Tom Myers, Ph.D.
Hydrologic Consultant
6320 Walnut Creek Road
Reno, NV 89523
775-530-1483
tommyers1872@gmail.com

Technical Memorandum

Review of Proposed Natural Gas Regulations as Proposed by the Delaware River Basin Commission

March 12, 2018

INTRODUCTION

The Delaware River Basin Commission (DRBC) published Draft Natural Gas Regulations on 30 November 2017 as proposed amendments to its Administrative Manual and Special Regulations regarding natural gas development activities, as well as additional clarifying amendments (18CFR401.35, 18CFR401.43, and 18CFR440). The proposed regulations include: (a) a prohibition on the production of natural gas utilizing horizontal drilling and hydraulic fracturing within the Basin 18CFR440.3(b), (b) provisions for allowing the storage, treatment, disposal, and/or discharge of wastewater within the Basin associated with horizontal drilling and hydraulic fracturing for the production of natural gas where permitted elsewhere (18CFR440.5), and (c) regulation of the inter-basin transfer of water and wastewater for purposes of natural gas development where permitted elsewhere (18CFR440.4).

There are two primary pathways for contaminants to reach waters of the Delaware River Basin –across the ground surface and through groundwater. The primary source of contaminants on the ground surface is spills from operations or transportation. The proposed DRBC regulations would not allow fracking within the watershed but would allow the importation of fracking waste fluids, which could be spilled where they can either run off into surface water or percolate into the ground and contaminate shallow groundwater.

This technical memorandum provides and discusses several reasons why the DRBC should not allow the importation of any wastewater, or produced water, into the Delaware River Basin (DRB) for treatment or disposal. These include the fact that spills of waste water are a hazardous waste spill that can contaminate soil and provide a source of contamination to shallow groundwater and streams for a long period. Disposal of waste by spreading onto roads is really no different than a spill, with contaminants spread along the roadway. The most hazardous aspects of road-spreading is the chemicals in the brine, which are similar whether the source is unconventional shale or conventional gas. Brine from any oil and gas wells should not be spread onto roads to prevent contamination.

There are many reasons to ban fracking within the DRB based on the actual process. In addition to spills, there are many pathways for contamination to reach shallow groundwater from either the well bore or the targeted shale. The pathways include fracture and faults, faulty wellbores, and seismic activity mobilizing gas at shallow levels. The memorandum discusses these in detail and refutes the many arguments presented by industry to counter them.

GROUNDWATER POLLUTION DUE TO SPILLS OF WASTEWATER IMPORTED INTO THE BASIN

The proposed regulations would allow the importation of "produced water" or CWT wastewater, with submission to the Commission for determination as to whether the project would impair or conflict with the Comprehensive Plan (18CFR401.35.b(18)). Specifically, the rule allows "[t]he importation, treatment, or discharge to basin land or water of "produced water" or CWT wastewater as those terms are defined in 18 CFR 440.2" (Id.). CWT wastewater presumably is wastewater reporting to a centralized waste treatment (CWT) facility as defined in 18 CFR440.2, which includes any hazardous or non-hazardous industrial waste or wastewater, presumably not limited to fracking waste. Produced water is the "water that flows out of an oil or gas well, typically including other fluids and pollutants and other substances from the hydrocarbon-bearing strata. Produced water may contain 'flowback' fluids, fracturing fluids and any chemicals injected during the stimulation process, formation water, and constituents leached from geologic formation" (18 CFR 440.2). The regulations therefore would allow importation of water that comes from the well at any point during the hydraulic fracturing process or the period afterwards.

The regulation would allow the discharge of the wastewater to waters, and presumably that would include discharge to groundwater. Presumably, that would include disposal through injection wells, although there are only eight current injection wells within Pennsylvania permitted for oil and gas (O&G) waste disposal. Those wells are in western Pennsylvania, outside of the DRB. Injection would be regulated by the US Environmental Protection Agency (EPA), if proposed. In general, Pennsylvania is considered unsuitable geologically for the disposal of O&G wastewater through injection wells.

A groundwater flow pathway unique to headwaters regions within the DRB is shallow transport from spills or leaks of surface storage. The distance from any point on a drainage basin to a first-order stream is short, on the order of a few hundred to perhaps a thousand feet. Shallow aquifers especially on ridges are thin (Taylor 1984) and the water table follows the topography. Thus, spills would move as interflow from the source to streams relatively quickly, on the order of days. As outlined in the next section, this vulnerability is a reason for the DRBC to prohibit the import of wastewater to the DRB for any reason. The same reasoning also applies to the potential for road spreading of brine to contaminate DRB waters. DRBC should not allow the import of any wastewater to prevent any pollution from that wastewater within the DRB.

Pollution from Spills

Contamination can reach surface water near a gas well by flowing across the ground surface through small drainages to streams downhill from the source. The potential for spills or leaks to follow such a path is clear, but there is little specific research. Lefebvre (2017) found that spills or other surface releases represent the most probable mechanism leading to groundwater contamination. Most research concerning spills of fluids associated with O&G development focuses on well pad spills. For example, EPA's review of fracking-related spills was limited to spills near the pad (EPA 2015). In a substantial review paper concerning the impact of shale gas on regional water quality (Vidic et al. 2013), the authors cited just one report from grey literature (Considine et al. 2012) regarding spills and one journal article from the early 1980s regarding spills transporting through shallow groundwater (Harrison 1983). A more recent article (Maloney et al 2017) summarized details of the threats of spills at the well site harming nearby streams.

Considering O&G development in four states, Pennsylvania, Colorado, New Mexico, and North Dakota, Maloney et al (2017) reviewed data from 6622 spills that occurred for 21,300 unconventional wells, a ratio of one spill for every 3.2 wells. The proximity to streams was smallest in Pennsylvania, with an average distance of 268 meters (Id.). This could be due to the higher density of streams in a humid-regions state like Pennsylvania as compared to the other states. Over the four states, 7% of spills were within 100 feet of a stream, and 5.3% of the spills in Pennsylvania were within this distance. Maloney et al (2017) reported that the required setback in Pennsylvania is 100 feet, so decisionmakers should not rely on compliance with regulations to protect streams. The statistics regarding spills shows that DRBC is correct to ban fracking within the DRB to protect streams within the basin.

The frequency and volume of spills during transport should not differ from spills during the transport of hazardous waste overall because of similar methods. Public Source (2014) analyzed records of 40,000 spills occurring in Pennsylvania between 1971 and 2013, which included spills on highways, waterways, and airway (www.publicsource.org/pa-fifth-in-the-nation-in-hazardous-spills/). More than 12,500 events have occurred since 2000. Fifty-nine of the events caused evacuations and 96 events closed transportation arteries. Spills were rated as serious 2% of the time. It is fair to conclude that serious spills of fracking waste would occur within the DRB if the DRBC allows importation and that some of those spills will be serious.

Transportation-related pathways were the fourth largest of 14 potential pathways for spills to reach water supplies, where the third largest was the unknown pathway (or pathway unreported) (Patterson et al 2017). For Pennsylvania, the average was 1.7 transportation-related spills for every thousand well years. Of the total number of spills in Pennsylvania, human error was the number one cause for spills with an identified cause. The high number of unidentified causes and pathways in Pennsylvania was likely due to the State not requiring this information be reported as it is in Colorado and New Mexico.

Spills of fracking fluids include hydrocarbons and petroleum distillates which linger in the soils and are difficult to clean up (Maloney et al 2017), regardless of whether the spill is at the pad or during transportation. Ripendra (2016) found contamination by wastewater disposal and accidental leaks and spills of wastewater and chemicals used during drilling and the hydraulic fracturing process to be two of the four primary threats to water quality posed by fracking, with the other two being well integrity related.

Drollette et al (2015) found in the Marcellus region an elevated concentration of diesel range organic chemicals linked to hydraulic fracturing fluid within shallow groundwater. They associated it with spills, primarily at the well sites, by correlating DRO concentration with distance from wells. They did not test for distance from other types of spills, presumably because the location of those spills is not available in the data base. In addition to showing potential for long-term contamination near well sites, these results suggest there would be long term DRO contamination near all spill sites. The contamination from spills into clay-rich soils is likely to linger as much as 25 times longer than for gravely soils (Cai and Li 2017). The contamination is also likely to contain higher concentrations of various radioactive substance (Lauer and Vengosh 2016).

Road Spreading of Brine

It is common in the United States to dispose of O&G produced brine by spreading it on roads for dust or ice control. No jurisdictions in Canada allow the spreading of O&G wastewater on roads (Goss et al 2015). The popular press describes the use and unpopularity of the process in northern and western Pennsylvania (for example, http://www.newsweek.com/oil-and-gas-wastewater-used-de-ice-roads-new-york-and-pennsylvania-little-310684). However, Pennsylvania does not currently allow the use of brine from unconventional shale deposits for road spreading (PDEP 2017), it does allow brine from conventional deposits. Dr. Avner Vengosh was quoted in the Newsweek article cited above as stating there is not much difference because it is the brine chemicals, salt, ammonium, naturally occurring source of radioactive materials (NORM), and others, that make the brine deleterious to shallow groundwater, not the organic fracking fluid chemicals. Brown (2014) also noted the high levels of NORM, which can be technologically concentrated in brine.

Skalak et al (2014) examined sediments around a series of sites that had received road-spread brine. They found that concentrations in the sediments had increases of radium, strontium, calcium, and sodium of 1.2, 3.0, 5.3 and 6.2 times, respectively, as compared to background concentrations that did not have road spreading of brine. The authors also found a variability of up to 30 times, meaning that some areas could received concentrated runoff. The concentrations could be limited due to surface runoff dissolving the cations or infiltration flushing it to shallow groundwater. These results indicate that road spreading of O&G brine can contaminate soils and that those soils can be a source of contamination to shallow groundwater and surface water. It does not appear that brine is used on roads at this time within the DRB, and there is no reason the DRBC should allow it in the future.

GROUNDWATER POLLUTION DUE TO THE FRACKING PROCESS

The proposed DRBC regulations would prohibit fracking, at least that using greater than 300,000 gallons of fracking fluid, (18CFR440.3(b)) because the Commission "determined that high volume hydraulic fracturing poses significant, immediate and long-term risks to the development, conservation, utilization, management, and preservation of the water resources of the Delaware River Basin and to Special Protection Waters of the Basin …" (18CFR440.3(a)). The definition of high-volume hydraulic fracturing is hydraulic fracturing that uses a "combined total of 300,000 or more gallons of water during all stages in a well completion, whether the well is vertical or directional, including horizontal, and whether the water is fresh or recycled and regardless of the chemicals or other additives mixed with the water" (18CFR440.2). The regulation would allow very small fracking operations (<300,000 gallons). Fracking of unconventional oil/gas formations generally requires substantially more fluid to adequately fracture the formation, although there is no formal minimum required amount. Hydraulic fracturing has other applications which generally use less fluids without chemicals; those that are relevant to the DRB are water well production, block cave mining, and rock stress testing (Adams and Row 2013).

There are multiple reasons that the prohibition of fracking is desirable, and the following sections discusses how the process of fracking, even if completed as designed, can contaminate shallow groundwater and surface water in the DRB.

Underground Paths

The most complex transport pathways for contaminants from fracking to reach Watershed lands occur underground, between the point of fracking and shallow groundwater or surface water. At least three different substances released by fracking can reach shallow groundwater or surface in the DRB – natural gas (shallow biogenic and deep thermogenic gas), formation brine, and fracking fluid. All would be part of produced water as defined by the proposed regulations if they transported up the well bore to shallow groundwater or surface water. These contaminants can follow pathways through natural faults and fractures, through abandoned wells or poorly constructed gas well, or a combination of both. This section discusses gas and liquid transport separately because the pathways and timescales are different.

Natural Gas Pathways

Many studies have highlighted the increase in CH_4 concentration[1] within one kilometer of fracked wells, with the CH_4 being identified as thermogenic (Darrah et al. 2014; Jackson et al. 2013; Osborn et al. 2011). Others have noted the presence of increased CH_4 in valley locations along faults and lineaments (Molofsky et al. 2013; Fountain and Jacobi 2000). Fractures caused by faulting provide pathways to the surface. Darrah et al. (2014) listed the following scenarios that can lead to higher methane concentrations in shallow groundwater:

> (i) in situ microbial methane production;
>
> (ii) natural in situ presence or tectonically driven migration over geological time of gas-rich brine from an underlying source formation or gas-bearing formation of intermediate depth (e.g., Lock Haven/Catskill Fm. Or Strawn Fm.);
>
> (iii) exsolution of hydrocarbon gas already present in shallow aquifers following scenario 1 or 2, driven by vibrations or water level fluctuations from drilling activities;
>
> (iv) leakage from the target or intermediate-depth formations through a poorly cemented well annulus;
>
> (v) leakage from the target formation through faulty well casings (e.g., poorly joined or corroded casings);
>
> (vi) migration of hydrocarbon gas from the target or overlying formations along natural deformation features (e.g., faults, joints, or fractures) or those initiated by drilling (e.g., faults or fractures created, reopened, or intersected by drilling or hydraulic fracturing activities);

[1] Natural gas is a mixture of carbon-chain gases, with CH4 (methane) being the most dominant.

(vii) migration of target or intermediate-depth gases through abandoned or legacy wells

Scenarios one and two are not anthropogenic, but fracking could enhance the second scenario (Gassiat et al. 2013; Myers 2012). Warner et al. (2012) and Llewellyn (2014) provide evidence for the type of brine movement discussed in scenario 2. Drilling or vibrations caused by fracking can release dissolved gas or change its transport through shallow groundwater so that it affects water wells. Because the vibrations caused by fracking are tantamount to a seismic vibration, earthquakes associated with increased fracking would likely also cause additional gas to be released.

The third scenario is a mechanism by which fracking releases gas into shallow groundwater through which it can flow to surface lands. Fracking-caused earthquakes could enhance the release of gas. The fourth and fifth scenario describes the potential movement of gas from depth along the well, due to faulty construction, to shallow groundwater. The sixth scenario is the movement of gas from the target formation through natural pathways, such as faults or fractures, to shallow groundwater. Where there are abandoned wells, scenario 7 is an obvious potential scenario, although it includes transport through bedrock to the abandoned well. Regardless of the mechanism causing methane to reach shallow groundwater, either as dissolved or buoyant gas, it would contaminate groundwater within the DRB. Groundwater discharges to streams and springs within the DRB.

Darrah et al. (2014) studied seven locations in Pennsylvania and one in Texas and found based on the amount of noble gases in the sample that scenario 6 is unlikely because the gases in the shallow groundwater did not resemble those that have followed a natural pathway from the shale to the shallow groundwater. The paper rules out transport of gas freshly liberated from the target shale through natural fractures because the diagnostic gas isotope ratios do not reflect the changes through fractionation that would occur as the gas migrates through the water-saturated crust. Their conclusion ignores the fact that the gas would be transported through the same formations whether from depth, the layer of the shale, or for up to a kilometer through shallow aquifers which are similar bedrock types. Darrah et al's conclusions also require that the gas undergo the same transformation in weeks as gas would have undergone in millions of years of brine transport to shallow groundwater. Leaks from deep formations that occurred at a storage facility in Tioga County reached shallow groundwater (Breen et al. 2007), which suggests the transport of gas through pathways not accepted by Darrah et al.

Other studies have documented the rate at which gas released by fracking can move through the groundwater. Gas tracers released during fracking were found at production wells 750 feet away from the source within days (Hammock et al 2014). They also found evidence of gas migration to a sandstone formation 3000 feet above the Marcellus shale (Id., Figure 33). A model study based on conditions found at the southwest Pennsylvania site used in Hammock et al. estimated that gas can flow from a well bore leak through a sandstone rock matrix to a well 170 m away in times ranging from 89 days to 17 years depending on conditions (Zhang et al 2014). Darrah et al. (2014) found several gas wells within one kilometer of fracked wells that experienced large increases in gas concentration between annual sampling events which suggests that gas transport of up to a kilometer occurred in a time period of less than a year.

Additional evidence of gas movement along faults through the earth's crust to shallow groundwater may be seen through studies concerning CO_2 sequestration. Shipton et al. (2004) found that fluids (liquid and gas) can move vertically through low permeability faults, including those otherwise considered to be sealed with calcite. Critically, gas migration is extremely heterogeneous with large fluxes occurring through high-permeability pathways resulting in large gas loads hitting very small areas (Annunnziatellis et al. 2008). The distribution of methane seeping through a fault is much more variable than the distribution of either helium or carbon dioxide following the same general pathway (Annunziatellis et al. 2008). These authors described the extreme variability in gas flow as the"'spot' nature of gas migration along spatially restricted channels" (Annunziatelis et al. 2008, p 363). Even along a single fault, the flux is highly variable and intersecting joints or faults add variability in an additional direction. The spot nature of gas flow is probably responsible for highly variable readings in domestic water wells even in small areas and for the fact that the concentration in some wells may decrease while in others it remains steady or increases.

There is evidence that water wells near fault zones will likely have more gas occurrences naturally, but it is also clear that fracking should increase the occurrence of gas in these areas. Drainages in Pennsylvania have more natural gas occurrences than other areas (Molofsky et al. 2013; Fountain and Jacobi 2000). Fountain and Jacobi (2000) mapped the presence of thermogenic NG in soils as a means of detecting underlying lineaments and fracture zones, based on the assumption of a fault/fracture connection between thermogenic gas sources and the surface. It is likely that anthropogenic gas, regardless of the source (the well bore or the source shale formation), can follow faults and fractures to shallow groundwater. If fracking releases gas from shale and/or increases the connection between the shale and fracture zones, it seems likely that fracking will be responsible for increasing gas in the streams underlain by fracture systems (Jackson et al. 2013; Osborn et al. 2011) in the Basin.

Drainages in northeast Pennsylvania likely coincide with fault/fracture zones, as described by Taylor (1984):

> Wells in higher topographic positions (hilltops and hillsides) have smaller yields than those in lower topographic positions (valley, gullies, and draws). Valleys and draws often form where the rocks are most susceptible to physical or chemical weathering. Hilltops are generally underlain by more resistant rocks. Lithologic variations and weaknesses in rocks caused by bedding partings, joints, cleavage, and faults promote rapid weathering and can produce low areas in the topography. These types of geologic features often occur in high-permeability zones which yield significant amounts of water to wells. (Taylor 1984, p 29).

Although Taylor (1984) studied streams in the Susquehanna River basin, his observations apply to headwaters streams in the DRB. His description is of a pathway for gas to follow from O&G wells to streams.

The previous paragraphs describe the various pathways gas can flow from a fracked well to shallow groundwater, streams, and springs on nearby land. Whether the source is gas released directly from the shale or the well bore and whether the pathway is along a faulty well bore or natural fractures, these findings point to a significant risk that NG wells with fracking within the DRB significantly increase the risk for gas reaching shallow groundwater near stream channels. The chance is probably highest for higher order streams in fault-controlled valleys in the DRB, such as the Lackawanna River or DRB headwaters' drainages in the Catskill Mountains.

Most studies and monitoring of gas development impacts on surface water, either streams or springs, focus on contaminants easily carried through the water, such as geochemical indicators such as chloride or suspended sediment (Olmstead et al. 2014) or fracking fluids. It is common to ignore the presence of methane in streams. Methane degases from surface water, but without sufficient aeration, the methane decreases the dissolved oxygen in the surface water which would have severe aquatic effects. Essentially, methane discharges to streams increase the dissolved methane content of the stream thereby decreasing the dissolved oxygen content for areas near the methane source. This can lead to dead zones just as anything else that depletes oxygen.

Liquid Pathways

Formation brine naturally flows through faults and fractures from the Marcellus (Warner et al. 2012) or other deep Appalachian basins to shallow groundwater (Llewellyn 2014) based on geochemical and isotopic evidence. Both papers warn that these connections could allow more rapid brine flow or portend the flow of fracking fluid to shallow groundwater due to increased pressure or enhanced connections due to fracking. At least three published studies have documented fracking fluid reaching drinking water wells (Llewelyn et al 2015, DiGiulio et al. 2011; EPA 1987) and litigation settlements have prevented disclosure of the facts in similar circumstances. Llewelyn et al (2015) documented transport between a fault plane/well intersection 1600 feet BGS and a shallow aquifer.

Model studies for years have simulated the potential for deep brine to circulate to the surface naturally (Deming and Nunn 1991; Person and Baumgartner 1995) or in conjunction with deep waste or CO2 injection (Birkholzer and Zhou 2009)). The role of fractures to allow flow through shale layers has also been known for years, with Bredehoeft et al. (1983) finding that at a field scale, the vertical conductivity of shale is up to three orders of magnitude greater than the conductivity estimated from a column in a laboratory.

Recent model studies have estimated that fluids could flow from the Marcellus, or similar shale layers in similar sedimentary basins, to shallow aquifers naturally and that the flow could be enhanced by fracking to occur in less than 10,000 years depending on assumed conditions (Taherdangkoo et al 2017, Wilson et al 2017, Chesnauw et al. 2013; Gassiat et al. 2013; Kissinger et al. 2013; Myers 2012). Most modelers found conditions that would allow transport of liquids to occur due to fracking within a couple hundred years for some of the conditions they simulated. All of the model studies found the most rapid transport could occur through a vertical fault system. The primary difference in the time for transport depended on the conceptualization of formations and the hydrogeologic parameterization.

Myers (2012) found that transport from the Marcellus to shallow aquifers could occur over a period from 10 to more than a thousand years, depending on the conductivity assumed to result from fracking -- his model had the horizontal gas well intersecting a vertical fault connecting the shale to the near-surface. Gassiat et al. (2013) modeled a high permeability, continuous, 10-m wide fault zone from the shale to the shallow groundwater with fracking simulated as a change in permeability over a 2-km long, 150-m thick zone. Kissinger et al. (2013) simulated a continuous 30-m thick vertical fault with a head drop of up to 60 m to drive a plume of fracking fluid into the lower aquifer. After 30 years under this scenario, simulated fracking fluid had reached the shallow aquifer. Lateral migration of contaminants occurred at rates up to 25 m/y (Lange et al. 2013). Chesnauw et al. (2013) modeled flow along a fracture pathway between a target shale zone and surface aquifer in a two-dimensional framework, 3000-m long by 3000-m deep and 1 m thick. The modeling studies utilized generic stratigraphic and topographic cross-sections with idealized formation properties due to a lack of specific aquifer data. Also, they considered flow through a fault, but likely underestimated the potential for preferential flow through small but highly permeable fractures even within a preferential flow zone. Taherdangkoo et al (2017) found that upward fluid migration to a shallow aquifer depended on the characteristics of the fault, but argued the probability remained small; they did not consider out-of-formation fractures intersecting the fault or a natural upward gradient in the fault zone due to common basin topographic circulation

(Deming and Nunn 1991). Wilson et al (2017) used model simulations to show that fracking fluid could reach shallow aquifers through fault zones from a target shale greater than 2000 meters bgs. Travel time was quicker for increased induced fracture extent (out of formation fractures), absence of deep high hydraulic conductivity strata, and low fault hydraulic conductivity. The authors found that high conductivity horizontal formations intersecting the fault and high conductivity faults allowed fluids to leak off thereby reducing the mass reaching shallow groundwater.

At least two studies (Engelder et al. 2014; Flewelling and Sharma 2013) have attempted to counter the model study by arguing that brine and fracking fluid cannot reach shallow aquifers due to stratigraphic barriers, lack of a driving force, the Marcellus being dry, and imbibition removing fracking fluid like a sponge, etc. Both studies have serious flaws including their "facts" being countered by many other studies.

Flewelling and Sharma considered the permeability of the bulk formations and ignored potential fault connections between the shale and the surface. They incorrectly claimed that other studies (Myers 2012) rely on out-of-formation fracturing to provide a pathway all the way to shallow groundwater. The modeling studies cited above assume a fault connection to the top of the shale so that fracking fluid only must reach the top of the shale. Out-of-formation fractures that extend above the shale (Hammock et al. 2014; Fisher and Warpinski 2011) may short circuit the pathway making transport faster than simulated in the studies cited herein. Out-of-formation fractures are not required for fracking fluid to reach shallow groundwater. Flewelling and Sharma mistakenly assume the transport would have to be widespread across a large area when the reality is that brine migration, and transport of fracking fluid, would focus flow to spatially restricted discharge zones, such as faults, that lead to springs or the shallow groundwater beneath valleys (Deming and Nunn 1991).

Engelder et al. (2014) also makes arguments not supported by facts. The first is that potential transport as simulated by Myers (2012) and others depends on "single phase Darcy Law physics" which they claim is inappropriate when there is gas and water present. They are wrong because most of the gas occurs within the bulk matrix of the shale layers and most flow occurs in fractures and joints which are predominantly water. This may be seen even in the well log presented by Engelder et al. showing significant free water in a one-meter portion of the shale where the core likely crosses a significant fracture zone. The formations above and below the shale in the well log are also almost saturated. Additionally, the large model scale employed by the models renders multiphase flow considerations irrelevant, as argued for modeling CO2 sequestration as a single phase (Cihan et al. 2011).

The second is they claim that even if all the salt in the Marcellus shale reached the shallow groundwater it would be so diluted as to be irrelevant. The fallacy in their argument is they assume the salt disperses evenly and instantaneously through shallow groundwater when reality is a high concentration flow would enter at a small fault zone intersecting the shallow aquifers, such as at Salt Springs State Park.

Their third argument is they believe that all fracking fluid not returning to the surface as flowback becomes imbibed in the shale. Birdsell et al (2015) also argues that Myers (2012) and other modeling studies have ignored imbibition. Imbibition is a process whereby liquid enters the micropores and becomes bound to the shale matrix, like water soaking into a sponge. Certainly, some fracking fluid becomes imbibed, so their argument applies to fracking fluid that remains in the shale. Birdsell et al (2015) rely on theoretical calculations dependent on theoretical, not measured, parameters. They estimate a range from 15 to 95% of the injected fluid being imbibed. Obviously, much injected fluid is not imbibed even at their estimate at the 15% end of the range.

Much fracking fluid leaves the shale through out-of-formation fractures which extend as much as 1500 feet above the Marcellus shale (Hammock et al. 2014; Fisher and Warpinski 2011). Hammock et al. (2014) documented 10,286 microseismic events as much as 1900 feet above the shale from 56 fracking stages for six Marcellus wells, including many events that extended above the Tully limestone, which had been considered a barrier to fracturing. The fractures provide a pathway from the shale to much more permeable formations, including those that consist of sandstone or limestone, near shallow groundwater. The new fractures also potentially connect with natural fractures. The modeling studies (Taherdangkoo et al 2017, Gassiat et al 2013, Myers 2012) apply to injected fluids that leave the shale and are by design not imbibed. It simply cannot be argued, therefore, that all fracking fluid that does not flowback to the surface through the well remains within the shale.

The Marcellus shale is also not essentially dry unless one considers only the bulk matrix in which most of the methane is bound. As shown on the well log presented by Engelder et al., fracture zones with higher secondary permeability within the shale contain free water. It is these zones that fracking fluid flows through. New fractures would connect zones of secondary permeability that contain free water, or brine. Fracking provides a pathway for Marcellus brine, the free water, to flow to the gas well, probably becoming dominant after the fracking fluid remaining most closely near the well goes back up the well as flowback.

Haluszczak et al (2012) showed that brine dominated the flowback, based on the rapid increase in concentrations of various constituents, including TDS, Cl, Br, Na, Ca, Sr, Ba, and Ra, in the flowback to levels several times that of seawater. Flowback was not fracking fluid that had dissolved rock minerals from the shale as claimed by Engelder et al. Kohl et al. (2014) used strontium isotope ratios found in flowback to isolate the source formation; the strontium signatures would not be as representative of the source formation if its presence was due only to high velocity dissolution during fracking. Rowan et al. (in press, abstract, emphasis added) conclude that the "δ18O values and relationships between Na, Cl, and Br, provide evidence that the water produced after compositional stabilization is **natural formation water**, whose salinity originated primarily from evaporatively concentrated paleoseawater".

In other words, the shale is not dry but contains a substantial amount of naturally occurring brine that fracking causes to be released from the shale. It is clear therefore that scenario 2 (Darrah et al. 2014) facilitating the movement of brine from depth to shallow groundwater could also portend the movement of fracking fluid or enhanced flow of brine due to fracking. The flow could occur much faster than occurs naturally for brine because of the increased permeability due to fracking, fracking fluid pushing brine from the shale, and the added pressure due to fracking injection. This contaminant movement threatens water sources in the DRB if the DRBC allows fracking within the DRB.

Contamination of Groundwater Due to Fracking

The proposed regulations properly prohibit fracking within the Delaware watershed. This section has described how fracking has been shown to cause pollution or how it is likely to do so in the future, both through the actual process of fracking and from well bore leaks. The potential for contaminants to reach groundwater through these pathways is a good reason for banning the process within the watershed. DRBC is correct in doing so.

REFERENCES

Adams J, Row C (2013) Differentiating applications of hydraulic fracturing. Chapter 18 in Bunger AP, McLennan J, Jeffrey R (eds), Effective and Sustainable Hydraulic Fracturing.

Annunziatellis A, Beaubien SE, Bigi S, Ciotoli G, Coltella M, Lombardi S(2008) Gas migration along fault systems and through the vadose zone in Latera caldera (central Italy): Implications for CO2 geological storage. Int J Greenh Gas Contr 2:353-372. Doi:10.1016/j.ijggc.2008.02.003

Birdsell DT, Rajaram H, Lackey G (2015) Imbibition of hydraulic fracturing fluids into partially saturate shale. Water Resour Res 51:6787-6796, doi 10.1002/2015WR017621

Birkholzer JT, Q Zhou (2009) Basin-scale hydrologic impacts of CO2 storage: Regulatory and capacity implications. Int J Grnhs Gas Control

Bredehoeft JD, CE Neuzil, PCD Milly (1983) Regional Flow in the Dakota Aquifer: A Study of the Role of Confining Layers, U.S. Geological Survey Water-Supply Paper 2237.

Breen KJ, K Revesz, FH Baldassare, SD McAuley (2007) Natural gases in ground water near Tioga Junction, Tioga County, North-Central Pennsylvania – Occurrence and of isotopes to determine origin, 2005. US Geological Survey Scientific Investigations Report 2007-5085. 65 p.

Brown VJ (2014) Focus: Radionuclide in Fracking Wastewater. Env Health Persp 122(2):A50-A55.

Cai Z, Li L (2016) How long to natural waters “remember” release incidents of Marcellus Shale waters: a first order approximation using reactive transport modeling. Geochem Tran 17:6. Doi 10.1186/s12932-016-0038-4.

Cai Z, Ofterdinger U (2014) Numerical assessment of potential impacts of hydraulically fractured Bowland Shale on overlying aquifers. Wat Resour Res doi:10.1002/2013WR014943

Chesnaux R, dal Soglio L, Wendling G (2013) Modelling the impacts of shale gas extraction on groundwater and surface water resources. Presented at GEOMontreal 2013, September 29 – October 3, 2013, Montreal, Quebec

Cihan A, Birkholzer JT, Zhou Q (2013) Pressure buildup and brine migration during CO2 storage in multilayered aquifers. Groundwater 51(2):252-267, doi: 10.1111/j.1745-6584.2012.00972.x.

Considine TJ, Watson RW, Considine NB, Martin JP (2013) Environmental regulation and compliance of Marcellus shale gas drilling. Environ Geosci 20:1-16

Darrah, T.H, A Vengosh, R.B. Jackson, N.R. Warner, and R.J.Poreda. 2014. Nobel gases identify the mechanisms of fugitive gas contamination in drinking-water wells overlying the Marcellus and Barnett Shales. PNAS Early Edition. Doi:10;.1073/pnas.1322107111.

Deming D, Nunn JA (1991) Numerical simulations of brine migration by topographically driven recharge. Journal of Geophysical Research 96(B2):2485-2499.

DiGiulio, D. C., R. T. Wilkin, C. Miller, and G. Oberly (2011), DRAFT: Investigation of Ground Water Contamination near Pavillion, Wyoming, U.S. Environmental Prodection Agency, Office of Research and Development.

Drollette BD, Hoelzer K, Warner NR, Darrah TH, Karatum O, O’Connor MP, Nelson RK, Fernandez LA, Reddy CM, Vengosh A, Jackson RB, Elsner M, Plata DL (2015) Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. Proc Natl Acad Sci 112(43):13184-13189. Doi 10.1073pnas.1511474112.

Engelder T, Cathles LM, Bryndzia LT (2014) The fate of residual treatment water in gas shale. J Unconventional Oil and Gas Resources 7:33-48

EPA (US Environmental Protection Agency) (2015) Review of state and industry spill data: Characterization of hydraulic fracturing-related spills. EPA/601/$-14/001

Fisher K, Warpinski N (2011) Hydraulic fracture-height growth: real data. Paper SPE presented at the Annual Technical Conference and Exhibition, Denver, Colorado. DOI:10.2118/145949 – MS.

Flewelling SA, Sharma M (2013) Constraints on upward migration of hydraulic fracturing fluid and brine. Groundwater, doi:10.1111/gwat.12095.

Fountain JC, Jacobi RD (2000) Detection of buried faults and fractures using soil gas analysis. Environ Eng Geosci 6(3):201-208

Gassiat CT, Gleeson T, Lefebvre R, McKenzie J (2013) Hydraulic fracturing in faulted sedimentary basins: Numerical simulation of potential contamination of shallow aquifers over long time scales. Wat Resour Res 49:8310-8327, doi:10.1002/2013WR014287.

Goss G, Alessi D, Allen D, GEhman J, Brisbois J, Kletke S, Sharak AZ, Notte C, Thompson DY, Hong K, Junes VRC, Neto WBG, Prosser C (2015) Unconventional wastewater management: a comparative review and analysis of hydraulic fracturing wastewater management practices across four North America basins. Prepared for Canadian Water Network. University of Alberta.

Haluszczak LO, Rose AW, Kump LR (2012) Geochemical evaluation of flowback brine from Marcellus gas wells in Pennsylvania, USA. Appl Geochem 28: 55-61

Hammack, R., W. Harbert, S. Sharma, B. Stewart, R. Capo, A. Wall, A. Wells, R Diehl, D. Blaushild, J. Sams, and G. Veloski. 2014. An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells are Hydraulically Fractured in Greene County, Pennsylvania, NETL-TRS-3-2014, EPAct Technical Report Series. U.S. Department of Energy, National Energy Technology Laboratory. Pittsburgh, PA. 76 p.

Harrison SS (1983) Evaluating system for ground-water contamination hazards due to gas-well drilling on the glaciated Appalachian Plateau. Ground Water 21(6):689-701

Jackson RB, Vengosh A, Darrah TH, Warner NR, Down A, Poreda RJ, Osborn SG, ZhaoK, Karr JD (2013) Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. Proc Natl Acad Sci, USA 110(28):11250-11255

Kissinger A, Helmig R, Ebigbo A, Class H, Lange T, Sauter M, Heitfeld M, Klunker J (2013) Hydraulic fracturing in unconventional gas reservoirs: risks in the geological system, part 2. Env Earth Sci, doi 10.1007/s12665-013-2578-6

Kohl CAK, RC Capo, BWStewart, AJ Wall, KT Schroeder, RW Hammack, GD Guthrie (in press) Strontium isotopes test long-term zonal isolation of injected and Marcellus formations water after hydraulic fracturing. Environ Sci Technol doi/10.1021/es501099k

Lange T, Sauter M, Heitfeld M, Schetelig K, Brosig K, Jahnke W, Kissinger A, Helmig R, Ebigbo A, Class H (2013) Hydraulic fracturing in unconventional gas reservoirs: risks in the geological system part 1. Environ Earth Sci DOI 10.1007/s12665-013-2803-3.

Lauer N, Vengosh A (2016) Age dating oil and gas wastewater spills using radio isotopes and their decay products in impacted soil and sediment. Environ. Sci. Technol. Lett. 3:205-209. Doi:10.1021/acs.estlett.6b00118.

Lefebvre R (2017) Mechanisms leading to potential impacts of shale gas development on groundwater quality. Wiley Interdisciplinary Reviews: Water 4(1): E1188

Llewellyn GT (2014) Evidence and mechanisms for Appalachian Basin brine migration into shallow aquifers in NE Pennsylvania, USA. Hydrog J DOI 10.1007/s10040-014-1125-1

Llewellyn GT, Dorman F, Westland JL, Yoxtheimer D, Grieve P, Sowers T, Humston-Fulmer E, Brantley SL (2015) Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. Proc Natl Acad Sci 112(20):6325-6330, doi 10.1073/phas.1420279112.

Molofsky LJ, Connor JA, Wylie AS, Wagner T, Farhat SK (2013) Evaluation of methane sources in groundwater in northeastern Pennsylvania. Groundwater 51(3):333-349, Doi:10.1111/gwat.12056

Myers T (2012) Potential contaminant pathways from hydraulically fractured shale to aquifers. Ground Water 50(6): 872-882 doi: 10.1111/j.1745-6584.2012.00933.x

Olmstead SM, Muehlenbachs LA, Shih J,Chu Z, Krupnick AJ (2013) Shale gas development impacts on surface water quality in Pennsylvania. Proc Natl Acad Sci, USA 110(13):4962-4967

Osborn SG, Vengosh A, Warner NR, Jackson RB (2011a) Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing. Proc Natl Acad Sci, USA 108:8172-8176

Patterson LA, Konschnik KE, Wiseman H, Fargione J, Maloney KO, Kieseck J, Nicot J, Baruch-Mordo S, Entrekin S, Trainor A, Saiers JE (2017) Unconventional oil and gas spills: Risks, mitigation priorities, and state reporting requirements. Env Sci Tech *****

PDEP (Pennsylvania Department of Environmental Protection) (2017) Road-spreading of brine for dust control and road stabilization. 800-FS-DEP1801.

Person M, L Baumgartner (1995) New evidence for long-distance fluid migration within the Earth's crust. Reviews of Geophysics, Supplement p 1083-1091.

Ripendra A (2016) Hydraulic Fracturing and Its Potential Impact on Shallow Groundwater, Chapter 2 in Emerging Issues in Groundwater Resources.

Rowan EL, MA Engle, TI Kraemer, KT Schroeder, RW Hammack, MW Doughten (in press) Geomechanical and isotopic evolution of water produced from Middle Devonian Marcellus Shale gase wells, Appalachian Basin, Pennsylvania. AAPG Bulletin, doi: 10.1306/07071413146.

Shipton ZK, JP Evans, D Kirchner, PT Kolesar, AP Williams, J Heath (2004) Analysis of CO2 leakage through "low-permeability" faults from natural reservoirs in the Colorado Plateau, southern Utah. In: Baines, SJ, RH Worden (eds.) *Geologic Storage of Carbon Dioxide*. Geological Society, London, Special Publications 233, 43-58.

Skalak KJ, Engle MA, Rowan EL, Jolly GD, Conko KM, Benthem AJ, Kraemer TF (2014) Surface disposal of produced waters in western and southwestern Pennyslvania: Potential for accumulation of alkali-earth elements in sediments. Int J Coal Geol 126:162-170. Doi 10.1016/j.coal.2013.12.001

Taylor LE (1984) Groundwater Resources of the Upper Susquehanna River Basin, Pennsylvania. Pennsylvania Geological Survey, Harrisburg PA.

Taherdangkoo R, Tatomir A, Taylor R, Sauter M (2017) Numerical investigations of upward migration of fracking fluid along a a fault zone during and after stimulation. Energy Procedia 125:126-135.

U.S. Environmental Protection Agency (EPA) (1987) Report to Congress: Management of wastes from the exploration, development, and production of crude oil, natural gas, and geothermal energy, U.S. Environmental Protection Agency, Washington, DC.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE (1980) The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37(1):130-137. Doil 10.1139/f80-017.

Vidic RD, Brantley SL, Vandenbossche JM, Yoxtheimer D, Abad JD (2013) Impact of shale gas development on regional water quality. Science 340, 1235009 (2013). DOI: 10.1126/science.1235009

Warner NR, Jackson RB, Darrah TH, Osborn SG, Down A, Zhao K, White A, Vengosh A. 2012a. Geochemical evidence for possible natural migration of Marcellus Formation brine to shallow aquifers in Pennsylvania. Proceedings of the National Academy of Sciences pnas.1121181109

Wilson MP, Worrall F, Davies RJ, Hart A (2017) Shallow aquifer vulnerability from subsurface fluid injection at a proposed shale gas hydraulic fracturing site. Water Resour Res 53(11): 9922-9940

Zhang, L., N. Anderson, R. Dilmore, D.J. Soeder, and G. Bromhal. 2014. Leakage detection of Marcellus shale natural gas at an upper Devonian gas monitoring well: A 3-D numerical modeling approach. Environmental Science and Technology 48:10795-10803, doi:10.1021/es501997p.

Review of the Draft Delaware River Basin Commission's Regulations on Hydraulic Fracturing in Shale and Other Formations

Prepared for the
Delaware Riverkeeper Network
Bristol, Pennsylvania

Prepared by
Glenn C. Miller, Ph.D.
Consulting Environmental Chemist
Reno, NV

March 20, 2018

Introduction: This document represents a review of the Draft Delaware River Basin Commission's Regulations on Hydraulic Fracturing in Shale and Other Formations, specifically regarding the concerns surrounding management and potential discharge of brines derived and released during and after fracturing operations in the Delaware River Basin or at locations outside of the Basin.

I have examined many of the chemical and toxicological issues, particularly related to potential treatment and discharge into the Delaware River Basin of waters associated with hydraulic fracturing, primarily produced and flowback (formation) water. This issue has confronted the Delaware River Basin Commission for several years now, and I appreciate the thought that has gone into these regulations. I feel strongly that, due to the chemical complexity of these highly contaminated waters, the best solution is to simply remove the option of disposal of any hydraulic fracture (HF) associated waters to any surface water in the Delaware Basin. The areas of the river designated by the Commission as Special Protection Waters (the nontidal river) cannot maintain adopted or proposed water quality standards nor meet the "No measurable change" requirement enforced by the Commission if the waters produced by hydraulic fracturing are discharged to the Basin's waterways, particularly if the HF waters are not treated to remove metals, salts and norm. The region below Philadelphia already receives a variety of discharges, and potentially adding a major load of a complicated array of contaminants from HF water should simply be prohibited. The industry is currently reusing these contaminated waters in other HF gas wells, and/or disposing of them in deep receiving wells where the geological conditions allow deep well injection. This latter option is presently being used, and will likely be used in the future.

The following comments should be considered.

A. The flowback and produced water that flows back up the wells following hydraulic fracturing is heavily contaminated, primarily with the Marcellus formation contaminants. The produced brines that are released during gas production are complex and contain a variety of problematic contaminants and represent a serious chemical contamination potential.

The Commission clearly recognizes the problems with contaminants in HF waters, particularly in the non-tidal portions of the Delaware River. However, further efforts are required for understanding <u>all</u> of the contaminants in the flowback and produced water, their management and disposal. Four problematic components of the flowback water and produced brines include (1) the inorganic salts (including bromide), metals and metalloids, (2) the radioactive component (NORM), (3) the organic substances (from the hydrocarbon formation) and, (4) the chemical additives that increase the efficiency of gas recovery.

1. ***Salts and inorganic constituents in the formation water, that are brought to the surface both as flowback and as production brines*:** The largest mass component of the formation water is salts and other inorganic constituents. The concentration of these constituents varies widely, as does their toxicity. Because the geological formation waters are proposed to be collected and temporarily stored in closed systems, disposal of these large volumes of water is, in my opinion, the largest problem with their management. The Commission clearly understands the problems with management of this water, and, in particular the discharge of high TDS water into receiving waters and recognizes that these brines will need to be regulated as industrial wastewater.

   The associated EPA study (EPA, 2016) on management of HF water shows that produced waters containing the formation water are variable in chemical composition, but include not only simple salts (e.g. sodium, potassium, chloride, bromide, sulfate, fluoride etc.) but also a variety of metals with varying frequency (cadmium, mercury, cobalt, nickel) and metalloids (arsenic, selenium, boron). Some of the constituent concentrations are very high, particularly sodium chloride, which has a mean concentration of on the order of 10% by weight. Some samples had over 30% by weight of simple salts plus other contaminants. The extreme contamination of these wastewaters, and the high variability of contaminant levels, make these waters complicated for treatment and potential reuse, as well as for tracking and disposal. If improperly managed and released to surface or groundwater, potentially severe contamination is likely. In particular, if this contaminated water intercepts domestic groundwater or surface water used as a drinking water source, the potential exists that these sources of water may need to be removed as a domestic source. While the proposed regulations effectively may not allow discharge of these waters into a surface stream that can be used as drinking water, that appears to not be the case for the more saline portions of the Basin.

   While recognizing the problems with management of this water, the Commission fails to clearly state how this water will be either disposed in a manner that protects human health and the environment, or otherwise treated to remove the contaminants. While a range of alternatives potentially exist, effectively none of these is likely to be accomplished in even a centralized waste treatment facility, and simply eliminating these waters from the Basin is the prudent alternative.

   A particular constituent that has been problematic in Pennsylvania waters receiving partially treated hydraulic fracturing water is bromide. When water is taken in to be treated as a drinking water, normal disinfection processes (chlorine and chloramine) convert bromide ion to bromide radical, which reacts with naturally occurring organic matter to produce the probable carcinogenic brominated trihalomethanes (THM). Because of the higher molecular weight of the brominated trihalomethane, the drinking water can violate drinking water for trihalomethanes (Chowdhury, et al., 2010; EPA, 2016) Use of ozone as a disinfectant can generate bromate, a known carcinogen (Fellet, 2014).

2. ***Radioactive Substances (NORM):***
The Commission also certainly recognizes the issues associated with management of NORM that comes to the surface either in the flowback or the production brines. However, similar to the salt problem discussed above, no indication on how treatment to remove these materials will be conducted.

Examples of NORM concentrations are presented from flowback in the EPA study (EPA, 2016).

The level of radioactivity as gross alpha is very high, from about 18,000 pCi /L to 123,000 pCi/L. The drinking water standard is 15 pCi/L (gross alpha).

What is to be done with these waters, and what is to be done with the residual NORM, if it is removed from the produced water and the flowback water? Dilution of the brines to a drinking standard of 15 pCi/L (gross alpha) will require 1000x to 10,000x dilutions, and is unlikely to be acceptable in nearly all jurisdictions, particularly when the components that are causing the radioactivity are not specified.

Ultimately, these radioactive materials will need to be removed offsite. Where will these radioactive materials be disposed, and will they be included with the very large tonnage of salts that results from an evaporation-crystallization treatment, or will they be separated into a metal/radioactive fraction by some (unknown?) chemical precipitation process?   These issues are critical for an analysis of the potential impacts of management of these materials, and the lack of a thorough analysis presents a serious problem when assessing the risk of these substances.   There is effectively no discussion of how these materials will be disposed, other than a general suggestion that they would be "treated" in a centralized treatment facility. In fact, there is no demonstrated economic and chemically efficient method for disposal of these wastes which is why most of this waste is transported to a deep well disposal site.

3. ***Hydrocarbons present in the formation water:*** Hydrocarbons present in the flowback and produced water are characteristic of fuel hydrocarbons, and are represented by (a) compounds that, in some cases, are carcinogenic (e.g. benzene, benzo(a)pyrene), (b) common solvents (e.g. toluene, ethylbenze), and (c) the primary fuel components of natural gas, particularly methane. But, these components are only part of the mix that is contained in fracking water.   Other components include heterocyclic amines, sulfur (odor) containing compounds, and an array of unknown compounds that have not

yet been identified from specific wells. The characterization of these constituents before and after treatment has not been completed. Without knowing what these chemicals are, and the toxicity of each of them, it is difficult to know how to treat them. The associated risk is primarily ecological, and, again, simply eliminating discharge of HF waters is the safe option.

4.Hydraulic fracturing additives: The range of hydraulic fracturing additives is very large, and difficult to assess from a risk perspective, since the list is almost certainly incomplete, specific information on the chemicals is lacking, and the specific rate of usage is not offered. Thus, not knowing the composition of the specific additives and the amounts provides effectively no basis for estimating the risk of these components on the biota of the receiving water. A mere laundry list of these components does not meet requirements for analysis of their potential impacts. The list is so long, and the data on each component so meager, that it falls far short of an analysis of risk. Additionally, many additives used are given proprietary trade names, and while the regulators may have information on the constituents in those products, the public does not, and thus the public cannot legitimately understand the risk of these products. Additionally, treatment of those proprietary compounds, even in a CWT, is not understood and ultimate disposal in a surface water constitutes a risk that can be avoided entirely by requiring deep well disposal in a permitted facility outside of the Basin.

B. Permissible treatment of the flowback and the produced water is not well defined. It is unclear how the post-treatment residual salts and radioactivity will be managed. There does not appear to be any complete treatment of these waters that will allow discharge of the water in any surface water of the Delaware River Basin.

In my opinion, there are no treatment options that can remove the contaminants in a cost effective manner, and suggest that until such a process is developed, discharge of HF water should simply be banned within the basin to avoid the unreasonable risk of the contamination and loss of drinking water resources. This is particularly the case for drinking water sources, but also for lower basin waters, primarily associated with ecological risk. Some of the membrane processes (e.g. reverse osmosis, nanofiltration) may meet the standards in some cases for a portion of the water, although the reject water will still need to be disposed out of the basin and will contain higher concentrations of all of the contaminants. Effectively, there is no reasonable cost alternative to simply transporting the HF waters to regions where deep well disposal is permitted, which is the way those waters are being managed to date.

The methods for treatment of the water for discharge to a surface water are not considered, and how specific requirements for discharge could be met by various treatment processes (e.g. membrane, ion exchange or evaporative processes) are not mentioned. The residual contaminants removed by evaporative or membrane processes, and thus concentrated to form even more contaminated water, were not discussed, other than to indicate that the residual salts, or concentrated brine will require "further treatment or disposal". For flowback or brine containing 7% (70,000 mg/L) salts, upwards of 300 tons of salts will exist in every million gallons of water, plus the concentrated NORM as well as a portion of the hydrocarbons. The source of the alpha emitters also will need to be identified. If, as is suspected, polonium is present in the flowback water, it represents an additional management burden of the flowback and produced water.

C. **The best option is simply to prohibit storage or treatment of HF water in the Delaware River Basin entirely.** Odors are a particular problem for management/storage/treatment of HF waters, and a variety of chemicals are present in hydrocarbon formations that can present a serious odor problem, which can be both a serious human health issue and can affect the quality of life of persons living near these sites. A very common, but toxic, constituent is hydrogen sulfide, characterized by a rotten egg smell. Other organic sulfides can also be present, including a variety of alkyl sulfides. Odors are very difficult to regulate, due to the vagaries associated with odor detection, acclimation, and differential effects on different persons. The severity of an odor is in the nose of the beholder. Odors are particularly bothersome to persons living downwind, and storage of HF waters in the Basin can very likely lead to complaints, which should be taken seriously.

Spills are another problem with HF waters, and the EPA (EPA, 2016) has noted spills occurring throughout the HF industry. These spills can be minor or major, but each spill has the potential to contaminate surface and groundwater, and will likely sterilize the ground that it contaminates.

Banning management of these waters in the Basin will substantially lessen the impact of HF waters on residents of the basin from both spills and odors.

D. **Tidal versus Non-Tidal facilities:**

From my read of the proposed regulations, it appears that disposal of HF waste water will be effectively prohibited through even a centralized water treatment (CWT) facility in areas where the receiving water can potentially be a drinking water, and in the areas designated as Special Protection Waters. With a TDS limit of 500 mg/L limit, the salt load in these HF waters would effectively preclude any reasonable treatment (other than a membrane treatment) for discharge.

However, on a closer reading this may not be the case for the tidal waters that have a higher TDS limit. The language in the 440.5(f) section contain words that allow a broad discretion on whether a facility can be sited in the saltier sections of the River, with discretionary terms such as "mixing zone" or "or a concentration established by the Commission that is compatible with designated water uses and stream quality objects".

Existing discharges to the lower portion of the basin, from POTW and other industrial discharges already provide a source of contaminants that are of concern. While the Delaware River water quality has improved through dedicated efforts of the Commission, the lower stretch of the Delaware River Basin already receives discharges from other industries. While a pure sodium chloride discharge may not have a major negative impact on the biota of the Basin, the other constituents in HF water, including organic compounds and the radioactivity can still provide an unacceptable risk to the ecological integrity of the Basin.

Conclusion: There is no compelling reason to allow any storage/treatment/discharge of HF water in the Delaware River Basin, and many reasons why this presents an unacceptable risk to the region. With the very large efforts that have been implemented to improve and protect the Basin, adding an additional risk by allowing HF waters in the Basin is unwise and will set back the success that has been realized to date. Production of natural gas near the Basin requires consideration of a variety of economic factors, and one of them should be that the production entities need to factor in the costs of reuse of these waters in other HF wells, or transport of these highly contaminated water to a permitted disposal well facility, which is presently the current method of disposal of these wastes. The disposal of these waters should not be placed on the communities who enjoy the values of the Delaware River Basin that presently exist, or the 15-17 million people who rely on the Delaware River Watershed for their drinking water.

References

Chowdhury, S., P. Champagne, and J. McLellen, (2010) "Investigating effects of bromide ions on trihalomethanes and developing model for predicting bromodichlormethane in drinking water" Water Research, 44:2349-59)

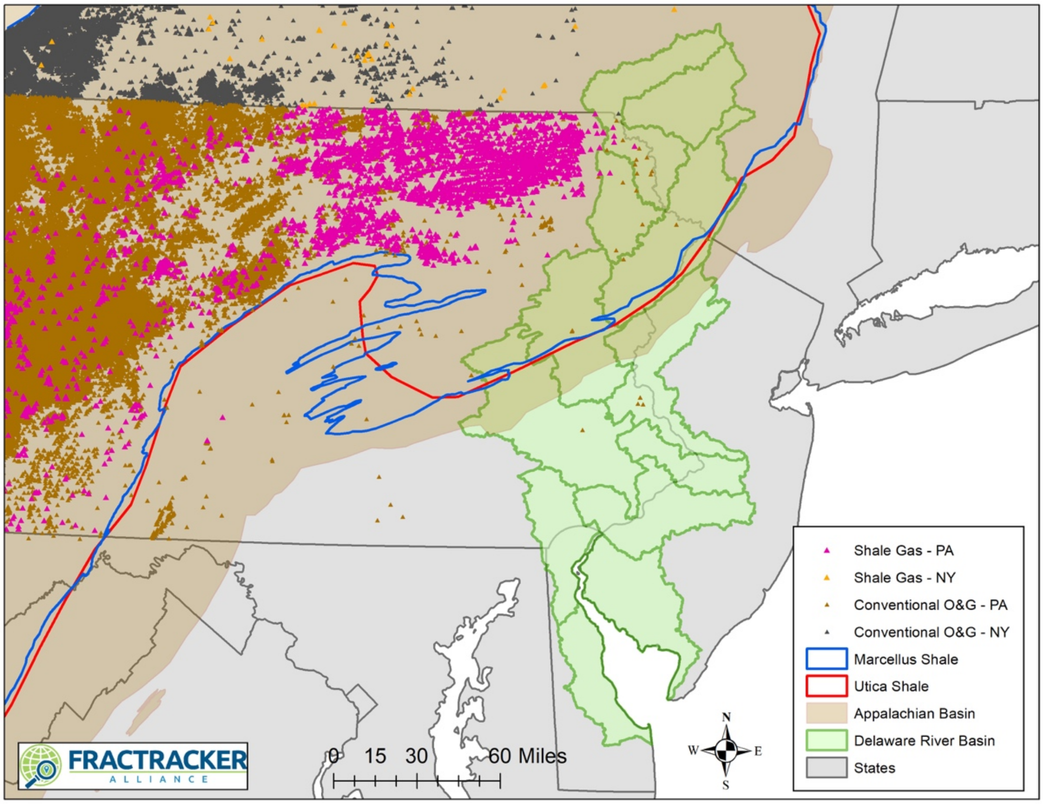
EPA, (2016) "Technical Development for the Effluent Limitations Guidelines and Standards for the Oil and Gas Extraction Point Source Category" US EPA Office of Water, Washington, D.C. EPA-820-R-16-003

Fellet, Melissae, (2014) "Fracking Wastewater Could Encourage Formation of Toxic Compounds During Drinking Water Disinfection" Chemical and Engineering News, September 23, 2014,

FRACTRACKER ALLIANCE

Potential Impacts of Unconventional Oil and Gas on the Delaware River Basin

March 20, 2018 / FracTracker Alliance Issue Paper / Main Author: Matt Kelso



Author:
FracTracker Alliance
1845 Market St, Ste. 204,
Camp Hill, PA 17011
(717) 303-0403
info@fractracker.org
www.fractracker.org

Prepared for:
Delaware Riverkeeper Network
925 Canal St Suite 3701
Bristol, PA 19007
drn@delawareriverkeeper.org
www.delawareriverkeeper.org

Executive Summary

The Delaware River Basin Commission (DRBC) is considering new regulations that will ban high volume hydraulic fracturing within its jurisdiction, noting:[1]

> The Commission has determined that high volume hydraulic fracturing poses significant, immediate and long-term risks to the development, conservation, utilization, management, and preservation of the water resources of the Delaware River Basin and to Special Protection Waters of the Basin…

However, the same bans will not be extended to some of the ancillary activities of the industry, including large-scale water withdrawals and waste disposal, both of which will simply be "discouraged" under the new policy. Oil and gas (O&G) wastewater disposal will be permitted at centralized waste treatment facilities, the effluent of which will contain some level of contaminants that will be discharged to the Basin's waterways. Solid waste from the O&G industry will continue to be disposed of within the basin, as well.

Acknowledgements

This report was developed by Matt Kelso of FracTracker Alliance for use by the Delaware Riverkeeper Network (DRN). It was reviewed by Samantha Rubright of FracTracker and Tracy Carluccio of DRN.

Delaware Riverkeeper Network provided the funding for this research.

Information about the report's methodology for determining water usage for oil and gas wells in Pennsylvania, including a link to the original dataset, can be found in Appendix A, below.

[1] Delaware River Basin Commission. Proposed New 18 CFR Part 440 - Hydraulic Fracturing in Shale and Other Formations: http://www.nj.gov/drbc/library/documents/HydraulicFracturing/18CFR440_HydraulicFracturing_draft-for-comment_113017.pdf

Summary of the O&G Industry in the Delaware Basin

As natural gas is both a market-driven and weather-driven commodity, the number of wells that the industry will drill in any given year will vary significantly. For example, unconventional drillers in Pennsylvania spudded 1,959 unconventional wells in 2011.[2] Five years later, the industry drilled only 504 such wells, although the number of wells being drilled is now increasing once again as stored gas supplies are consumed and new pipelines are added to ship the commodities out of the region.

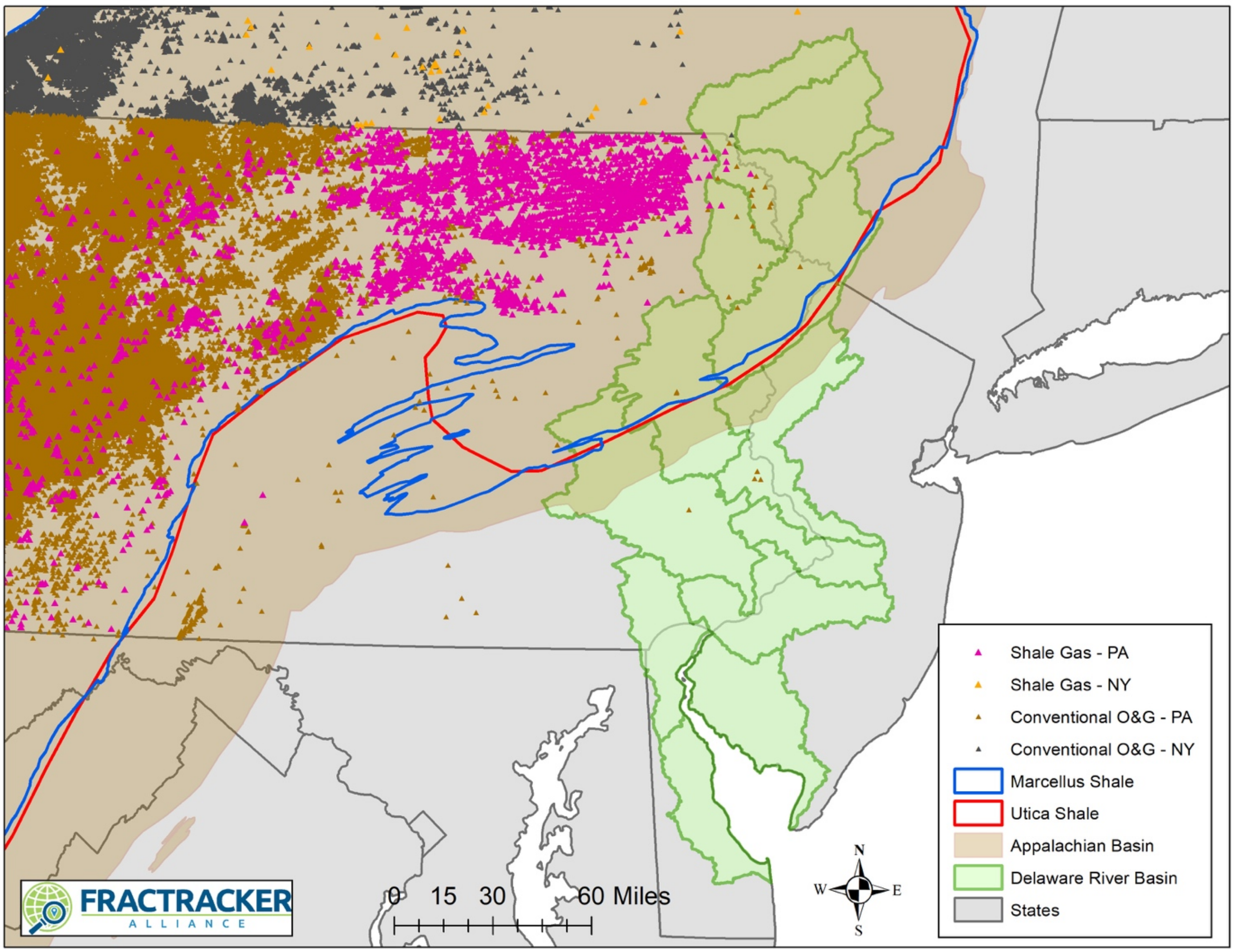


Figure 1. O&G resources and activity near the Delaware River Basin. If the New York ban and DRBC de facto moratorium were lifted, the potential impact of unconventional drilling on the Delaware River Basin could be substantial.

[2] PA DEP spud report: http://www.depreportingservices.state.pa.us/ReportServer?/Oil_Gas/Spud_External_Data

The Delaware River Basin is on the eastern margin of the oil and gas producing region known as the Appalachian Basin, which includes both the Utica and Marcellus shale gas plays (See Figure 1). While the Delaware basin may not have the same extensive coverage of O&G resources, industry analysts estimate that there could be 4,000 wells drilled into the region[3] if the DRBC's de facto moratorium and New York's ban were lifted, just from the Interior Marcellus formation.

Even if these O&G resources remain undeveloped, the Delaware River Basin will see no shortage of impact. Pipelines crisscross the region, taking oil and gas products from producing areas west to processing plants, population centers, natural gas power plants, and export terminals along the coast. The basin might also serve as a water supply for highly consumptive wells in the nearby Susquehanna River Basin, and its role in processing O&G waste products are likely to increase as the industry struggles to deal with an ever-increasing quantity of both liquid and solid waste.[4]

While conventional O&G activity does have an impact on the Delaware River Basin, the focus of this paper will be on unconventional wells, due to the proximity of a large number of these wells to the basin, the very large amount of water that they consume and waste that they generate.

Water Usage

While operators of conventional wells in Pennsylvania and New York have been using hydraulic fracturing to stimulate production of oil and gas for decades, unconventional wells drilled into shale like the Marcellus Shale formation require much more stimulation to release their carbon content. Such industrial-scaled operations use volumes of water that are multiple orders of magnitude greater than their conventional counterparts.[5]

---

[3] Habicht S, Hanson L, Faeth P. (2015). The Potential Environmental Impact from Fracking in the Delaware River Basin. CNA Corporation. https://www.cna.org/cna_files/pdf/IRM-2015-U-011300.pdf
[4] PA DEP. Oil and Gas Waste Reporting Database. https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Welcome/Agreement.aspx
[5] Magill B. (2015). Water Use Rises as Fracking Expands. Scientific American. https://www.scientificamerican.com/article/water-use-rises-as-fracking-expands/

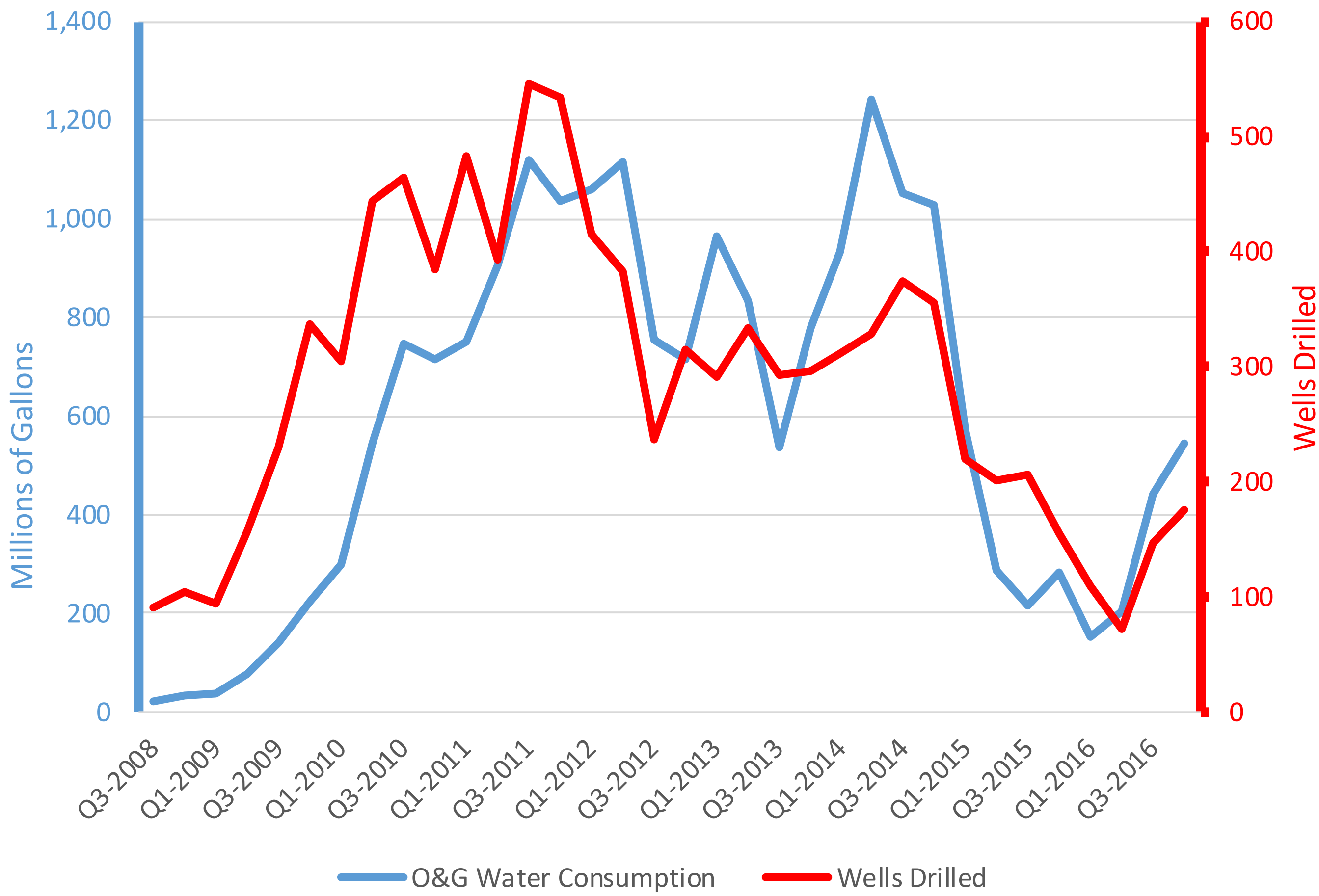


Figure 2. PA Drilled Wells and O&G Water Consumption in the Susquehanna River Basin over time

Figure 2 includes oil and gas related water withdrawals from the Susquehanna River Basin, and statewide unconventional drilled well totals by quarter.[6] There is a substantial amount of correlation between the two as one might expect, with peaks in drilling activity (red) requiring higher volumes of water (blue) for hydraulic fracturing well stimulation. Water withdrawals from the Ohio River Basin in Pennsylvania are known to be substantial but are not included in this analysis.

The number of wells drilled is not the only significant variable, however. According to the industry's hydraulic fracturing chemical disclosure registry, FracFocus, the amount of water used per well has more than doubled since 2011.

[6] This information originated from Unpublished SRBC water withdrawal data and a FracTracker analysis of FracFocus data from http://fracfocus.org/data-download

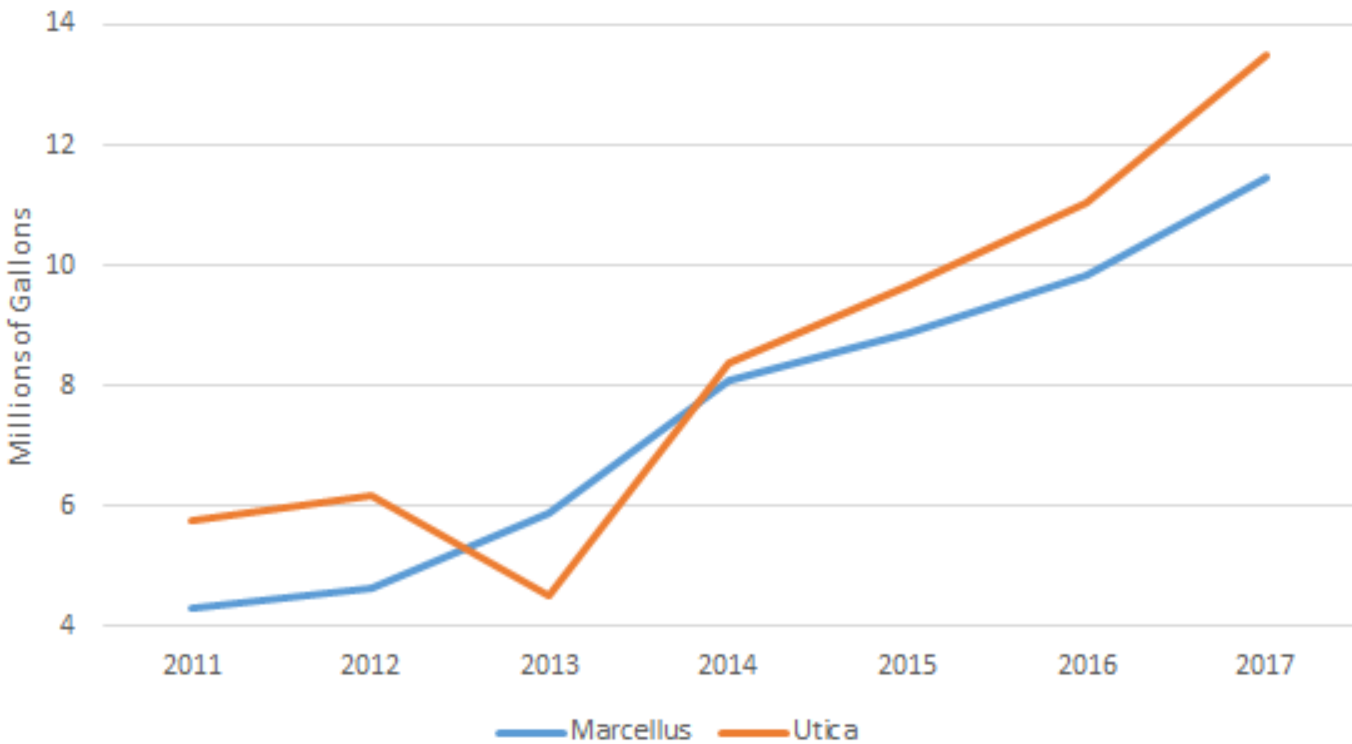


Figure 3. Water use per wells in PA based on industry data submitted to FracFocus

Water usage for Marcellus wells in Pennsylvania have increased from an average of 4.3 million gallons in 2011 to 11.4 million gallons in 2017, while water use in the deeper Utica formation has increased from 5.8 million 13.5 million gallons per well over the same time frame. The reason for this increase is twofold. First, drillers are using increasingly longer bore holes in the Appalachian basin, the lateral portion of which is starting to exceed 4 miles[7,8] in some cases. The resulting effect is more surface area to stimulate (which inherently uses more water). And second, operators in the Appalachian basin are using significantly more water per lateral foot than in years past.[9]

7 Litvak A. (2018). These days, oil and gas companies are super-sizing their well pads. Pittsburgh Post-Gazette. http://www.post-gazette.com/powersource/companies/2018/01/15/These-days-oil-and-gas-companies-are-super-sizing-their-well-pads/stories/201801140023

8 This horizontal well in question was ~4.8 miles in length. Smith M. (2018). Ensign drills Canada's longest well at Fox Creek. JWN. http://www.jwnenergy.com/article/2018/2/ensign-drills-canadas-longest-well-fox-creek/

9 Auch T. (2017). The Freshwater and Liquid Waste Impact of Unconventional Oil and Gas in Ohio and West Virginia FracTracker Alliance presentation. http://midatlanticwrc.org/wp-content/uploads/2017/11/The-Freshwater-and-Liquid-Waste-Impact-of-Unconventional-Oil-and-Gas-in-Ohio-and-West-Virginia.pdf

It is difficult to predict when, if ever, the per-well water demand will begin to level off, but there are other pressures on total water usage, as well. As additional midstream infrastructure enables the export of gas from the region to accelerate, the prices for gas will go up, thereby making drilling more profitable, resulting in more wells drilled. This rebound is already in progress, with 35 more unconventional wells drilled in 2017 than in the year prior.

Table 1. Wells drilled and water used (gallons) per year in Pennsylvania, 2011-17

Year	Wells Drilled	Average Water	Estimated Water
2011	1,959	4,340,524	8,503,086,609
2012	1,350	4,640,585	6,264,790,136
2013	1,214	5,838,822	7,088,329,348
2014	1,371	8,112,099	11,121,687,702
2015	784	9,089,367	7,126,063,393
2016	504	10,058,239	5,069,352,370
2017	539	11,590,975	6,247,535,763
Total	**7,721**	**53,670,611**	**51,420,845,321**

In the table above, we multiplied the number of unconventional wells drilled in Pennsylvania by the average per-well water consumption figure based on self-reported data to FracFocus, the industry's hydraulic fracturing chemical registry. Alternatively, we could have simply aggregated FracFocus water usage within the state, however, reporting the contents of hydraulic fracturing fluid to the registry was not originally compulsory in Pennsylvania, and as such, we found early records to be incomplete.

In all, we estimate that the industry used 51.4 billion gallons of water to stimulate 7,721 unconventional wells in Pennsylvania in the seven-year period from 2011 through 2017.

Currently, none of the Pennsylvania O&G related surface or ground water withdrawal sites are in the Delaware River Basin, although with such an increasing demand for fresh water, drilling operators would likely make extensive use of hydrological resources there.

Dealing with Waste

Although the number of conventional O&G wells that reported generating waste in PA during this timeframe outnumber their unconventional counterparts by a 3 to 1 margin, the unconventional wells cumulatively generate more than 10 times the amount of liquid waste.[10]

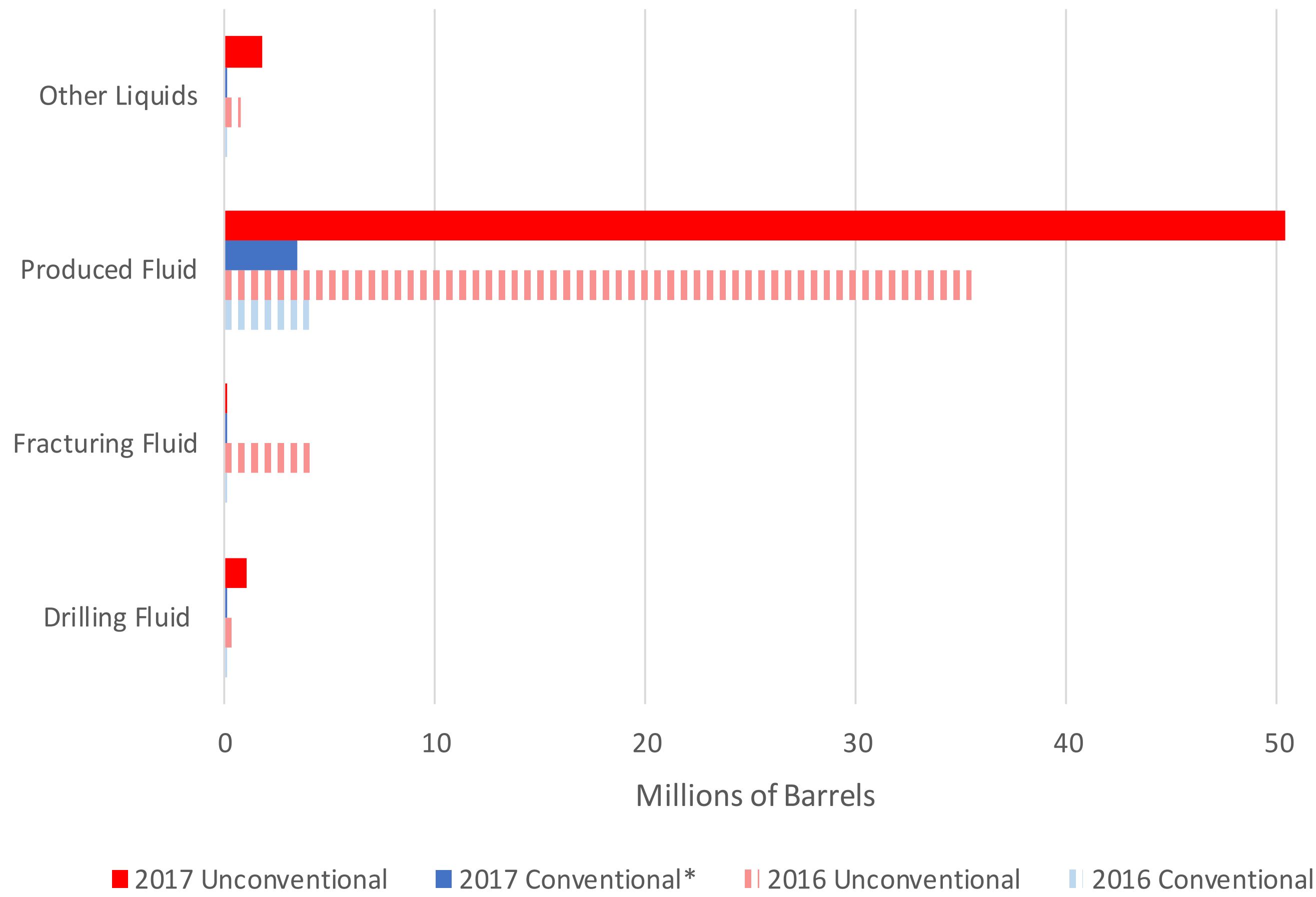


Figure 4. 2016-17 Liquid O&G Waste in Pennsylvania[11] (in millions of barrels). Totals for some waste types do not show on the scale of this chart, but are shown in Table 2, below.

[10] PA DEP. Oil and Gas Waste Report.
https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Welcome/Agreement.asp

[11] An explanation of waste types can be found here: PA DEP. Oil and Gas Production and Waste Reporting Manual.
http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Greenport/Userguides/Oil%20and%20Gas%20Reporting%20Electronic%20Production%20and%20Waste%20Reporting%20Guide.pdf

Table 2. Liquid waste totals in barrels (42 gallons) by year from conventional and unconventional wells in Pennsylvania

Report	Wells Reporting	Basic Sediment	Drilling Fluid	Fracturing Fluid	Produced Fluid	Servicing Fluid	Spent Lubricant	Other Liquids	Total Liquids
2016 Conventional	26,096	166	1,665	1,720	4,026,219	18,371		6,360	4,054,502
2016 Unconventional	7,997	1,191	529,675	4,278,074	35,464,252	69,364	391	731,798	41,074,745
2017 Conventional*	6,259	416	2,072	360	3,427,970	4,022	29	2,326	3,437,194
2017 Unconventional	8,979	122	990,559	27,805	50,355,199	18,210	433	1,775,156	53,167,483

* We suspect the conventional waste report was substantially incomplete at the date downloaded.

Note that the 2017 conventional report appears to be incomplete as of February 15, 2018, with only about one quarter the number of wells reporting waste as the year prior. However, the total waste volume is 85% of the 2016 figure, indicating that most of the largest producers of waste in this category are likely accounted for. Wells appearing on the report but not reporting waste figures were not included in the well counts. Figures are in 42-gallon barrels.

Dealing with such large quantities of liquid waste has been problematic in Pennsylvania in recent years. Originally, much of this liquid O&G waste was treated in publicly owned treatment facilities, but due to rising contaminant levels in the rivers, the Pennsylvania DEP requested a voluntary cessation of the practice in April 2011,[12] a move that was later made compulsory. However, other surface treatment facilities were not affected by this decision.

Many other states rely heavily on oil and gas wastewater disposal wells to avoid surface treatment. This practice has created a number of problems as well, however, including aquifer contamination[13] and induced seismic activity.[14] In Pennsylvania, much of the geology has been deemed unsuitable[15] for underground injection, although there are recent efforts to expand this program[16] due to the immense volume of liquid waste now being generated by the industry. In March 2018, the US Environmental

[12] Soeder DJ. (2017). Unconventional: Natural Gas Development from Marcellus Shale. Geological Society of America. Volume 527 of Special Papers, page 84.

[13] McLin SG. (1986). Evaluation of Aquifer Contamination from Salt Water Disposal Wells. In Proceedings of the Oklahoma Academy of Science (Vol. 66, pp. 53-61). http://digital.library.okstate.edu/OAS/oas_pdf/v66/p53_61.pdf

[14] Virginia Tech Seismological Observatory. Induced Earthquakes Throughout the United States. http://www.magma.geos.vt.edu/vtso/induced_quakes.html

[15] Arthur JD, Bohm B, Layne M. (2009). Considerations for development of Marcellus Shale gas. World Oil, 230(7), 65-69. Page 67. http://www.all-llc.com/publicdownloads/WO0709Arthur.pdf

[16] Hurdle J. (2017). PA DEP approved 11th underground injection well for oil and gas waste. StateImpact PA. https://stateimpact.npr.org/pennsylvania/2017/06/05/pa-dep-approved-11th-underground-injection-well-for-oil-and-gas-waste/

Protection Agencies issued permits for two more of these disposal wells, including facilities in Allegheny[17] and Elk[18] counties. The industry does try to reuse some of this produced fluid, but there are limits to what they can do in that regard.

Table 3. Pennsylvania unconventional O&G liquid waste disposal methods and their 2017 disposal volumes in barrels (42 gallons/barrel)

Liquid Waste Disposal Method	Barrels
Centralized Treatment - NPDES Discharge	49,208
Centralized Treatment Plant - Recycle	114,481
Injection Disposal Well	3,005,090
Landfill	18,888
On Site Encapsulation	440
Public Sewage Treatment Plant	77
Residual Waste Processing Facility	17,882,965
Residual Waste Transfer Facility	22,273
Reuse (At Well Pad)	26,664,947
Reuse at A Conventional Well Site in PA	3,757
Reuse at A Well Pad Outside PA	691,634
Reuse Other Than Road Spreading	3,142
Storage Pending Disposal or Reuse	147,448
Surface Impoundment	4,563,133
Grand Total	**53,167,483**

Table 3 shows the disposal method for unconventional liquid waste in Pennsylvania in 2017. Figures are in 42-gallon barrels. The vast majority of the waste (49.4 million barrels, 93%) remained in Pennsylvania, with the remainder sent to Michigan, New York, Ohio, and West Virginia.

Solid waste disposal is also a concern for water quality, as there is the potential for toxic, radioactive contaminants[19] such as Radium-226 to enter the water cycle via landfill leachate. Landfills in Pennsylvania

---

[17] US EPA. (2018). Public Notice: Penneco Environmental Solutions, LLC - PAS2D701BALL, Delmont, PA. https://www.epa.gov/pa/penneco-environmental-solutions-llc-pas2d701ball-delmont-pa

[18] US EPA. (2018). Public Notice: Seneca Resource Corporation - Pittsburgh, PA PAS2D026BELK. https://www.epa.gov/pa/seneca-resource-corporation-pittsburgh-pa-pas2d026belk

[19] Resnikoff M. (2015). Review of Pennsylvania Department of Environmental Protection Technologically Enhanced Naturally Occurring Radioactivity Materials (TENORM) Study Report. http://www.delawareriverkeeper.org/sites/default/files/Review%20of%20PA%20DEP%20NORM%20Study-12.14.15%20FINALdocx.pdf

have monthly radiation quotas, the limits of which were reached 87 times[20] in 2015 due to oil and gas waste.

Table 4. Solid waste disposal from Pennsylvania's unconventional wells in 2017 in tons

Disposal Method	Tons
Centralized Treatment - NPDES Discharge	1,283
Centralized Treatment - Recycle	639
Injection Disposal Well	1,279
Land Application	103
Landfill	977,277
On Site Pit	192
Residual Waste Processing Facility	56,438
Residual Waste Transfer Facility	10,307
Reuse (At Well Pad)	5,536
Storage Pending Disposal or Reuse	272
Surface Impoundment	2,272
Grand Total	**1,055,598**

Table 4 shows the disposal method for unconventional solid waste in Pennsylvania in 2017. As with liquid waste, there is an attempt to recycle some of the solid waste, but with limitations; 93% of the solid waste is disposed of at a landfill.

Three facilities in the Pennsylvania portion of the Delaware River Basin already accept waste from unconventional oil and gas wells in Pennsylvania, including Berks Transfer in Reading, Berks County; Republic Environmental Systems Inc. in Hatfield, Montgomery County; and Waste Recovery Solutions in Myerstown, Lebanon County.

[20] Zou JJ. (2016). Hot mess: states struggle to deal with radioactive fracking waste. Center for Public Integrity. https://www.publicintegrity.org/2016/06/16/19784/hot-mess-states-struggle-deal-radioactive-fracking-waste

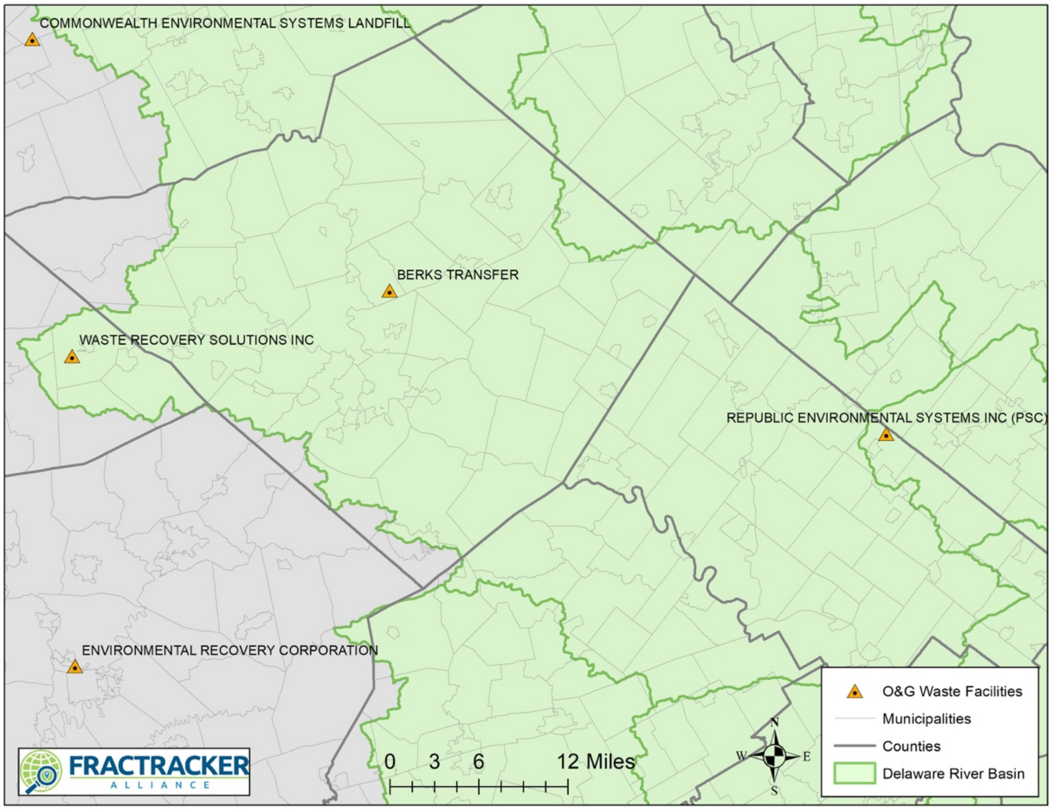


Figure 5. Map of facilities in Pennsylvania's section of the Delaware River Basin that accept solid oil and gas waste for disposal

Table 5. Waste facilities within the Delaware River Basin and the unconventional O&G waste quantities received in 2017

Waste Facility	Waste Type	Liquid (Bbls)	Solid (Tons)
Berks Transfer	Soil Contaminated by Oil & Gas Related Spills - RWC 811		3.5
Republic Environmental Systems Inc. (Psc)	Drill Cuttings - RWC 810		34,150.7
	Filter Socks - RWC 812		69.1
	Produced Fluid - RWC 802	171.6	
	Produced Fluid - RWC 802		840.1
	Servicing Fluid - RWC 808	65.6	
	Servicing Fluid - RWC 808		152.0
	Soil Contaminated by Oil & Gas Related Spills - RWC 811		114.2
	Synthetic Liner Materials - RWC 806		193.1
Waste Recovery Solutions Inc.	Filter Socks - RWC 812		0.5
	Other Oil & Gas Wastes - RWC 899		4.7
	Soil Contaminated by Oil & Gas Related Spills - RWC 811		3.6
Waste Disposed in Delaware RB	**All Types**	**237.2**	**35,531.4**

Although just a small fraction of the statewide O&G waste management picture, the waste accepted by facilities in the Delaware River Basin is significant, especially the more than 34,000 tons of drill cuttings disposed of at the Republic Environmental Systems facility. With waste haulers being willing to drive as far a Michigan[21] to dispose of some Pennsylvania's waste, the economic pressure of finding closer destinations is likely considerable.

Conclusion

The de facto moratorium on unconventional oil and gas development put in place by the Delaware River Basin Commission has afforded the region significant protections from serious impacts in recent years that the Susquehanna River Basin and Ohio River Basins have not been provided. Through 2017, the oil and gas industry in PA drilled 10,652 unconventional wells[22]; caused 7,956 incidents receiving violations.[23] In 2017 alone, the industry required over 6 billion gallons of fresh water in Pennsylvania and generated 53 million barrels (2.2 billion gallons) of liquid waste and 1.1 million tons (2.1 billion pounds) of solid waste, despite being a relatively light year in terms of the total number of wells drilled.

With its proposed ban as written, the Delaware River Basin Commission looks to protect the basin from the direct impacts of drilling, but if the ancillary industries of water withdrawals and waste disposal are permitted, such activities will have an adverse effect on the waters within the basin.

In an industry expecting to drill roughly 45,000 more wells just in the Interior Marcellus Formation of PA through 2045,[24] the pressure to find new water sources and waste disposal sites will be ongoing in the coming decades, including within the Delaware River Basin. This will require over half a trillion gallons of water to stimulate, assuming that the per-well water consumption does not continue to increase beyond 2017 figures. If waste figures also hold steady, we will see 1.4 billion barrels (60 billion gallons) of toxic liquid waste and 28.5 million tons of solid waste that will need to be processed in the coming years. The actual figure is likely to be much more than that, however, as the current waste figures are based on the

[21] Matheny K. (2014). Michigan landfill taking other states' radioactive fracking waste. Lansing State Journal. https://www.lansingstatejournal.com/story/news/local/michigan/2014/08/19/michigan-takes-in-radioactive-sludge/14275129/
[22] PA DEP. Spud Report. http://www.depreportingservices.state.pa.us/ReportServer?/Oil_Gas/Spud_External_Data
[23] PA DEP. Oil and Gas Compliance – Report Viewer. http://www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance
[24] Hanson L, Habicht S, Faeth P. (2016). Potential Environmental Impacts of Full-development of the Marcellus Shale in Pennsylvania - Map Set 1: Development Projections. CNA. https://www.cna.org/cna_files/pdf/Maps1_WellProjections.pdf

output of just 8,000 wells – if the industry drills 45,000 more, there will likely be times where there are tens of thousands of active unconventional wells generating immense volumes of waste simultaneously.

We expect substantial pressure will be placed on the basin to help shoulder the burdens of O&G water withdrawals and waste disposal in the coming decades. By ignoring these ancillary industries in its proposed ban of unconventional drilling, the Delaware River Basin Commission is taking a half-measure towards protecting the waters in its jurisdiction from substantial impacts in the years ahead.

insights empowering action

1845 Market St, Ste. 204,
Camp Hill, PA 17011
(717) 303-0403
info@fractracker.org
www.fractracker.org
@FracTracker

FracTracker Alliance studies, maps, and communicates the risks of oil and gas development to protect our planet and support the renewable energy transformation.

Analysis: Matt Kelso, Manager of Data and Technology, FracTracker Alliance
Layout and Editing: Samantha Rubright, DrPH, CPH, Manager of Communications and Partnerships, FracTracker Alliance

Appendix A

Methodology & Data Download

The FracTracker Alliance determined water usage for oil and gas (O&G) wells in Pennsylvania using data obtained from the industry's chemical disclosure registry, FracFocus. The formation of these wells was determined by matching the API numbers of these wells to the Pennsylvania O&G Formations Report. This Appendix includes the methodology and data used for that analysis.

Methodology

- Download data from http://fracfocus.org/data-download in Microsoft Excel compatible format
- Open files "registryupload_1.csv" and "registryupload_2.csv"
- Filter data for Pennsylvania for each including " PA", "PA", "PA ", "Pennslvania", "Pennsylavania", "Pennsylvania", "Pennsylvania", "Pennsylvanya", and "Penssylvania". Rename all to "Pennsylvania".
- combine in new Excel document
- Use the Excel YEAR function to extract the year from the "JobStartDate" field
- Reformat API number to "XXX-XXXX" format used by the Pennsylvania O&G Formations Report at http://www.depreportingservices.state.pa.us/ReportServer?/Oil_Gas/OG_Well_Formations
- Copy API numbers, formation names, and counties from Formation Report onto a new tab of the worksheet
- Use the Excel VLOOKUP function to associate data for the "Formation" and "County_DEP" fields
- Create a Pivot Table of the data to determine the average number of gallons of water "TotalBaseWaterVolume" by year for the Marcellus and Utica formations, as well as the totals for all Pennsylvania data

Data Download

Click on the link below to download an Excel spreadsheet of the data used to compile the water use information contained in FracTracker's Potential Impacts of Unconventional Oil and Gas on the Delaware River Basin report, 2018.

https://s3-us-west-2.amazonaws.com/downloads.fractracker.org/FF_SummaryData_Pennsylvania_02022018.xlsx

Comments on Proposed Regulations

of

The Delaware River Basin Commission

Concerning

High Volume Hydraulic Fracturing to Produce Oil and Gas

Prepared for: **Delaware Riverkeeper Network**
925 Canal Street
Bristol, Pennsylvania 19007
215-369-1188 www.delawareriverkeeper.org

Prepared by: **Schmid & Company, Inc., Consulting Ecologists**
1201 Cedar Grove Road
Media, Pennsylvania 19063
610-356-1416 www.schmidco.com

19 March 2018

Background

The Delaware River Basin Commission (DRBC) is proposing to amend its *Special Regulations* and its *Administrative Manual Rules of Practice and Procedure* in regard to the extraction of petroleum hydrocarbons using technology known as high volume hydraulic fracturing (HVHF or fracking) that both consumes and contaminates large volumes of water. In addition, changes are proposed regarding the regulation of wetlands and of leachate from solid waste disposal facilities. The Delaware Riverkeeper Network commissioned this commentary as part of its submission pursuant to the DRBC's 30 November 2017 request for comments from the public on the proposed regulations.

The DRBC is an interagency entity formed in 1961 by compact between the States of Delaware, New Jersey, New York, and Pennsylvania (Figure 1)[1] and the federal government to manage water resources jointly in the Delaware River basin (the Basin). The Basin includes all or portions of 42 counties (Figure 2) and all or portions of 838 municipalities.

The DRBC has designated part of its jurisdictional area as Special Protection Waters (Figure 3), and it has established water quality criteria for them. Special Protection Waters drain approximately 4.4 million acres of land and are located within the northern half of the DRBC area. The distribution of Special Protection Water drainage areas in the Basin is as follows (none is in Delaware):

Pennsylvania	=	50%
New York	=	35%
New Jersey	=	15%

Basin water resources are used by more than 15 million people. The quantity of water available in the Basin varies over time, and shortages occur during periods of drought. Water quality varies across the Basin in large part in response to human activities but also as a result of natural environmental factors. The streams and groundwaters of the Basin have a limited capacity to assimilate polluting substances in discharged wastewater while maintaining designated uses as suitable sources of potable water, aquatic life support, and other human purposes. The DRBC traditionally has focused on large-scale activities that affect large quantities of water, rather than the activities of individual householders.

DRBC proposes to amend certain of its regulations at 18 CFR 401 and add a new part 440 in order (1) to prohibit permanently the use of fracking to extract oil and gas within the Basin, (2) to regulate the export of any freshwater from the Basin to be used for fracking elsewhere, (3) to regulate the import of any oil and gas wastewater into the Basin from fracking elsewhere, (4) to change its procedure for authorizing activities affecting wetlands,

[1] Figures are displayed at the end of the text.

and (5) to change its regulations to address specifically the leachate from solid waste disposal facilities rather than the landfills and other facilities themselves. Since 2010 DRBC has maintained a moratorium on fracking for shale gas production within the Basin. There is also a ban on fracking in effect at present in New York State and in several of its municipalities aimed at protecting public health and the environment.

DRBC specifically requested comments on the effects its proposed rules may have on

- Water availability,
- Control and abatement of water pollution,
- Economic development,
- Conservation and protection of drinking water supplies,
- Conservation and protection of aquatic life,
- Conservation and protection of water quality in Special Protection Waters, and
- Protection, maintenance, and improvement of water quality and quantity basinwide.

Schmid & Company professionals have decades of experience applying their expertise in wetlands, stream protection, and environmental impact assessment throughout the Basin and the mid Atlantic region. These comments draw upon experience gained from our diverse project work on behalf of environmental permit applicants, for conservation groups, and in direct support of regulatory agencies at the federal, State, and municipal levels.

Fracking of Hydrocarbon Resources

Geological formations known as the Marcellus Shale and the even deeper Utica Shale underlie the northern 40% of the Delaware River Basin in eastern Pennsylvania and southern New York, typically 7 to 10 thousand feet below the present land surface. They constitute the largest petroleum-producing deposits in the United States. Organic remains slowly accumulated in the beds of shallow seas as these shales were laid down during the Devonian period some 400 million years ago. As the Appalachian Mountains rose in response to colliding tectonic plates, the organic deposits were buried and altered to form hydrocarbons deemed useful today for industrial purposes.

The northern portion of the Marcellus Shale underlies portions of Pennsylvania, Ohio, West Virginia, Virginia, Maryland, and New York (Figure 4). Of the total area of Marcellus Shale reserves, only 5% underlies the DRBC area. Within the Basin, Marcellus Shale is located only in Pennsylvania and New York; none is within New Jersey or Delaware. Most sections of the Basin underlain by Marcellus Shale reserves are designated Special Protection Waters (Figure 5). In New York, almost all (98%) of the area designated Special Protection Waters is underlain by Marcellus Shale reserves. In Pennsylvania, approximately two-thirds (67%) of the area designated Special Protection Waters is underlain by Marcellus Shale reserves.

Until the present century the petroleum trapped in these “tight” Marcellus and Utica Shale formations was deemed not economically recoverable using traditional vertical wells that had been developed to tap oil and gas held in sandstone and carbonate rocks. During the past decade innovative combinations of drilling and hydraulic fracturing technology have been employed to extract natural gas and other hydrocarbons from these formations in Pennsylvania and other States. Depending on the worldwide market for fossil fuels, industry may seek to exploit the natural gas reserves long trapped beneath the Basin.

Current unconventional technology employs mixtures of water, sand (the most common proppant for holding cracks open), and chemicals injected under high pressure by diesel-powered pumps to break apart shale rocks so that long-trapped natural gas and other hydrocarbons can make their way to the surface through bored wells. Drilling technology now allows the advance of borings that extend thousands of feet deep and thousands of feet horizontally from the drill rig. To be classed by DRBC as HVHF, a well must use more than 300,000 gallons of water during its development. Each unconventional well currently makes use of 4 to 10 million gallons of water each time it is fracked, and the volumes of water needed increase significantly as well bores become longer. The typical 8 to 10-acre well pad may accommodate as many as a dozen wells. Most of that water remains in the underground strata; the rest returns as “produced” wastewater to the surface. Much of the produced water returns during the weeks shortly after the hydraulic pressure is released, but lesser flows continue throughout the life of each well.

The water necessary for fracking is obtained from surface sources or occasionally from wells in groundwater aquifers that are shallow relative to the target shale deposits. Near-surface aquifers are linked with surface waters, from which they can receive both replenishment and pollutants. The quantities of water required for fracking are large enough that they can deplete local streams and groundwater aquifers, especially during periods of drought. Such quantities of water require hundreds of large trucks for transport, and in some cases are moved by pipelines laid above or below ground. The wastewater produced at well pads contains high concentrations of harmful chemicals that are technically difficult and costly to separate from the water itself.

Explosives and frackwater pressure open existing cracks and create new fractures in the rock layers surrounding each well bore. Much of the fracking fluid binds to the rocks underground. Drillers store nearby in ponds or containers the produced water that returns to the surface after hydraulic pressure is released and reuse it to frack multiple wells; the remainder is transported long distances to deep injection wells where it is intended to be isolated permanently, far below potable groundwater aquifers. Relatively little produced water is treated for release to surface streams and rivers. Hence the use of water for fracking is deemed by DRBC to be a “consumptive” use. More than 90% of frackwater would be lost to natural recycling within the Basin. This contrasts sharply with most other industrial and municipal uses of water within the Basin, more than 90% of which volume returns to the Basin’s water cycle after human use and treatment to remove pollutants.

Chemicals typically are added to frackwater to reduce friction and prevent bacterial growth. About 1,000 kinds of substances have been added to the water as drillers seek to optimize their recovery of energy-producing hydrocarbons. The mixes of added chemicals, together with various salts plus organic and naturally occurring radioactive compounds extracted from the shale by the frackwater, render produced water toxic to people, animals, and plants in the event that it is released or spilled into the environment. Frackwater must be transported primarily by truck to and from well sites, where it is stored temporarily in open basins or closed containers. Containment capacity must be provided at each well pad yielding gas to store the continually produced wastewater after drilling stops. Fractured rock layers near well bores can intercept natural faults or abandoned wells through which the pressurized fluid can escape unintentionally. Escaped or leaking frackwater contaminates groundwater aquifers and the land surface as it flows by gravity into wetlands and streams. Unscrupulous operators may spread frackwater on roads as concentrated brine intended to reduce dust or to melt snow and ice. Several hundred tons of mineral salts are produced in the brine from an individual HVHF well.

The dramatic results of unintended leaks from unconventional gas wells have received wide publicity when invisible and odorless methane (natural gas) renders the tap water from home wells flammable. So have catastrophic explosions of high-pressure pipelines transporting natural gas and other hydrocarbons from wells to users. Other leaked or spilled contaminants can impart undesirable color or odor or taste or poisons to drinking water. Some of the contaminants present in frackwater do not break down readily into benign compounds; salts are not removed by normal publicly owned sewage treatment systems. Other pollutants can be transformed in the environment into low, difficult-to-detect, but still toxic concentrations of compounds linked to genetic mutations and cancers. Routine drinking water treatment can yield unhealthy concentrations of brominated hydrocarbons that originated in frackwater in public water supplies downstream from wastewater treatment plants. Hence produced frackwater can pose serious but hard-to-manage risks, either transient or permanent, to public health and to the environment. Yet information regarding the proprietary mix of chemicals injected at each well and produced by dissolution of in-ground substances is seldom collected or disclosed to the public, making human health symptoms difficult to diagnose and treat by health professionals.

Some of the produced frackwater pollutants that affect water quality already are found in the environment as a result of natural conditions and/or legacy human activities that formerly extracted oil and coal. The locations of many thousands of abandoned wells are unknown in Pennsylvania. Existing data on old wells are incomplete, and drillers may miss such features when planning new wells. Background concentrations of pollutants are not required to be documented in nearby wells and streams prior to HVHF well installation. Spills and leaks are not always reported, and required agency inspections may provide inadequate and infrequent oversight. As a January 2018 white paper from PADEP addressing proposed reforms of its permitting stated,

> DEP's oil and gas staff complement has been decreased from 226 employees to 190 employees. Well permit review staff have been reduced by 43% in the Southwest District Office, and by 15% in the Northwest District Office. These reductions have unquestionably impacted the timeliness of permit review, and the department's ability to oversee its responsibilities.
> (http://files.dep.state.pa.us/LicensingPermitsCertification/PermitDecisionGuaranteePortalFiles/Permitting_Reform_01262018.pdf)

PADEP has asked the Governor and General Assembly to increase permit application fees to help increase regulatory staff in its Oil and Gas Program.

Leakage from new well casings is common; over time the failure of cement casing can affect large numbers of frack well bores, allowing the uncontrolled escape of methane and other pollutants into aquifers and the surface environment (Ingraffea *et al*. 2014). In consequence, about 10,000 complaints of stream and well pollution in lands where gas and oil drilling and fracking are underway have been filed with State regulators in Pennsylvania over the past decade in response to encounters with the consequences of pollution from some 11,000 new oil and gas wells (all drilled outside the Basin). But documenting the sources responsible for specific episodes of water contamination often proves difficult. Meanwhile, opportunities for public participation in decisionmaking about fracking are limited, and shortages of information have generated widespread concern among residents of oil and gas fields where HVHF is utilized.

Drawing upon the growing scientific literature, DRBC staff summarized the dangers associated with shale gas production using fracking in their notice of proposed rulemaking (http://www.nj.gov/drbc/meetings/proposed/notice_hydraulic-fracturing.html). There is no need to repeat that well organized information here. Schmid & Company staff concur that the proposed permanent ban on fracking in the Basin is warranted for the reasons set forth by DRBC in that document in order to protect the waters of the Basin, human health, and the environment. Keeping unconventional oil and gas operations out of the Basin will eliminate a potentially major consumer and polluter of water. It also will bar from the Basin a poorly understood source of human health problems associated with unconventional well pads and the vehicular traffic and diesel generators associated with them as HVHF industrial uses spread into residential landscapes (Currie, Greenstone & Meckel 2017).

Based on drilling elsewhere in Pennsylvania, many shale gas HVHF wells may be sited in upstream headwaters distant from major rivers. Prohibition of fracking is an efficient means of protecting water quality directly in the 40% of Basin land underlain by Marcellus and Utica Shales. In most of those shale-gas lands (which overall are about 85% forested; http://www.nj.gov/drbc/library/documents/bush_CDRWforum102214.pdf), the streams have been designated Special Protection Waters by DRBC. Streams in the Schuylkill River subbasin and other waters discharging into the tidal Delaware River below Trenton have not been designated as Special Protection Waters by DRBC.

Six of the seven concerns listed above obviously are benefited by a permanent ban on fracking and require no discussion here. The seventh DRBC concern---economic development---also is virtually certain to be benefited. Fracking poses very real risks at present to human health and to the environment in the Basin in consequence of 1) primitive available technology for gas extraction and waste treatment, 2) the minimal inventory of potentially affected resources currently required by DRBC and other agencies for permitting, 3) the scarcity of qualified personnel reviewing permits and inspecting operations on the ground and low probability of increased regulatory budgets, 4) the uncertain and fluctuating economic demand for natural gas that has long characterized the boom-and-bust oil and gas industry that has produced focus on quick production and profit with slight concern for long-term consequences, and 5) the ever-growing certainty that most known reserves of fossil fuels worldwide must be kept permanently unburned and below ground to forestall massive climate disruption (McGlade & Ekins 2015). These concerns exist over and above the localized resource damages from fracking that threaten vital water resources, recreation, tourism, and other sustainable economic activities within the Basin. The sacrifice of long-term economic and environmental values within the Basin's tiny proportion of the shale gas resource land on behalf of short-term benefits from HVHF gas flowing primarily to large energy corporations would not be prudent. Were the shale gas ever needed by future generations of people, it could be extracted by them, potentially with far less damaging consequences as a result of technological advances unknown at present.

Hence this report concentrates on the export of fresh water associated with HVHF gas production from and import of produced frackwater into the Basin, which the DRBC proposes to regulate. Based on experience elsewhere in Pennsylvania during the past decade, the drilling industry would be expected to seek approval for water withdrawals from and discharges of treated wastewater to streams situated high in the watershed along headwaters relatively close to drilling pads. The use of wells drilled specifically for extraction of groundwater for shale fracking or for disposal of wastewater by injection has not been common in Pennsylvania. Injection wells for frackwater disposal elsewhere have led to earthquakes. We have concerns that DRBC authorization of import and export of waters used in unconventional oil and gas production may prove unwise as well as inconsistent, and we recommend that import and export of frackwaters---like fracking wells themselves---also should be banned permanently in the Basin. These activities pose many of the same likely impacts on water resources as drilling and fracking operations, with even less opportunity for economic benefits to Basin residents.

The Regulation of Fracking

The DRBC currently relies, and proposes in the future to rely, primarily upon State and federal regulators who implement the programs of other agencies to protect the public and the environment from the impacts of exporting freshwater to and importing produced wastewater from HVHF gas wells constructed outside the Basin. DRBC seeks to minimize regulatory duplication through coordination of its permit review and approvals with other agencies and via administrative agreements with the States. Historically, DRBC has focused chiefly on water quantity management and secondarily on water quality preservation. The information uniquely solicited by its current permit application forms primarily concerns water quantity.

At present DRBC has established no limit on the total volume of water that can be exported from or of wastewater that can be imported into the Basin. Instead, its permits (granted primarily to public utilities) to export an average of more than 100,000 gallons per day (based on a 30-day average) of fresh water from the Basin for any purposes other than oil and gas production ordinarily---after permit review---are deemed to have no substantial effect on the Basin's resources. Smaller withdrawals are not required to undergo DRBC review or obtain permits at all, unless specifically so notified. A lower minimum threshold for groundwater withdrawal review is set at 10,000 gallons per day in the Southeastern Pennsylvania Groundwater Protected Area consisting of parts of five counties, where shortages have been most problematic. DRBC seeks to impose restrictions on water withdrawal during periods of drought, and it assigns lower priority to industrial than to domestic water uses.

The withdrawal of any quantity of surface water or groundwater within the Basin for the purposes of HVHF, however, is proposed to require a full permit review. DRBC hopes somehow to "discourage" approval of such permits. The quantities of water extracted from the Basin at various locations for HVHF use are likely to be much more variable over time than the extraction of water by public utilities for potable water supplies. There are no currently approved DRBC permits for this purpose.

Because the capacity of the Basin's waters to accept treated wastewater also is considered limited, DRBC reviews permit applications to import more than 50,000 gallons per day (30-day average) of most wastewaters into (or to export such wastewaters out of) the Basin. The lower import permit threshold for typical wastewater discharges reaching Special Protection Waters is 10,000 gallons per day. The importation or treatment of produced frackwater in any quantity into the Basin, however, is proposed not to be allowed except after DRBC permit approval. Fracking wastes are considered to be different from other wastewaters currently discharged into the Basin. There are no currently approved DRBC permits for this purpose.

The proposed regulations would continue to allow the future export or import of water associated with HVHF if and when permits are requested by the industry. Future discharge of HVHF wastes anywhere within the Basin would be allowed only after treatment in a centralized waste treatment (CWT) facility. DRBC apparently would require a permit for all such transfers regardless of volume, as well as requiring approval of each CWT itself. Centralized waste treatment is an industrial category subject to specific US Environmental Protection Agency regulations for treatment technology. DRBC expects that the continuing imposition of its permit review would "discourage" proposals to transfer out-of-basin oil and gas wastewaters to CWTs discharging into Special Protection Waters, consistent with longstanding DRBC policy regarding direct discharges (Water Quality Regulations 3.10.3.A.2.c.[1]). Most CWTs for frackwaters would be expected to discharge directly into streams in accordance with a National Pollutant Discharge Elimination System permit, because USEPA has now banned the discharge of treated frackwaters into publicly owned treatment works. Each applicant would have to demonstrate an absence of out-of-basin alternatives (including the no-project alternative), as well as detail the impacts of each alternative on and benefits to the Basin. Applications for all frackwater import also would have to include a treatability analysis by a licensed engineer showing that the discharge by the intended CWT will meet all applicable standards plus achieve no exceedance of background concentrations in ordinary receiving waters and no measureable change (except toward natural conditions) in Special Protection Waters, as calculated by DRBC.

It is not clear why DRBC is proposing to allow, yet discourage, the export of fresh water to and import of frackwater generated by out-of-basin HVHF activities, while banning those activities within the Basin itself. The term "discourage" is not defined in the DRBC regulations, which are silent as to how the term might be applied. Perhaps DRBC deems the proposed fees at 18 CFR 401.43 constitute sufficient discouragement. No specific criteria that must be met to overcome discouragement are set forth in the DRBC proposal.

DRBC regulations already require submission of State approvals of proposed large freshwater withdrawal and wastewater discharge activities as part of its permit applications. Thus it is appropriate to examine the information required in DRBC applications. Traditionally DRBC has regulated water export from the Basin in large quantities on a relatively permanent basis by municipal users. The hydraulic fracturing of a well requires millions of gallons of water during a period of about one week, followed by flowback of hundreds of thousands of gallons of polluted water over a relatively short period. After that occurs a much reduced flowback of produced water throughout the life of the well. After a period of years the entire fracking process may be repeated to stimulate the ever dwindling flow of shale gas. The quantities of water used can be significant in small streams near the headwaters at the edges of the Basin and locally wherever groundwater resources are scarce. Over time a given withdrawal point on a stream or other body of surface water can be used to supply many wells on nearby pads, and a CWT capable of treating frackwater can generate variable flows of wastewater discharged into a stream. Thus the impacts from withdrawal of water and discharge of treated waste can vary depending on site conditions. Depending on the timing of gas well development, simultaneous fracking activities can occur in localized areas of abundant production ("sweet spots"). This could concentrate water import and export into relatively short, intense periods of time and into localized clusters of water resources.

There is little information concerning the potential impacts of such withdrawal and/or discharge in specific Basin watersheds, and permit applications at present do not require documentation of baseline conditions against which any resulting changes could be compared. Permit conditions imposed by DRBC do not require biological monitoring of impacts from approved facilities. DRBC apparently would have to close this regulatory gap, but has not explained how it plans to do so.

Withdrawal of Fresh Water for Fracking

DRBC has not explained how it intends to implement the requirements of its *Water Code* and *Water Quality Regulations* when authorizing stream water withdrawal for HVHF uses. In particular, it does not indicate how it will assure compliance with its adopted biocriteria. Those biocriteria appear not to be addressed by other agencies. DRBC has offered no detailed regulations or technical guidance specifying how such assessments will be made and reported in order to fill the current regulatory gap.[2]

Fresh water for transport to HVHF activities outside the Basin could be purchased from municipal suppliers using surface or groundwater sources, if they have excess approved capacity, apparently without specific DRBC approval. It is not clear whether DRBC notification would be required for such HVHF-related purchases, and the ultimately

[2] Other segments of the fossil fuel industry already are required to inventory baseline conditions and monitor impacts on macroinvertebrates and other existing conditions in streams at risk of biological degradation by loss of flow or discharge of pollutants. PADEP, for example, has adopted requirements for inventory and assessment of macroinvertebrates as part of its comprehensive stream monitoring in permit applications for coal mining activities [*see* 25 *Pennsylvania Code* §89.35; PADEP Bituminous Underground Mining Permit Application Module 8, Form 5600-PM-BMP0324, last revised July 2013; and PADEP Technical Guidance Document 563-2000-655].

adopted language should make this clear to all parties. Fresh water also could be withdrawn from specifically drilled wells following DRBC permit approval. To date water for fracking in Pennsylvania has been obtained primarily from surface sources rather than from groundwater.

Import of Produced Wastewater

USEPA prohibits the unregulated discharge of pollutants to surface waters of the United States from the onshore oil and gas industry. The discharge of wastewaters that contain pollutants is authorized by permits issued in accordance with the misleadingly named National Pollutant Discharge *Elimination* System administered primarily by the States. DRBC coordinates its discharge approvals with NPDES requirements and permits. Now DRBC proposes to authorize, yet also somehow to "discourage," future discharges of treated HVHF wastewater generated by oil and gas activities operating outside the Basin into waters within the Basin by requiring them to use approved CWTs.

DRBC and other agencies have established maximum concentrations of several specific pollutants allowable in wastewaters discharged from CWTs and into Special Protection Waters and other surface waters. DRBC regulations state that the most stringent applicable effluent limitations apply. Despite many years of study, USEPA has not established federal standards for treatment of fracking wastewater at CWTs. USEPA has prohibited the processing of frackwater at publicly owned wastewater treatment works (POTWs). Apparently DRBC has no plans to do so. Not all specific chemicals or combinations of chemicals that appear in frackwater have been assigned effluent limitations by any agency.

DRBC proposed regulations do not require baseline biological inventory or stream monitoring in receiving waters during wastewater discharge operations, as appears especially warranted at minimum in the Basin's Special Protection watersheds if future discharges of treated water were to be permitted for frackwater wastes generated outside the Basin. Such baseline inventory and biological monitoring by permittees is warranted to insure that the DRBC biocriteria for Special Protection Waters are being maintained.   Such data should be collected and reported by applicants, used to assess habitat features and potential impacts of changing the flow regime on the species and habitats present, submitted electronically, and made available for timely review by the affected public during the review period for permit applications. The monitoring data also should be reviewed and publicly reported annually by DRBC staff to substantiate industry compliance with DRBC requirements for water resource protection. As noted above, biological monitoring already is required for potentially polluting discharges in other segments of the fossil fuel industry.

It is not clear whether each driller proposing to dispose any truckload of frackwater, wherever generated, anywhere within the Basin must apply to DRBC for a permit, although each CWT seeking to accept and treat frackwater apparently would have to do so. If every individual truckload of HVHF waste entering the Basin is going to require a separate permit from DRBC, a great deal of paperwork may be generated, and DRBC must specify precisely what information will be needed in such applications.

Landfill Leachate

Given the DRBC's focus on water resource protection, it is not unreasonable that it clarify its regulations at proposed 18 *CFR* 401.35(b)(14) to focus its concerns with landfill leachate, as opposed to other aspects of landfill regulation. Compact States have their own regulations governing the siting and operation of landfills.

Wetland Regulation

Wetlands are among the most threatened ecosystems on our planet. They are degraded and converted to human uses more rapidly than any other ecosystem, and the status of freshwater species is deteriorating faster than for other species. Since wetlands are essentially characterized by hydrologic conditions, changes in water volumes and timing of flows are major threats, as are discharges of various pollutants (Verones *et al*. 2013, Zedler 2005). Withdrawals of surface waters or groundwaters, and discharges of wastewaters have the potential for negatively impacting wetlands throughout the Basin. Given its focus on water quantity and quality, DRBC probably could oversee proposed changes in hydrology to wetlands within the Basin, especially including wetland drainage, more effectively than other agencies that focus on the placement of structures and fill material into wetlands and other regulated surface waters.

DRBC typically restricts its review of projects affecting wetlands to those projects affecting more than 25 acres of wetlands. It deems projects affecting less than 25 acres of wetlands normally as not having a substantial effect on the water resources of the Basin [18 *CFR* 401.35(a)(15)]. It is not clear that a 25-acre minimum threshold for wetland review is appropriate, especially if DRBC considers it essential to review water withdrawals and discharges of any size within the Basin when those activities are related to oil and gas development. Other agencies may not be able to review the impacts of proposed water withdrawals from and discharges into wetlands as thoroughly as DRBC staff.

The proposed change at 18 *CFR* 401.35(a)(15) would make clear that DRBC will review proposed impacts on wetlands involving less than 25 acres, but only when no State or federal agency already has done so. This could be an opportunity to partially fill a regulatory gap, but it is not clear how such a provision would be implemented. There are no detailed maps of regulated wetlands in the Basin. Existing National Wetland Inventory maps show the general location of wetlands recognizable from aerial photographs, but omit many forested wetlands, which are characteristic in the Special Protection watersheds of the Basin, and which offer special habitat values over and above other kinds of wetlands in this biome (Schmid & Co., Inc. 2014). DRBC has no capability of identifying small wetlands subject to impact that are not known already to other agencies. Similarly, published maps available from the United States Geological Survey and from the online National Hydrography database omit many headwater streams. Apparently DRBC expects to rely upon the affected public to identify small wetlands and streams at risk from its water-related permits that applicants and other agencies have overlooked. How it might condition its permits to protect such resources is not clear.

DRBC should issue detailed regulations and/or technical guidance for implementing its intended wetland review requirement. DRBC should require that applicants prepare detailed onsite field surveys and standard written documentation of the nature and extent of wetlands and other surface water conditions on any property to be disturbed by any proposed construction within the Basin associated with the regulated withdrawal of water or disposal of wastewater, and review all such information that has been compiled already for, and approved by, another State or federal agency.

Authorship

This report was prepared by James A. Schmid with the assistance of Stephen P. Kunz. Dr. Schmid is a biogeographer and plant ecologist with 45 years of applied environmental consulting experience in the mid Atlantic States. Mr. Kunz is a Senior Ecologist at Schmid & Company with 40 years experience in environmental consulting. Both Dr. Schmid and Mr. Kunz are certified as Senior Ecologists by the Ecological Society of America, as Professional Wetland Scientists by the Society of Wetland Scientists, and as Wetland Delineators by the Army Corps of Engineers.

References Consulted

Adams, M. B. 2011. Land application of hydrofracturing fluids damages a deciduous forest stand in West Virginia. *Journal of Environmental Quality* 40(4):1340–1344.

Brantley, S. L., D.A. Yoxtheimer,, S. Arjmand,, P. Grieve, R. Vidic, J. Pollak, G.T. Llewellyn, J. Abad, and C. Simon. 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. *International Journal of Coal Geology* 126:140–156.

Currie, Janet, M. Greenstone, and K. Meckel. 2017. Hydraulic fracturing and infant health: New evidence from Pennsylvania. *Science Advances* 3(12).

Entrekin, S., M. Evans-White, B. Johnson, and E. Hagenbuch. 2011. Rapid expansion of natural gas development poses a threat to surface waters. *Frontiers in Ecology and the Environment* 9(9):503–511.

He, Can, T. Zhang, X. Zheng, Y. Li, and R.D. Vidic. 2014. Management of Marcellus shale produced water in Pennsylvania: a review of current strategies and perspectives. Energy Technology 2(12):968-976.

Hladik, M.L., M.J. Focazio, and M. Engle. 2014. Discharges of produced waters from oil and gas extraction via wastewater treatment plants are sources of disinfection by-products to receiving streams. *Science of the Total Environment* 466–467:1085–1093.

Ingraffea, Anthony R., M.T. Wells, R.L. Santoro, and S.B.C. Shonkoff. 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. *Proceedings of the National Academy of Sciences* 111(30):10955-10960.

Jackson, R. B., A. Vengosh, J.W. Carey, R.J. Davies, T.H. Darrah, F. O'Sullivan, and G. Pétron. 2014. The environmental costs and benefits of fracking. *Annual Review of Environment and Resources* 39:237– 362.

Llewellyn, G.T. 2014. Evidence and mechanisms for Appalachian Basin brine migration into shallow aquifers in NE Pennsylvania, USA. *Hydrogeology Journal 22*(5):1055–1066.

McGlade, Christophe, and P. Ekins. 2015. The geographical distribution of fossil fuels unused when limiting global warming to 2° C. *Nature* 517:187-190.

Maloney, Kelly O., J.A. Young, S.P. Faulkner, A. Hailegiorgis, E.T. Slonecker, and L.E. Milheim. 2018. A detailed risk assessment of shale gas development on headwater streams in the Pennsylvania portion of the Upper Susquehanna River Basin, U.S.A. *Science of the Total Environment* 610-611:154-166.

Maloney, Kelly O., S. Baruch-Mordo, L.A. Patterson, J-P. Nicot, S.A. Entrekin, J.E. Fargione, J.M. Kiesecker, K.E. Konschnik, J.N. Ryan, A.M. Trainor, J.E. Saiers, and H.J. Wiseman. 2017. Unconventional oil and gas spills: Materials, volumes, and risks to surface waters in four states of the U.S. *Science of the Total Environment* 581-582:369-377.

Maloney, Kelly O., and D.A. Yoxtheimer. 2012. Production and disposal of waste materials from gas and oil extraction from the Marcellus shale play in Pennsylvania. *Environmental Practice* 14(4):278-287.

Patnode, Kathleen A., E. Hittle, R.M. Anderson, L. Zimmerman, and J.W. Fulton. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. *Journal of Fish and Wildlife Management* 6(1):55-70.

Patterson, Lauren A., K.E. Konschnick, H. Wiseman, J. Fargione, K.O. Maloney, J. Kiesecker, J-P. Nicot, S. Baruch-Mordo, S. Entrekin, A. Trainor, and J.E. Saiers. 2017. Unconventional oil and gas spills: Risks, mitigation priorities, and state reporting requirements. *Environmental Science and Technology* 5(15):2563-2573.

Rahm, B. G., J.T. Bates, L.R. Bertoia, A.E. Galford, D.A.Yoxtheimer, and S.J. Riha. 2013. Wastewater management and Marcellus Shale gas development: Trends, drivers, and planning implications. *Journal of Environmental Management* 120:105–113.

Rhodes, A.L., and N.J. Horton. 2015. Establishing baseline water quality for household wells within the Marcellus Shale gas region, Susquehanna County, Pennsylvania, USA. *Applied Geochemistry* 60:14–28.

Schmid & Company, Inc. 2014. The effects of converting forest or scrub wetlands into herbaceous wetlands in Pennsylvania. Prepared for the Delaware Riverkeeper Network. Media PA. 48 p.

Skalak, K. J., M.A. Engle, E.L. Rowan, G.D. Jolly, K.M. Conko, A.J. Benthem, *et al*. 2014. Surface disposal of produced waters in western and southwestern Pennsylvania: Potential for accumulation of alkali-earth elements in sediments. *International Journal of Coal Geology* 126:162–170.

Verones, Francesca, D. Saner, S. Pfister, D. Baisero, C. Rondinini, and S. Hellweg. 2013. Effects of consumptive water use on biodiversity in wetlands of international importance. *Environmental Science & Technology*47:12248−12257.

Vidic, R.D., S. L. Brantley, J.M. Vandenbossche, D. Yoxtheimer, and J.D. Abad. 2013. Impact of shale gas development on regional water quality. *Science* 340(6134).

Zedler, J. B., and S. Kercher. 2005. Wetland resources: Status, trends, ecosystem services, and restorability. *Annual Review of Environmental Resources* 30:39−74.

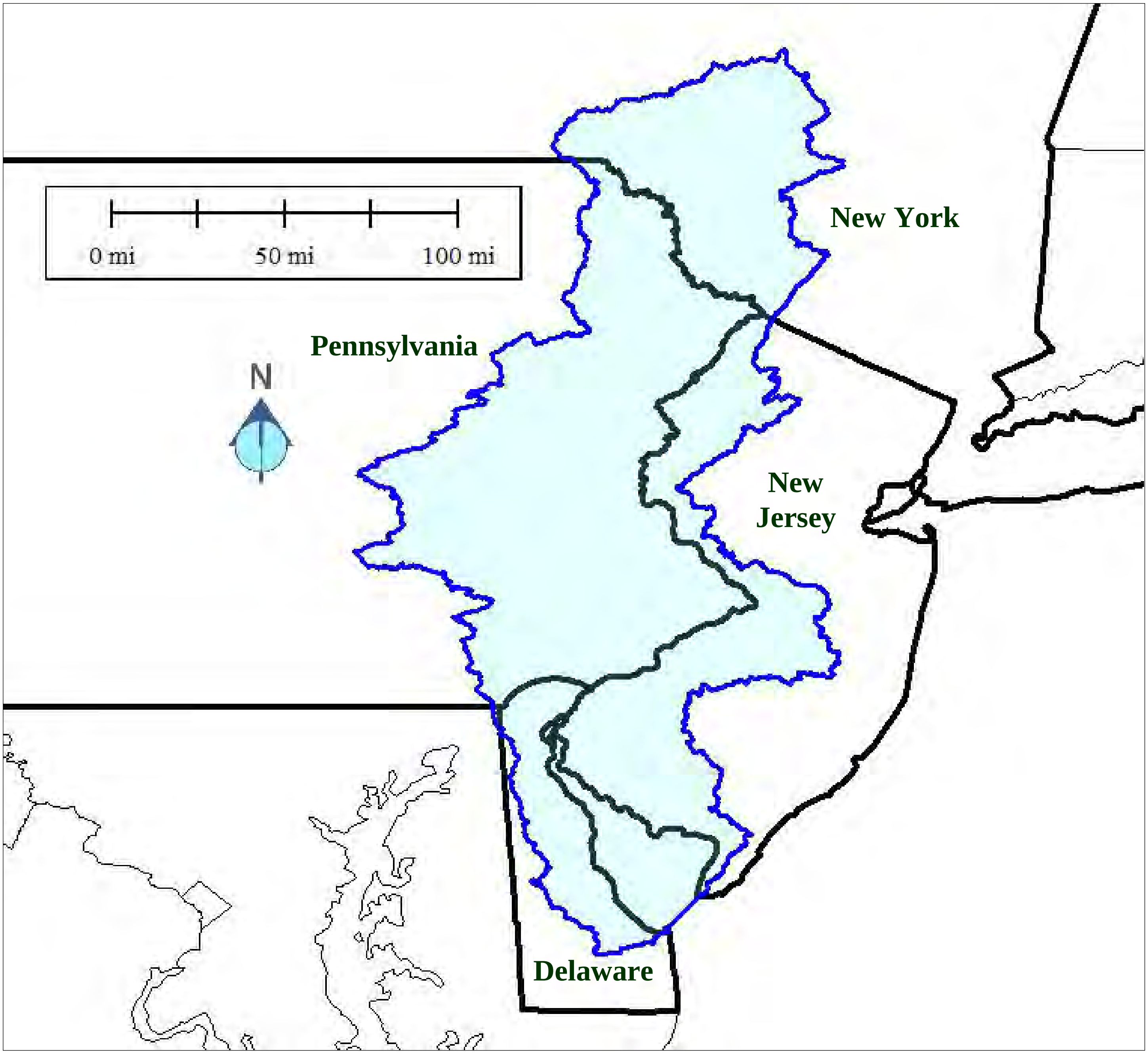


FIGURE 1. Location of the Delaware River Basin (blue) in Pennsylvania, New York, New Jersey, and Delaware.

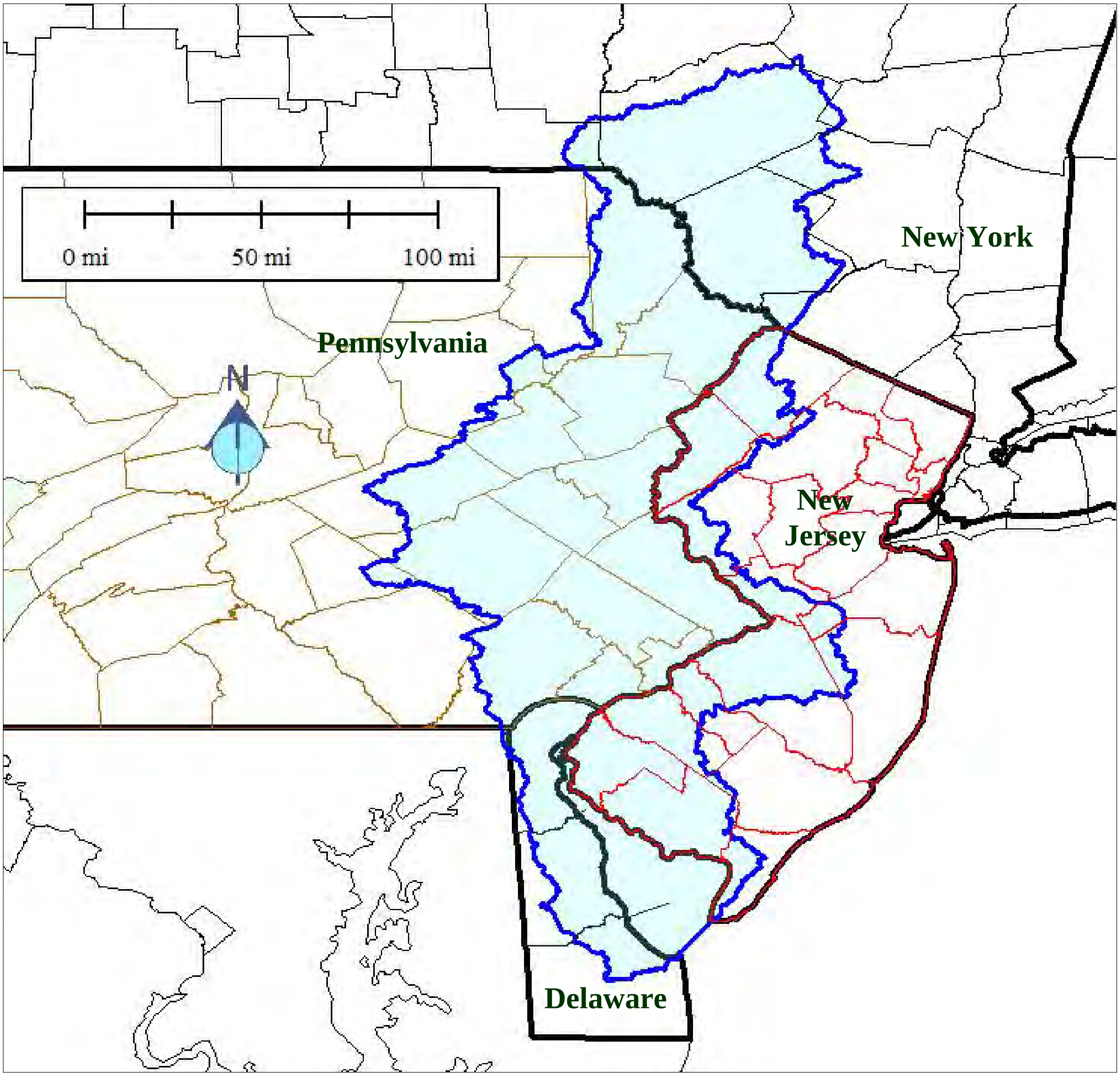


FIGURE 2. Location of the Delaware River Basin (blue) in Pennsylvania, New York, New Jersey, and Delaware, with counties outlined.

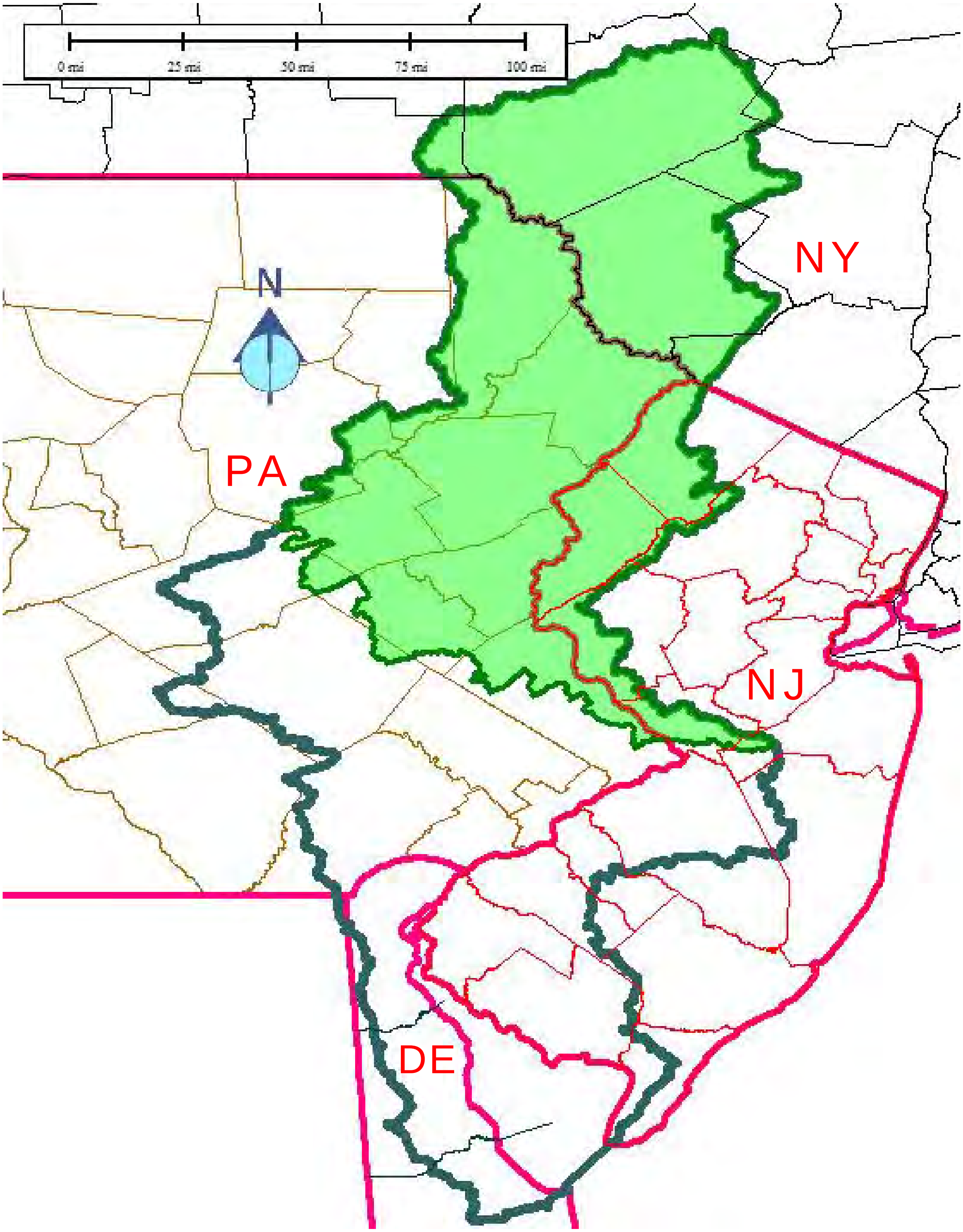


FIGURE 3. Identification of the Special Protection Waters area (green) within the jurisdiction of the DRBC (heavy outline) and member states (red). Counties also are shown. Approximately 50% of the DRBC Special Protection Waters are in PA, 35% are in NY, and 15% are in NJ.

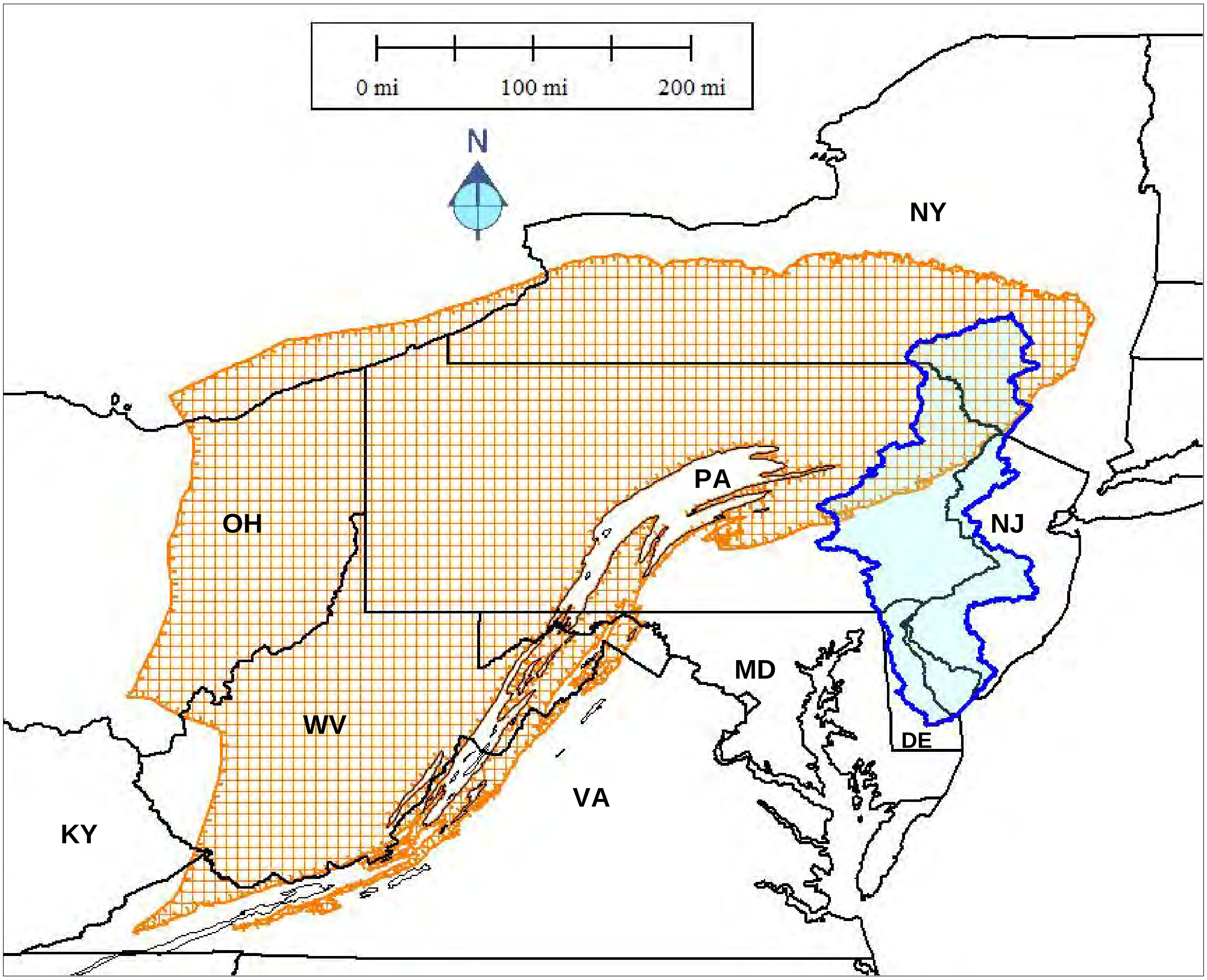


FIGURE 4. Location of area within the northeastern United States underlain by Marcellus Shale reserves (orange crosshatch). Delaware River Basin is in blue. Only 5% of the Marcellus Shale is within the Delaware River Basin, and it is found only within Pennsylvania and New York.

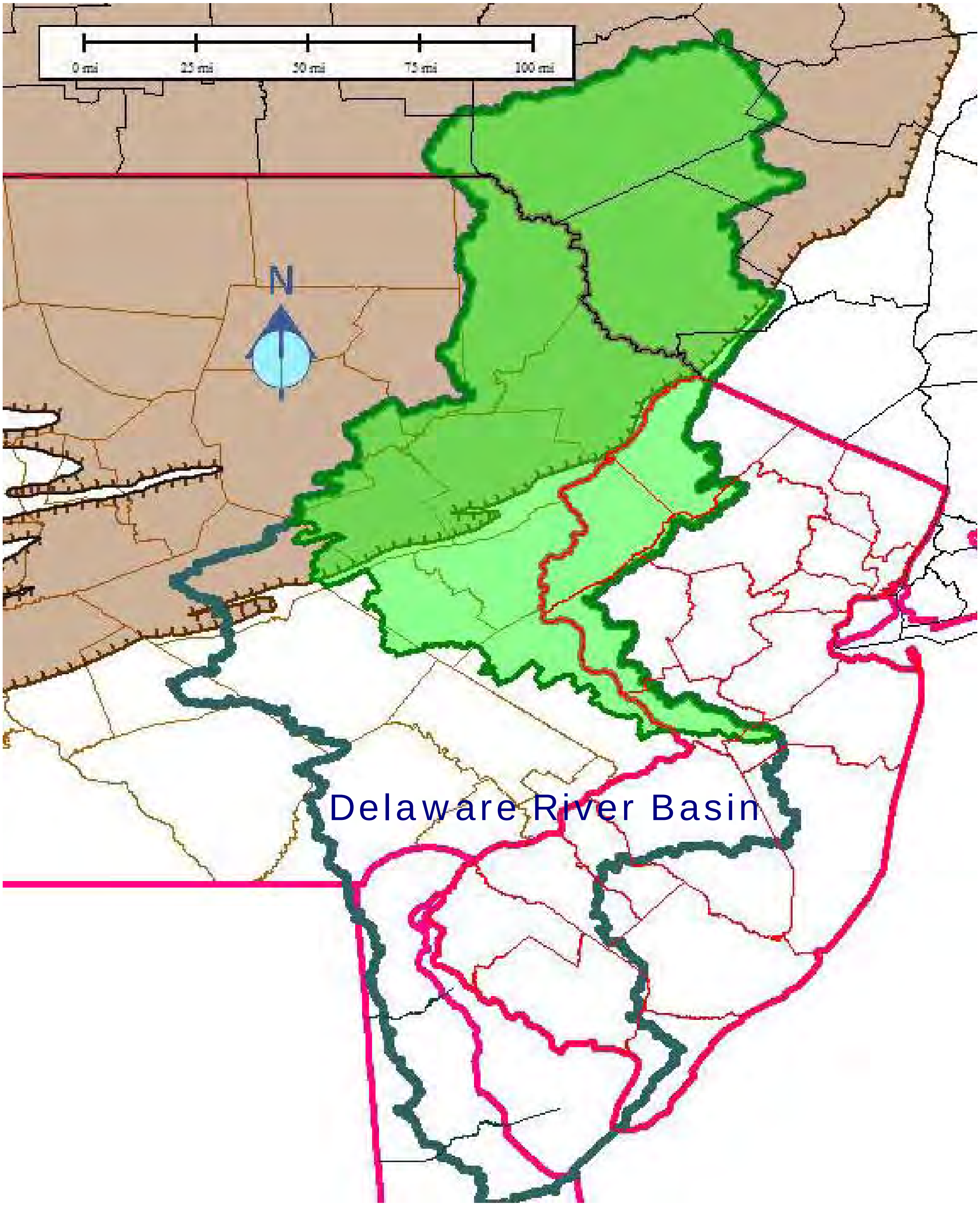


FIGURE 5. Location of Marcellus Shale reserves (brown) in relation to the Special Protection Waters section (green) of the Delaware River Basin (heavy outline). State boundaries are in red. Counties also are shown.

Rushing Rivers Inc.

Ecological review of the DRBC Draft 18 CFR Parts 401 and 440

Proposed Amendments to the Administrative Manual and Special Regulations

Regarding Natural Gas Development Activities.

February 2018

Report

prepared for

Delaware Riverkeeper Network

Prepared by

Piotr Parasiewicz, PhD, A.Prof.

616 Corporate Way, Suite 2-3932 | Valley Cottage, NY 10989 | www.rushingrivers.com| piotr@rushingrivers.com | 617 500 4884

EXECUTIVE SUMMARY

This testimony addresses the question whether the proposed Amendments to the Administrative Manual and Special Regulations Regarding Natural Gas are adequate to protect the ecological resources of the Delaware River Basin. The proposed 18 CFR Part 440 - Hydraulic Fracturing in Shale and Other Formations, with its additions and revisions, rule making notice were reviewed, as well as the efforts to establish an Ecological Flow Regime for the Upper Delaware River. The regulations are analyzed through the prism of the ecological data gathered by the scientists working on the Delaware River and is supported by a review of publications and scientific reports related to the Delaware River.

A thorough review of existing information made it clear that complete prohibition of shale gas extraction is an appropriate decision for protection of public health and resources in the Delaware River Basin. This prohibition, however should also include water exportation from and wastewater imports to the Watershed. Offering permitting options will encourage development of extraction wells in near proximity of the Delaware Watershed imposing the public and wildlife to associated risks. Particularly the substantial uncertainty with long term effects of the pollutants in produced water and our ability of stopping them from entering into the waters of the area calls for very strict regulation without permitting options.

I concluded that the regulations, which even contemplate permitting options for water exportation and waste water imports are contrary to current efforts of the DRBC to protect and maintain healthy aquatic populations, which is declared as the goal in the Water Resources Plan. I recommend that the prohibition of Natural Gas Development within the Delaware River Basin will be full and includes water exportation and wastewater importation for these purposes.

I. STATEMENT OF QUALIFICATIONS

1. **Education.** I received a Ph.D., M.S. and G.E. in natural resources management and water engineering with a focus on fisheries ecology from the University of Agricultural Sciences in Austria. I am also professor in Inland Fisheries awarded from the S. Sakowicz Inland Fisheries Institute in Poland. My Curriculum Vitae is provided as **Exhibit 1**.

2. **Experience.**

    a. I am an associate professor at S. Sakowicz Inland Fisheries Institute in Poland, August-Wilhelm Scheer Visiting Professor 2018 at the Technical University of Munich in Germany, Honorary Fellow of TUM Institute for Advanced Study and adjunct professor at the University of Nebraska Lincoln.

    b. I am the founder and director of Rushing Rivers Institute, a non-profit organization promoting river science in river management.

    c. I have been a Research Associate at the Department of Natural Resources of Cornell University, a Research Associate Professor at the Department of Natural Resources Conservation at the University of Massachusetts and held the position of Research Associate Adjunct Professor and Director of the Northeast Instream Habitat Program at Mt. Holyoke College in South Hadley, Massachusetts.

    d. I am also a founding member of the International Aquatic Modeling Group, and a member of the American Fisheries Society, the River Management Society, the International Society for River Science, the International Association for Hydraulic Research.

    e. I developed the MesoHABSIM model and the associate SimStream software, a computer simulation system for fish and mussel habitat restoration planning that has been applied around the US and abroad and is currently used for the development of Protected Instream Flow Standards in the State of New Hampshire, Poland and Italy.

f. My primary research area is in the assessment and simulation of physical habitats for fish and invertebrate communities as a basis for ecosystem restoration. My recent projects focus on river habitat simulation, instream flows and comprehensive river restoration planning.

g. I have 32 years of extensive experience in the planning and implementation of river restoration projects, the design of nature-like bypass channels to support fish passage and the restoration of migratory species, as well as the assessment of ecological integrity.

h. I have assisted in the drafting of laws and policies to protect instream flow in the states of MA, NH, CT and Poland. These projects are designed to determine water allocation methods with the goal of balancing human needs with ecological needs.

i. I am very familiar with the Upper Delaware River, the adjacent area and issues involved in flow management. I was a project leader on the study of Dwarf Wedgemussel Habitat in the Upper Delaware River and a member of the Subcommittee for Ecological Flows for Delaware River Basin Commission. The results of the study are published in three high impact research journals.

II OPINIONS

1. My report is organized as follows. In the Background section, I describe the circumstances of the rule and my professional perspective on the overall impact and proposed permitting conditions. In following sections, I address the technical issues and concerns associated with the proposed rule. The conclusions and recommendation sections provide a brief synopsis and the conclusions of my review.

Background

2. The dramatic impact of human-induced alterations on freshwater flora and fauna is widely reported (Gleick et al., 2001; UNEP, 1999). Running water ecosystems belong to the most severely human-impacted habitats on Earth (Nilsson et al., 2005; Malmqvist and Rundle, 2002). Of more than 3,500 species currently threatened with extinction worldwide, one-quarter are fish and amphibians.
3. In freshwaters, the projected decline in species diversity is about five times greater than in terrestrial ecosystems (Pimm et al., 1995). This rate is similar to that of great prehistoric extinctions (Malmqvist and Rundle, 2002).
4. It has been suggested that some 30-35% of all freshwater fish species are already extinct or in serious decline worldwide (Stiassny, 1999). Ninety-three percent of these reductions occurred during the last 50 years, indicating extinction of freshwater fishes is a serious and accelerating global trend (Harrison and Stiassny, 1999).
5. The freshwater mussel is one of the most imperiled animal groups in North America with only 25% of the existing species having stable populations (Williams et al., 1995). Freshwater mussels fulfill many crucial ecosystem services such as the filtering of large

amounts of water, which removes pollutants from the water. Hence, healthy assemblages of mussels are necessary to maintain high water quality standards.

6. Historical and ongoing urbanization of our landscape intensifies floods and droughts, causing damage to human property and stressing the fauna. Excessive water withdrawals due to human and industrial demands dry up rivers with increasing frequency.
7. The process of urbanization alters seasonal hydrographs by increasing peak flows and decreasing base flows (e.g., Bedient and Huber, 1988; Dunne & Black, 1970; Parasiewicz and Goettel, 2003; Petersen, 2001). In the Northeastern United States, this hydrological pattern appears to be a regional phenomenon and a lasting legacy of historic deforestation. Even in areas such as the Catskill Mountains that superficially appear to have recovered from the historical impacts of earlier timber harvests, similar effects can still be observed (Parasiewicz et al., 2010).
8. The change in our global climate further contributes to this impact by causing higher summer air temperatures, a longer summer season, and lower minimum river flows together with more frequent and severe flooding (Faloon and Betts, 2006).
9. The water in these reduced flows tends to warm up more quickly in rivers that have been widened by previous floods and historical logging operations. Shallow ponds, created by thousands of small dams, serve as natural solar collectors. Additionally, less cold water is entering the rivers from base flow because of increased ground water withdrawals. We are frequently now measuring summer water temperatures in excess of 80°F in long stretches of "coldwater" streams (e.g. Ballestero et al., 2007, Parasiewicz et al., 2007).
10. Consequently, scientists anticipate a loss of coldwater fauna from rivers and streams of the Northeastern United States and recommend that proactive management preventing

extended droughts and low flow levels by avoiding excessive water withdrawals must be a management priority.

11. Silk et al. (2000) eloquently suggests that "The natural ecosystem of any river is the product of millions of years of adaptation and evolution, which have created a myriad of variables and subtleties more complex than we can imagine." Due to this complexity and continuing conflicts of interest among competing water uses, a very precise planning and evaluation of potential development impacts is required.
12. Water allocation issues are not new, and many techniques have been developed in recent decades to address these problems (Stalnaker, 1995; Dunbar et al., 1998). Only recently we learned to recognize that not only is the quality and quantity of water released below a hydro-power or irrigation dam important, but also that modifications of hydrological patterns can have detrimental effects on aquatic life (Richter et al 1997).

Delaware River Watershed

13. The Catskill Mountains' and Poconos watersheds are generally rural, topographically steep areas with shallow, permeable soils overlaying restrictive bedrock or fragipans. Heightened flow peaks cause severe erosion, leading to the down-cutting and over-widening of river corridors (Parasiewicz et al., 2010). The notable lack of woody debris structure documented in the Stony Clove Creek study in the Catskill Mountains (Parasiewicz et al., 2003) was partially a consequence of increased flow peaks removing log jams before they can stabilize, but also due to frequent "cleanups" of woody debris as a flood protection and beautification measure.
14. These changes, in combination with reduced stream flows and groundwater levels, increase summer water temperatures and can cause creation of anchor ice in the winter.

Anchor ice is an ice forming at the bottom of the river that can create considerable damage to the aquatic fauna by forcing fish movements and increasing their mortality. In addition, many river corridors, especially those in urbanized areas, have been physically modified (e.g., straightened, widened, dredged or impounded), altering the character of the corridor (e.g. from braided to straightened) and leading to further modifications in the hydrological regime (Hewlett and Hibbert, 1967).

15. The most apparent consequences of such changes in hydrological patterns are a reduction in fish densities and modification of the fish community structure from specialized riverine species towards more generalized species. This phenomenon has been documented in several recent studies in the Northeast Region (eg. Parasiewicz and Goettel, 2003; Armstrong et al., 2001).
16. The Delaware River is considered an exceptionally healthy river mostly because of the length of its free flowing section. Among outstanding characteristics, there is a considerable number of freshwater mussel species, including the federally endangered dwarf wedgemussel (*Alasmidonta heterodon*), as well as a large number of migratory fish species, notably American eel and American shad.
17. Proximity to northeastern metropolitan areas as well as low population density makes the Upper Delaware River also a very valuable recreational resource for boaters, hunters and others searching for outdoor adventure and tranquility. The region is famous for its fly-fishing, creating a valuable recreational industry. The watershed is home to the National Park Service Wild and Scenic River program and multiple natural conservation areas.
18. However, the legacy of deforestation and an industrial past is still visible in its over-widened, shallow river channels and flashy hydrology with rapidly changing flows from

very low to very high. The watershed is also under pressure for hydropower use and as a drinking water supply for New York City (Parasiewicz et al., 2010).

19. As mentioned in the Rulemaking notice Delaware River Basin provides water for over 15 milion people and much of it is drinking water.

20. The flows in the river are strongly influenced by releases from upstream reservoirs: Cannonsville on the West Branch, Pepacton on the East Branch, Wallenpaupack on the Lackawaxen River, Mongaup on the Mongaup River and Neversink on the Neversink River. A Supreme Court decree was needed to manage the downstream salt wedge in Philadelphia by mandating the minimum flow releases. Due to complex management objectives, the current flows in the river can be erratic and unpredictable.

21. Consequently, the habitat conditions are quite unstable and high water temperatures have caused fish die offs and potentially reduced mussel populations in the past. As documented by an investigation of dwarf wedgemussel habitat, the existing populations are limited to a few locations that maintain hydraulic stability. The sedentary organisms like freshwater mussels are particularly vulnerable to the habitat reduction due to the lack of water than can be caused by water withdrawals or rapid fluctuations.

Watershed Management

22. The Delaware River Basin Commission recognizes the unique value of the watershed and its vision statement commits to be “the leader in protecting, enhancing, and developing the water resources of the Delaware River for present and future generations.” It includes “Protection and enhancement of ecological integrity” as a guiding principle of the Water Resources Plan. The DRBC adopted Special Protection Waters regulations to further protect a large portion of the watershed.

23. The same Rulemaking notice document cites the Delaware River Basin Laws stating the limitation of water availability in the Basin.

24. In consequence of a multiyear collaborative efforts the next Flexible Flow Management Plan including measures to protect federally endangered species such as the dwarf wedgemussel has been recently extended for another 5 years. It is a complex effort and intensive endeavor aiming towards managing numerous users and protecting the river ecology. During this time the DRBC and involved parties committed to continue investigations of the consequences of plan introduction searching for adaptive management options.

Impact of high volume hydraulic fracturing (HVHF)

25. The Rulemaking notice also very appropriately describes the impacts of HVHF, which are substantial and could threaten the public health and aquatic life of the watershed if permitted. With regard to the influence on the freshwater fauna there are three major issues:

    a. **Contamination**: Fracturing fluid pumped into the well entails water, chemicals, and proppants, which in the process also washes out contaminants from the target rock formations. Therefore, so called produced water consists of numerous pollutants such as

        i. salts, including chloride, bromide, sulfate, sodium, magnesium, and calcium;

        ii. Metals, including barium, manganese, iron, and strontium;

iii. Naturally-occurring organic compounds, including benzene, toluene, ethylbenzene, xylenes (BTEX), and oil and grease;

iv. Radioactive materials, including radium; and

v. Hydraulic fracturing chemicals and their chemical transformation products.

Many of these substances are highly toxic and their treatment is costly.

b. **Flow reduction:** HVHF requires high volumes of water (between 4 to 11 million gallons per fracturing event on one well only). Such withdrawals could easily destabilize the carefully crafted web of Flexible Flow Management Plan and other protective regulations.

c. **Higher runoff by increasing floods and droughts due to development of well pads.** With construction of thousands of wells we can expect massive construction of well pads, road building, impoundments, and forest clearing that will cause increased frequency and intensity of flooding as well as the frequency and duration of droughts. This would sharply exacerbate the impacts of global climate change, which has very similar consequences. In effect, we can expect less and warmer water in summer, degradation of water quality and therefore shifts in fish and invertebrate community structure towards fewer, but more generalist (pond) species.

Proposed DRBC amendments to Natural Gas Development Regulations

26. In face of the above mentioned issues the proposed amendments to the Administrative Manual and Special Regulations Regarding Natural Gas Development Activities rightly

prohibits the HVHF activities in the Delaware Basin for reasons of pollution control, protection of public health and preservation.

27. However, the Commission is willing to consider permitting *water exports* for utilization in hydraulic fracturing. Although the Commission requires also alternative analysis, in face of the ample evidence of water scarcity in the Delaware River Watershed this consideration seems to be inconsistent with declared policy of discouraging the exports.

28. Since HVHF requires substantial volumes of water there are two likely scenarios for which such exportation permit may be pursued by industry:

    a. Large volumes to run wells in close proximity of the Delaware River Basin watershed boundary. This scenario leads to asking DRBC to violate its own policy of discouraging the exportation and is threatening water availability in the basin. All above mentioned consequences affecting human and aquatic faunas health apply.

    b. Small volumes to supplement fracturing water taken elsewhere from river or aquifers in close proximity to watershed boundary. Similarly like in scenario a) such permit encourages construction of well pads in close proximity of the Delaware Watershed. With the ability of horizontal drilling with laterals up to 10000 ft, this may cause unintended impacts within the Delaware Watershed such as water contamination or even triggering small earthquakes.

29. In the proposed amendment the Commission is also willing to consider the approval of *importation of produced water* into the Delaware Watershed under condition of appropriate treatments.

30. Despite the requirement of alternatives analysis this proposition is also in contrast with

the declaration of protection of public health and aquatic life, because:

a. Many of the toxic substances occurring in the produced water of Marcellus Shale require special treatment with expensive technologies.
b. Safe concentration of some of these substances (total dissolved solids, barium, bromide, radium and strontium) are not yet regulated and treatability studies are still required even to characterize the pollutant loads in the produced water.
c. The long term bioaccumulation effects of these substances on biota is not well known. Water filtering organisms such as freshwater mussels may be particularly vulnerable to such toxic substances.
d. Similarly background concentrations that are required to be maintained according to the rule are yet to be determined.
e. Due to the fact that the produced water dissolves substances from target rock formation, it is conceivable that their concentration as well as their chemical composition may vary uncontrollably potentially exceeding the capacity of the treatment plant. Attempting to mitigate that would require toxic storage reservoirs with all associated and unacceptable risks of accidental breaching or leaching.
f. Transportation and handling of such substances is prone to accidental leaks, which are very difficult to control and account for.
g. It encourages the development of HVHF operations in the proximity of the Delaware Watershed with all the consequences described above.

Conclusions and Recommendations

31. The Upper Delaware River Watershed is a precious resource with a multitude of outstanding characteristics and users. The maintenance of the watershed's ecological

integrity requires careful and wise management. Such management is under development and measures that prevent degradation of aquatic fauna under climate change scenarios are not in place yet.

32. At this point adding more complexity and additional risks before such a program is in place is counterproductive, as obviously more time and resources are necessary to complete ongoing scientific efforts and take control over current issues in a way that will allow the protection and enhancement of ecological integrity.

33. Before contemplating any option associated with potential water withdrawals of any kind it would be necessary to conduct a comprehensive assessment of habitats and species in tributaries and main stem and to develop watershed models to forecast potential cumulative impacts. Such models need to inform the decision not only with regard to the possibility of water withdrawals, but also about necessary mitigation and compensation measures such as by-pass flows or channel improvements. Such documentation and models do not exist yet.

34. Therefore, I recommend that Natural Gas Development should be fully banned without encouraging HVHF activities, especially in the proximity of the Delaware River Watershed. This includes complete prohibition on water exports and wastewater imports for the purpose of natural gas mining as an unnecessary risk to the wellbeing and health of millions of citizens and the Delaware River Watershed’s water resources and natural ecosystems, including the species that live there.

II. REFERENCES

45. In preparing this report, I completed the following tasks:

a. I reviewed the following documents:

i. DRBC 18 CFR Part 440 - Hydraulic Fracturing in Shale and Other Formations

ii. DRBC Water Resources Plan

iii. Water Resources Program 2010-2015

iv. Other pertinent information available on the website of DRBC

d. I have cited and referred to the following literature in this report:

A. Ballestero, T., D. Kretchmar, L. Carboneau, P. Parasiewicz, J. Legros, J. Rogers, T. Steger, J. Jacobs. 2006. Souhegan River Protected Instream Flow Report, NHDES- R-WD-06-50, Concord, NH. Report for New Hampshire Department of Environmental Services. http://www.des.state.nh.us/rivers/instream/souhegan/study.html

B. Bedient, P.B. and W.C. Huber 1988. Hydrology and Floodplain Analysis. Addison-Wesley Publishing Co. New York. 650 p.

C. Bovee, K.D., Waddle, T.J., Bartholow, J., and Burris, L., 2007. A decision support framework for water management in the upper Delaware River: U.S. Geological Survey Open-File Report 2007-1172, 122 p.

D. Brown, R. S, Hubert, W.A and Daly, S. E. 2011. A primer on winter, ice and fish: What fisheries biologist should know about winter ice processes and stream dwelling fish. Fisheries 1 (**36**): 8-26.

E. Campbell, C.A, Lellis, W.A and Cole, J.C. 2006 Qualitative Freshwater Mussel Survey of the Lower Neversink River. Administrative Report Prepared for the U.S. Fish and Wildlife Service, Region 5

F. Cole, J.C., White, B.S. and Apse, C. 2004. A quantitative assessment of freshwater mussels (Bivalvia:Unionidae) in the Neversink River prior to the Cuddebackville Dam removal. Report to The Nature Conservancy, Cuddebackville, New York. 16 pp.

G. Cole, J.C and White, B.S. 2006. An assessment of freshwater mussels in the Neversink River following removal of the dam at Cuddebackville, NY and a severe spring flood event. Report to The Nature Conservancy, Cuddebackville, NY. 12 pp.

H. Dunbar, M.J., Acreman, M.C., Gustard A., and Elliott C.R.N. 1998. Overseas Approaches to Setting River Flow Objectives. Phase I Report to the Environment Agency. – Environment Agency R&D Technical Report W6-161, Bristol.

I. Dunne, T., and Black, R.D. 1970. Partial area contributions to storm runoff in a small New England watershed. Water Resour. Res. 6: 1296-1311.

J. Faloon, P.D. and Betts, R. A. 2006. The impact of climate change on global river flow in HadGEMI simulations. Atmos. Sci. Let. 7:62–68(2006). www.interscience.wiley.com.

K. Gleick, P.H., A. Singh, and H. Shi. 2001. Emerging Threats to the World's

Freshwater Resources. A Report of the Pacific Institute for Studies in Development, Environment, and Security, Oakland, California.

L. Harrison, I.J., and M.L.J. Stiassny. 1999. The quiet crisis. A preliminary listing of the freshwater fishes of the world that are extinct or 'missing in action'. Pages 271-331 in R.D.E. MacPhee (ed.) Extinctions in Near Time. Kluwer Academic/Plenum Publishers, New York.

M. Malmqvist, B., and S. Rundle. 2002. Threats to the running water ecosystems of the world. Environmental Conservation 29: 134-153.

N. Nilsson, C., Reidy, C. A., Dynesius M. and Revenga C. 2005. Fragmentation and flow regulation of the world large river systems. Science 308: 405-408.

O. NYNHP Conservation Guide – Dwarf Wedgemussel. http://www.acris.nynhp.org/report.php?id=8375

P. Petersen, N. 2001. Philadelphia Inquirer, Thursday edition, September 13, 2001.

Q. Parasiewicz, P. (2001). Strategy for Sustainable Management of the Upper Delaware River Basin. Trout Unlimited. NY. 21pp

R. Parasiewicz, P. and Goettel, M.T. 2003. Ecohydrology Study of the Quinebaug River, Final Report. Instream Habitat Program and New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, July.

S. Parasiewicz P., Ehmann, S. B. and Corp, P. 2003. Fish habitat assessment on Stony Clove Creek, NY using MesoHABSIM. Report for New York City Department of Environmental Protection and Green County Soil and Water Conservation District and New York State Water Resources Institute. pp 410.

T. Parasiewicz, P., J. Rogers, J. Legros and M. Wirth. 2007. Assessment and restoration of instream habitat of the Eightmile River in Connecticut – Developing MesoHABSIM model. The National Park Service, Wild and Scenic River Study for the Eightmile River and the Eightmile River Wild and Scenic Study Committee. pp 62. http://www.neihp.org/projects/eightmile/index.htm

U. Parasiewicz, O., Gillespie N., Sheppard D., Walter M.T. 2010. Strategy for Sustainable Management of the Upper Delaware River Basin. Environmental Research Journal. 5 (1). pp. 115-130

V. Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestergaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-784.

W. Pimm, S.L., G.J. Russell, J.L. Gittleman, and T.M. Brooks. 1995. The Future of Biodiversity. Science 269: 347-350.

X. Richter, B.D., Baumgartner, J.V., Wigington, R. and Braun, D.P. 1997. How much water does a river need? Freshwater Biology, 37 (1): 231-249.

Y. Stalnaker, C.1995. The Instream Flow Incremental Methodology: A primer for IFIM. – National Ecology Research Centre, Internal Publication. U.S Dept of the Interior, National Biological Service, Fort Collins, Colorado.

Z. Stiassny, M.L.J. 1999. The medium is the message: freshwater biodiversity in peril. Pages 53-71 in J. Cracraft and F.T. Grifo (eds.) The Living Planet in Crisis: Biodiversity Science and Policy. Columbia University Press, New

York.
AA. UNEP. 1999. Global Environment Outlook 2000.United Nations Environment Programme, Oxford University Press, New York.
BB. Williams, J.D, and Neves R.J. 1995. Freshwater Mussels: A Neglected and Declining Aquatic Resource. In LaRoe ET, Farris GS, Puckett CE, Doran PD, Mac MJ. Our Living Resources: a Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals, and Ecosystems. US Department of the Interior, National Biological Service, Washington DC, United States, 1995. 362 pp.
CC. Wiley, M.J., Hyndman, D.W., Pijanowski, B.C., Kendall, A.D., Riseng, C., Rutherford, E.S., Cheng, S.T., Carlson, M.L., Tyler, J.A., Stevenson, R.J., Steen, P.J., Richards, P.L., Seelbach, P.W., Koches, J.M. 2010. A Multi-Modeling Approach to Evaluating Climate and Land Use Change Impacts in a Great Lakes River Basin. Hydrobiologia 657: 243-262. DOI 10.1007/s10750-010-0239-2

Radioactive Waste
Management Associates

Memo

To: Tracy Carluccio

From: Marvin Resnikoff, Ph.D.

Date: February 19, 2018

Re: DRBC Comments

General Comments

While I support the Delaware River Basin Commission's (DRBC) prohibition on high-volume hydraulic fracturing (fracking), I do not support the proposed regulations of Part 440 that allow the import of radioactive waste and solids from fracking into the basin. To be clear, the oil and gas industry has a problem in disposing of fracking water and rock cuttings. To frack a well, approximately 5 to more than 11 million gallons of water are required; in 2017 the average volume of water used to frack a Marcellus Shale well in Pennsylvania was 11.4 million gallons.[1] That is primarily because of the longer well bores, increased now from 1 - 2 miles to 4 miles or more in some areas. Some of this drilling fluid can be recycled. But there are not enough deep disposal wells to accommodate the demand for the volume of fracking water produced. As a result, the oil and gas industry has pressured the DRBC to accept this contaminated water. Under Parts 400 the DRBC has proposed regulations for the acceptance of water from fracking and placed conditions on that acceptance. Just to be clear the DRBC could simply ban the importation of fracking water and rock cuttings, but instead have established regulations that allow that to proceed. The following specific comments are in support of some of the regulations DRBC has proposed and opposes others.

We support the commission's policy of no measurable change in existing water quality. But we strongly oppose approving centralized water treatment facilities.

Specific Comments

1. To review, the process of hydraulic fracturing consists of drilling a well down to the Marcellus shale formation 4000 to 8000 feet below ground and then extending the well

[1] http://fracfocus.org/data-download

horizontally in the shale formation for up to a mile, in some cases, up to 4 miles. Casings are constructed and the wells are placed under hydraulic pressure. Explosives shatter the shale formation and proppants maintain open the shattered shale formation. When the hydraulic pressure is released much of the contaminated water, consisting of drilling fluid and interstitial water along with rock cuttings (with the consistency of coarse sand) comes to the surface. This contaminated water is stored in an adjacent pond or in tank cars. After approximately two weeks, some of the remaining water continues to come up with natural gas. This salty water (brine) is highly radioactive and is separated from natural gas at the well surface and placed into condensate tanks or trucks. This produced water or brine contains high concentrations of total dissolved solids (TDS). As shown in the table below, the TDS concentrations increase over time. The TDS concentrations can range up to 345,000 mg/L by day 90 after the well is placed into production. At the present time flowback and production water is transported to a centralized water treatment facility (CWT). After processing, the rock cuttings and sludge are disposed in sanitary landfills and processed water is released to the environment. Under the proposed regulations the rock cuttings, sludges and processed water can be transported to the Delaware River basin and may be released to accessible waterways. The proposed DRBC regulations do not prohibit disposal of rock cuttings into landfills within the basin.

It has been known for over 50 years that the Marcellus shale formation is radioactive. In the late 1970s the USGS investigated the Marcellus shale for high concentrations of uranium. So clearly what is radioactive below ground does not become non- radioactive above ground; this is not alchemy where the radioactivity simply disappears. This radioactivity, consisting of radium-226 and 228 and decay products, is a problem faced by the DRBC in establishing regulations. Because all this radioactivity must go somewhere, the DRBC is essentially establishing regulations that set the radioactive concentrations that can enter the environment within the Delaware River Watershed.

2. We support some sections of the proposed regulations. We support section 440.3 which prohibits fracking within the Delaware River basin. This is important, not only for the potential release of drilling fluids and contaminated water into aquifers but also for minimizing the potential release of the radioactive inert gas radon. We also support the policy of the commission, section 440.5, that there be no measurable change in existing water quality and that the release should not create a menace to public health and safety at the point of discharge. Based on this policy, it is inconsistent that the commission will allow produced water and wastewater from central waste treatment facilities, even under regulated conditions.

3. To be clear, the reason the DRBC and the public are going through this regulatory process is because there is not sufficient deepwell disposal capacity to handle all the contaminated water that has been brought to the surface in Pennsylvania and West

Virginia. While there are well-known methods for removing or concentrating dissolved radium and disposing the solids at a licensed facility in Utah, these methods are more costly than releasing these contaminated liquids and solids directly into landfills, streams or deep wells.

Table 1. TDS (mg/L) as a Function of Time After Well Hydraulic Fractured[2]

Location	Day 0*	Day 1	Day 5	Day 14	Day 90
A	990	15,400	54,800	105,000	216,000
B	27,800	22,400	87,800	112,000	194,000
C	719	24,700	61,900	110,000	267,000
D	1,410	9,020	40,700		155,000
E	5,910	28,900	55,100	124,000	
F	462	61,200	116,000	157,000	
G	1,920	74,600	125,000	169,000	
H	7,080	19,200	150,000	206,000	345,000
I	265	122,000	238,000	261,000	
J	4,840	5,090	48,700	19,100	
K	804	18,600	39,400	3,010	
L	221	20,400	72,700	109,000	
M	371			228,000	
N	735	31,800	116,000		
O	2,670	17,400	125,000	186,000	
P	401	11,600	78,600	63,900	
Q	311	16,600	38,500	120,000	
R	481	15,100	46,900	20,900	
S	280	680	58,300	124,000	

* Day 0 sample was taken of the influent water plus additives without sand.

4. Centralized waste treatment facilities are not a panacea. Studies by the Pennsylvania Department of Radiation Protection show that concentrations of dissolved radium that enter a CWT are approximately equal to concentrations that leave a CWT[3]. Though there are methods for removing radium from water (methods have been used extensively in uranium mills), the process is more expensive than simply releasing this contamination to the environment or into a deep well. Even if CWT's were effective, what would be the final disposal solution for sludges and solids that were created? Essentially the radium dissolved in water would be converted to a solid that can be filtered. And what would be the final disposal solution for the rock cuttings? The radioactive content of the rock cuttings ranges from 30 pCi per gram to 204 pCi per gram (the radioactive concentration of rock cuttings that were sent to the Allied landfill in Niagara County New York)[4]. Released to waterways, Duke University scientists have measured radium concentrations and stream sediments at the point of discharge 200 times greater than upstream and background sediments and above radioactive waste

[2] Veil, J, "Overview of Shale Gas Water Issues," WEFTEC 2012, New Orleans, LA, October 2012.
[3] The DEP study showed that high Ra-226 effluent releases from CWT's were 26,000 pCi/L (DEP,ES-22) equal to the high Ra-226 concentrations into the CWT's and indicating that Ra-226 was not removed at the CWT's.
[4] NYSDEC, Division of Environmental Remediation, August 2012, re. Allied Landfill, Niagara County.

disposal threshold regulations. So we are mystified by what the commission is going to find in these treatability studies required in section 440.5.

5. Under the proposed DRBC regulations, TDS shall not exceed 500 mg/L or less in all but the estuary but as mentioned earlier, the TDS can be as high as 345,000 mg/L so it's unlikely that central waste treatment facilities are going to be able to reach concentrations as low as 500 mg/L.

6. The commission also states that effluent shall not exceed the more stringent of EPA or the host states primary drinking water standards. For combined radium 226 and 228, the drinking water standard is 5 pCi per liter. Produced water can contain concentrations up to 25,000 pCi per liter. It will be difficult to reach concentrations as low as 5 pCi/L.

7. It is important to reiterate that the commission will require that any releases should not exceed background concentrations. To do that the commission must require that background concentrations first be measured. The choice of a laboratory that carries out these measurements is important. The laboratory must be reliable and EPA-certified, and not connected with the gas and oil industry.