008).

<sup>91</sup> A.W. Gaudlip and L.O. Paugh, “Marcellus Shale Water Management Challenges in Pennsylvania,” SPE 119898 (2008).

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- <sup>92</sup> Jennifer K. Fichter, Karl French, Kelly Johnson, and Ron Oden, “Biocides Control Barnett Shale Fracturing Fluid Contamination,” *Oil & Gas Journal* 107, no. 19 (2009).
- <sup>93</sup> Truis Smith-Palmer and R. Pelton, “Flocculation of Particles,” in *Encyclopedia of Surface and Colloid Science*, 2nd ed., edited by Ponisseril Somasundaran (New York: Taylor & Francis, 2006).
- <sup>94</sup> Tamim Younos and Kimberly E. Tulou, “Overview of Desalination Techniques,” *Journal of Contemporary Water Research & Education* no. 132 (December 2005): 3-10, [http://ucowr.com/files/Achieved\\_Journal\\_Issues/v132Overview%20of%20Desalination%20Techniques.pdf](http://ucowr.com/files/Achieved_Journal_Issues/v132Overview%20of%20Desalination%20Techniques.pdf) (accessed February 20, 2018).
- <sup>95</sup> T. Hayes and D. Arthur, “Overview of Emerging Produced Water Treatment Technologies,” presented at the 11th Annual International Petroleum Environmental Conference, Albuquerque, New Mexico (2004).
- <sup>96</sup> Interstate Oil and Gas Compact Commission and ALL Consulting, *A Guide to Practical Management of Produced Water from Onshore Oil and Gas Operations in the United States*, prepared for the U.S. Department of Energy National Petroleum Technology Office (October 2006), <http://www.all-llc.com/publicdownloads/ALL-PWGuide.pdf> (accessed February 20, 2018).
- <sup>97</sup> Filters, Water & Instrumentation, Inc., “Ion Exchange Systems,” Technical Information Page (© 2016), <http://www.filterswater.com/water-purification/ion-exchange-systems/> (accessed February 16, 2018).
- <sup>98</sup> National Energy Technology Laboratory (NETL), “Membrane Processes,” Fact Sheet (no date), <http://www.netl.doe.gov/technologies/pwmis/techdesc/membrane/index.html> (accessed February 16, 2018).
- <sup>99</sup> Interstate Oil and Gas Compact Commission and ALL Consulting, *A Guide to Practical Management of Produced Water from Onshore Oil and Gas Operations in the United States*, prepared for the U.S. Department of Energy National Petroleum Technology Office (October 2006), <http://www.all-llc.com/publicdownloads/ALL-PWGuide.pdf> (accessed February 20, 2018).
- <sup>100</sup> Tamim Younos and Kimberly E. Tulou, “Overview of Desalination Techniques,” *Journal of Contemporary Water Research & Education* no. 132 (December 2005): 3-10, [http://ucowr.com/files/Achieved\\_Journal\\_Issues/v132Overview%20of%20Desalination%20Techniques.pdf](http://ucowr.com/files/Achieved_Journal_Issues/v132Overview%20of%20Desalination%20Techniques.pdf) (accessed February 20, 2018).
- <sup>101</sup> American Water Works Association (AWWA), *Electro dialysis and Electro dialysis Reversal*, M38 (AWWA Manual Library 38) (1995), 72.
- <sup>102</sup> R.E. Brunner, “Electrodialysis,” in *Saline Water Processing*. Hans-Gunter Heitmann: VCH Verlagsgesellschaft, Federal Republic of Germany (1990), 197-217, cited in Tamim Younos and Kimberly E. Tulou, “Overview of Desalination Techniques,” *Journal of Contemporary Water Research & Education* no. 132 (December 2005): 3-10, [http://ucowr.com/files/Achieved\\_Journal\\_Issues/v132Overview%20of%20Desalination%20Techniques.pdf](http://ucowr.com/files/Achieved_Journal_Issues/v132Overview%20of%20Desalination%20Techniques.pdf) (accessed February 20, 2018).
- <sup>103</sup> T. Hayes and D. Arthur, “Overview of Emerging Produced Water Treatment Technologies,” presented at the 11th Annual International Petroleum Environmental Conference, Albuquerque, New Mexico (2004).
- <sup>104</sup> Interstate Oil and Gas Compact Commission and ALL Consulting, *A Guide to Practical Management of Produced Water from Onshore Oil and Gas Operations in the United States*, prepared for the U.S. Department of Energy National Petroleum Technology Office (October 2006), <http://www.all-llc.com/publicdownloads/ALL-PWGuide.pdf> (accessed February 20, 2018).
- <sup>105</sup> “Brine Evaporators and Salt Production,” *Industry Animated* (no date), [http://www.industry-animated.org/teachers%20notes/brine\\_evaporation\\_pdf.pdf](http://www.industry-animated.org/teachers%20notes/brine_evaporation_pdf.pdf) (accessed February 15, 2018).
- <sup>106</sup> Colorado School of Mines, “An Integrated Framework for Treatment and Management of Produced Water,” RPSEA Project 07122-12 (November 2009).