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Overview

As a Ph.D. biologist with 18 years of professional experience, it is my view that exploratory well drilling projects within the drainage area of Delaware River Basin Special Protection Waters pose a substantial risk to the water quality and ecological condition of these waterways; this risk is expected to increase commensurately with the number of exploratory well projects. In this testimony, I describe many of the unique and sensitive attributes found within the Special Protection Waters region, including the high water quality which motivated the anti-degradation protections for the Delaware River and a number of its tributaries. I then review the multiple mechanisms by which exploratory well projects elevate the risks from environmental damage to these Special Protection Waters, and how the combined risks could lead to substantial effects on the resources, particularly when expanded in scale above the current level of activity. The juxtaposition of highly sensitive resources in an area that could see unprecedented industrial activity through exploratory well projects highlights the need for appropriate environmental safeguards, including review by the DRBC. Such safeguards provide a means to minimize the risks from exploratory wells, risks that could undermine the considerable efforts across the preceding decades to prevent degradation of these resources.

A. Physical Geography and Regulatory Context

The Delaware Basin covers an area of approximately 13,600 mi^2 across five states (NY, PA, NJ, DE, and MD). Within this area, the Marcellus Shale spans the drainages of the upper Schuylkill River, the upper Lehigh River, and the Lackawaxen River in PA; the Neversink River, the Mongaup River, and both the East and West Branches of the Delaware River in NY; as well as numerous direct tributaries to the Delaware River within this region of the basin (see Map 1). Among these drainages overlapping the Marcellus Shale, only the Schuylkill River falls outside of the area subject to DRBC's Special Protection Waters regulations. All other regions where the Marcellus Shale and the Delaware Basin overlap are included in the DRBC's Special Protection Waters jurisdiction, with an areal overlap of 4,669 mi^2 (69% of the total Special

Protection Waters drainage area of 6780 mi^2). Thus, the Marcellus formation underlies the large majority of the Special Protection Waters drainage for the DRBC. Other natural gas bearing formations that could be targeted for development (e.g., the Utica shale) extend beyond the Marcellus within the drainage area of the Special Protection Waters.

Within the Delaware River Basin's Water Quality Regulations, the Special Protection Program (§ 3.10.3 A.2) serves as the dominant component of DRBC's antidegradation program. Under these regulations, the quantitative measurement of water quality for both tributaries and the mainstem Delaware River at the time of designation is established as the benchmark for water quality regulations and assessments. These "existing" water quality conditions, codified in the regulations, are typically more protective of water quality and ecological conditions than the traditional effects-based water quality criteria promulgated by the DRBC, the states, and the federal government. For instance, DRBC's effects-based criterion in Zone 1D for in-stream Fecal Coliform is 200 cells/100 mL while Special Protection Waters benchmarks range from 20 to 100 cells/100 mL (*see* § 3.20.5 C.8 and Tables 2C, 2E, and 2I). Likewise, DRBC's effects-based criterion in Zone 1D for in-stream Dissolved Oxygen ranges from 4.0 to 5.0 mg/L while the Special Protection Waters benchmarks range from 7.9 to 8.5 mg/L (§ 3.20.5 C.1 and Tables 2C, 2E, and 2I). Furthermore, the intent and function of the Special Protection Waters regulation is to maintain water quality at the levels measured at the time of designation, unlike typical water quality programs operated through DRBC or the states where water quality is allowed to decline to the point where ambient or forecasted water quality simply attains the numeric criteria. Thus, the DRBC's Special Protection Waters regulations operate in a manner similar to the state and federal antidegradation programs under the Clean Water Act.

B. Delaware River Conditions

The Delaware River is an exceptional river within the eastern United States. The Delaware remains un-dammed on its mainstem for the 330 miles from the Atlantic Ocean to the confluence of its East Branch and West Branch at Hancock, NY, with free-flowing access to the principal headwaters extending an additional 60 miles via the East Branch Delaware and Beaver Kill rivers. As such, it is among the largest un-dammed rivers east of the Mississippi and one of the only large river systems draining to the Atlantic seaboard of the United States without a dam on its mainstem (Benke and Cushing 2005).

The free-flowing condition of the Delaware provides critical functions for the ecology of this large river. The most fundamental of these functions is the free access for migratory fish. The non-tidal Delaware River currently maintains strong populations or runs of many declining migratory fishes, including American eel, American shad, alewife, and blueback herring. The Delaware thus serves as an important component in the overall maintenance of these economic fisheries as well as the conservation of these fish species (ASMFC 2007, ASMFC 2009). Through the maintenance of these migratory fishes, the undammed river provides further indirect benefits to the ecosystem, as well. For example, recent evidence suggests the most dominant species of freshwater mussel in the Delaware River (*Elliptio complanata*) prefers American eels as its obligate host for juvenile glochidia (W.A. Lellis, USGS, *personal communication*). The free-flowing condition of the Delaware River, through its abundant eel population, therefore likely contributes to the Delaware's high densities of freshwater mussels, further maintaining the function and composition of the river's ecosystem in a form similar to what existed hundreds of year ago (Lellis 2001, Lellis 2002).

Lellis's surveys have also documented the persistence of 9 native mussel species in the mainstem Delaware River, indicating the Delaware remains a northeastern Atlantic slope stronghold for native mussels that are largely declining regionally and nationally (Bogan 1997, Strayer and Jirka 1997, Strayer et al. 2004, Nadeau 2008). These recent surveys on the Delaware River identified previously undiscovered populations of the dwarf wedgemussel (*Alasmidonta heterodon*) in the mainstem river between Hancock, NY, and Callicoon, NY, thus expanding the range of known populations of this Federally Endangered species within the Delaware Basin (Lellis 2001, Lellis 2002). It is significant to note that one of the largest remaining populations of *A.heterodon* lies within the Neversink River (USFWS 2007), located within the drainage area of the Special Protection Waters and underlain by the Marcellus Shale. The upper mainstem populations also lie in the region where the Special Protection Waters overlaps the Marcellus Shale. Thus, a diverse and imperiled mussel fauna occupies the central area within Special Protection Waters and could be affected by any negative environmental impacts from exploratory natural gas development projects in shale formations underlying the area.

High densities of freshwater bivalves can strongly affect water clarity and suspended materials (Caraco et al. 2006, Strayer et al. 2008). Thus, while the diversity and abundance of mussels benefits from the intact ecological conditions of the mainstem Delaware River and its headwater tributaries, the high water quality in the river likely is also enhanced by the high density of these large-bodied filter-feeding mussels.

The extraordinary quality of water within Special Protection Waters streams and rivers can readily be understood through a comparison of water quality data to surface water quality criteria. For instance, total dissolved solids (TDS) is a broad measure of the solid material contained in water but which passes through a standard filter (Eaton et al. 2005). Because of aesthetic issues with drinking water, water quality criteria for TDS have been recommended at 500 mg/L (USEPA 1986). Recent research and monitoring results indicate that high TDS likewise can negatively affect aquatic organisms (Pond et al. 2008), with states such as

Pennsylvania moving to protect both drinking water supplies and aquatic life with revised TDS requirements and criteria that closely match the 500 mg/L criteria recommended by the USEPA (PA Bulletin 2010). Current DRBC regulations likewise include a TDS water quality standard of 500 mg/L basin-wide, and also provide for a maximum increase in TDS of 33% over background by any proposed discharge (or group of discharges) as a means of minimizing effects on aquatic biota and keeping TDS at the more dilute levels seen through much of the basin (DRBC 2008a). Both the existing water quality defined by Special Protection Waters regulations and recent unpublished data (DRBC 2006-2009) indicate that TDS in Special Protection Waters streams and rivers typically ranges between 50 mg/L and 100 mg/L, five-to-ten times below the common 500 mg/L TDS criteria (DRBC 2008a, DRBC *unpublished data*). Thus, the Delaware River and its Special Protection Waters tributaries currently maintain concentrations of dissolved solids (including salts and other compounds) far below EPA-recommended criteria.

Nutrient concentrations in Special Protection Waters likewise are low relative to recommended or adopted nutrient criteria. This condition is notable given the high nutrient levels pervasive in waters throughout the United States and the water quality impairments caused by these excess nutrient levels (Dubrovsky et al. 2010). Among the DRBC and its four primary basin states, only New Jersey has numeric nutrient criteria for streams and only for phosphorus (100 μg/L TP; NJDEP 2010). In 2000 and 2001, the USEPA recommended candidate nutrient criteria for streams based solely on the distribution of nutrients at ecoregional reference sites; in the four ecoregions covering the Delaware River, total phosphorus recommendations ranged from 10 μg/L to 37 μg/L while total nitrogen recommendations ranged from 0.31mg/L to 0.71 mg/L (USEPA 2000a, USEPA 2000b, USEPA 2000c, USEPA 2001). Given these remarkably low recommendation from the USEPA, many states, tribes, and interstate agencies have sought to develop effects-based nutrient criteria rather than simply adopting the reference distribution-based criteria from the USEPA (USEPA 2008). New York is among the states developing such effects-based criteria, with recently-developed candidate criteria ranging from 30 to 65 μg/L for total phosphorus, and 0.7 mg/L for total nitrogen (Smith et al. 2006, Smith and Tran 2010). Yet the observed concentrations of nutrients in the mainstem Delaware for the Marcellus region have typically been around 30 μg/L total phosphorus and 0.50 mg/L total nitrogen (DRBC 2008). Recent results from tributaries around the Delaware Water Gap National Recreation Area (all within SPW; the PA tributaries overlapping Marcellus region) likewise indicate low nutrient concentrations, with median values around 20 μg/L for total phosphorus and 0.30 mg/L for total nitrogen (Hickman and Fischer 2007). Thus, both the mainstem Delaware River and SPW tributaries typically maintain nutrient concentrations in the range of the various recommended criteria, and far below the only established nutrient criterion in the basin of 100 μg/L total phosphorus (New Jersey). Again, for a water quality parameter central to maintaining the quality and health of the Delaware River and its tributaries, data indicate that the Delaware River maintains a quality comparable to regional reference conditions. Indeed, the Delaware River was selected as a regional reference site for the 2008-2009 National Rivers and Streams Assessment by USEPA (J. Kurtenbach, *personal communication*).

This combination of extraordinary qualities in a single river system helps maintain a high level of overall ecological health and diversity within the Special Protection Waters streams and rivers. This ecological health has been recognized, in part, through the disproportionate designation of streams in the region with the states' highest levels of anti-degradation protections. As noted above, such ecological distinction can also be seen in the high density of freshwater mussels in the Delaware River and the maintenance of the regional diversity of this increasingly imperiled group of organisms. Recent surveys of the fish community in the Delaware Water Gap National Recreation Area and the Upper Delaware Scenic & Recreational River likewise document the persistence and relatively strong populations of many native fishes (Horwitz et al. 2008).

The brook trout (*Salvelinus fontinalis*) is another species that provides evidence of the relatively intact ecological conditions of Special Protection Waters and their tributaries. While declining through much of its native range in the United States, brook trout populations within the Special Protection Waters watershed have persisted, and these populations remain vital for the conservation of this species both within the Delaware Basin and within the states of Pennsylvania, New Jersey, and New York (Hudy et al. 2008). Brook trout are noted for their sensitivity to elevated water temperatures, among other parameters, with forest clearing and riparian disturbance playing a key role in the decline of this species within the mid-Atlantic region (e.g., Stranko et al. 2008)

The extraordinary condition of the Delaware River is further demonstrated by its native aquatic plant community, with many species of aquatic plants continuing to thrive in the Delaware River (TNC 1994). Most notable among these is the single species from the family Podostomaceae within the United States, *Podostemum ceratophyllum* (common names of threadfoot or riverweed), a state-listed species across much of its distribution including New York (state-threatened; Young 2010). The Delaware River population remains the single largest remaining *Podostemum* population in the region, with a limited number of additional populations in Special Protection Waters tributaries (Munch 1993). This fast-water obligate plant is particularly relevant because of its acute sensitivity to mining activity, with complete elimination of the species in the Lehigh River and other Pennsylvania streams below the first mine drainage stream (Munch 1993). Thus, *Podostemum* may be among the most sensitive species to industrial activity within the Delaware basin, with the most abundant populations of this sensitive indicator within the overlapping areas of Marcellus Shale and Special Protection Waters.

More broadly, biological surveys of stream conditions within the Special Protection Waters region document the relatively pristine status of these streams' ecological structure. Such surveys are largely based on collections of benthic invertebrates, with the overall diversity across the Delaware Basin documented at more than 800 species (Bilger et al. 2005). These surveys have found the invertebrate communities to be diverse and abundant, maintaining a complement of sensitive species comparable to the highest quality reference streams for the region (DRBC 2008b, NYSDEC 2008, NJDEP 2009, NYSDEC 2010, DRBC 2010, PADEP 2010).

The Delaware River thus remains an exceptional river within the eastern United States, supporting diverse population of native mussels, fishes, plants, and invertebrates. Both its free-flowing status and its high water quality play critical roles in supporting and maintaining this healthy ecological condition. Moreover, many of these species are declining or imperiled within the larger region in which they historically thrived, further demonstrating the vital role the Delaware basin populations play in their overall conservation and underscoring the need to maintain the exceptional conditions upon which these species depend. The DRBC's Special Protection Waters program, adopted in 1992 (for control of point source discharges) and 1994 (for control on non-point source discharges), is the centerpiece of current protection efforts, but the region and the nation have invested in conserving the qualities of the non-tidal Delaware River for more than three decades, beginning with the designation of over 100 miles of the upper and middle Delaware to the federal Wild & Scenic Rivers System in 1978. Development of natural gas resources underlying the Special Protection Waters region must be undertaken deliberately and with great care if the qualities for which the region's exceptional water resources have been managed for more than three decades are to be protected.

C. Risk to SPW Resources Posed by Natural Gas Development

The exploration and development of natural gas shales, made possible by the application of horizontal drilling and hydraulic fracturing technologies, represents a new industrial activity for the Delaware River Basin. During the exploration phase alone, both novel landscape activities and expansions of existing human uses will occur. These activities and uses include:

- grading of exploratory well site pads
- construction of drilling pits
- storage of fuel and chemicals in previously undeveloped locations
- operation of heavy machinery
- improvement or construction of access roads
- clearing of natural vegetation, including forests
- mixing, use, and re-capture of drilling fluids

- transport of hazardous materials
- storage and disposal of deep-well drill cuttings
- direct interconnection of formerly isolated geologic formations
- diversion of surface waters

Each of these activities involves risks of environmental degradation affecting water resources. Such degradation can be direct (e.g., release of a toxic material into a stream) or indirect (e.g., hydrologic alterations from roads and site development), but the effects from these activities on water quality and aquatic organisms are well-established in the scientific literature. Below, I briefly review the mechanisms by which such environmental impacts can occur to document the risk that the development of natural gas exploratory wells may have a substantial adverse effect on DRBC's Special Protection Waters.

As I review these effects, it is important to note that the likelihood of environmental damage and ecological impacts increases with the extent of exploratory well drilling. For the majority of the impacts identified herein, limited exploratory well activity leads to a relatively low risk that environmental damage will be measureable and significant. Such low risk arises from two processes. First, the magnitude of the human alteration remains low for a small number of activities. Second, the likelihood of a single low-probability event (e.g., catastrophic spill) occurring with only a small number of actions remains low. Yet with increased activity, both of these processes increase. First, the magnitude of human alteration increases both locally and regionally, leading to greater effects within smaller watersheds and increased likelihood that effects will promulgate to larger streams and rivers. Second, low-probability events become increasingly likely to occur as the number of actions increases. To date, the exemptions allowed under the DRBC Supplemental Executive Director Determination (14-June-2010) provide opportunities for approximately twelve exploratory wells within the Delaware Basin. My understanding is that the actual number may be fewer. By contrast, the number of exploratory wells that could be developed and drilled in the Delaware basin without DRBC review in the absence of this Supplemental Determination would be unlimited and is not known. An increase by one to two orders of magnitude beyond the current activity would be accompanied by a commensurate increase in the risk to water quality and ecological conditions, with such an expansion possible if the exemption from DRBC review were to be extended indefinitely for all exploratory wells.

Site Preparation: Early in the exploration process, construction activities on the well-pad sites, including site grading and drilling pit excavation, increase the likelihood of higher sediment yields into receiving streams of DRBC's Special Protection Waters area (Wolman and Schick 1967, Williams et al. 2008). Such sedimentation within stream channels leads to multiple direct and indirect effects on water quality and biological communities (see reviews by Waters 1995, Wood and Armitage 1997). Reduced light penetration, increased bed scour, and direct deposition on benthic substrates negatively affect primary producers, the organisms at the base of these stream food webs. Sediment deposition can affect habitats and food quality of benthic invertebrates, and can cause direct fouling on filtering structures and on respiratory structures for different species. For fish, increases in fine sediments negatively affect spawning habitats and the survival of immature fish stages associated with sediments. Increased sediments also cause fouling of gills, and affect food quality and foraging efficiency. Increased sediment yield from exploratory well pad construction therefore provides many mechanisms for possible water quality changes, habitat alterations, and ecological effects throughout the aquatic food web.

Site Access: The expansion and improvement of the road network to transport equipment and materials to and from exploratory well pads provides multiple pathways for environmental contamination and degradation to Special Protection Waters. First, the roads themselves lead to negative effects on water quality and ecological conditions through altered hydrology, increased sediment yields, increased hydrocarbon and metals penetration into the landscape, altered stream channel dynamics, increases in water temperature, increased salt concentrations, interruption of dispersal pathways, and other mechanisms (Forman and Alexander 1998, Trombulak and Frissell 2000). Second, the development of exploratory wells will lead to increased industrial traffic and increased transport of fuels and chemicals into the region, thus increasing the probability of accidental spills of harmful compounds into surface waters and surficial aquifers (e.g., Hartle 2006). Third, road networks and increased road traffic elevate the risk from the introduction and spread of invasive species, putting native species and habitats at greater risk for ecological change and species replacements (Trombulak and Frissel 2000, Jodoin et al. 2008).

Operation and Maintenance of Exploratory Wells and Well Pads: The suite of industrial chemicals used in the operation and maintenance of exploratory wells and well pads includes many compounds with acute and chronic effects on a broad range of aquatic organisms (Cranford et al. 1999, Barlow and Kingston 2001, DRBC 2008a, USEPA 2009, Colburn et al. *in press*, Emofurieta and Odeh *in press*). The storage and use of fuels and industrial chemicals on drilling sites increases the risks that these materials will be released into surface waters. Recent widespread problems with fuel and chemical storage (e.g., MTBE groundwater contamination; see USEPA 2005) indicate that the risks from storage of such chemicals have not been eliminated. Moreover, the drilling of natural gas wells in shales involves the mixing, use, and re-capture of industrial chemicals on-site, further increasing the risk of accidents. The flammable and explosive potential from pressurized natural gas likewise presents a risk for catastrophic events, the severity of which may be magnified by the close proximity to industrial chemicals. The suite of these on-site activities further increases the risk of release of harmful chemicals into the surrounding landscape, leading to elevated risks to Special Protection Waters and the biological resources inhabiting them.

Storage and Disposal of Drilling Wastes: The storage and disposal of drill cuttings also poses a risk to Special Protection Waters. The combination of poorly weathered sediments, natural accumulations of metals and radioactive materials in formation rocks, and the addition of materials to assist in drilling operations provides a source of new material that is expected to differ strongly in composition and concentration compared to surficial soils in the Special Protection Waters region (see Resnikoff 2010). Weathering of these materials provides an additional source of environmental change, with documented effects from drill cuttings in other aquatic environments highlighting the potential for these materials to affect both water quality and the biota of Special Protection Waters (e.g., Trannum et al. 2010).

Hydrologic Alteration: The need to protect in-stream flows highlights an additional risk from the water withdrawals for exploratory wells (up to 100,000 gallons per well). The maintenance of in-stream flows, not solely during low flow periods but throughout the year and throughout the hydrologic cycle, has increasingly been recognized as a vital link in maintaining the ecological health of aquatic communities (Arthington et al. 2006, Acreman and Ferguson 2010). Seasonal flow cues, habitat protections at low and high flows, elimination of rapid flow ramping, and durations for low-flow and high-flow events are all important components to the flow regime that, if altered, can lead to negative effects on water quality and the living aquatic resources inhabiting streams and river. Thus, indiscriminate abstraction of water from Special Protection Waters streams and their tributaries has the potential to alter the hydrology of these systems and thus negatively affect these aquatic resources (e.g., Freeman and Marcinek 2006, Carlisle et al. 2010).

Invasive Species: In addition to the effects on hydrology, the diversion of surface water for exploratory wells creates a risk for invasive species introductions and spread. The Delaware River basin now harbors populations of the invasive diatom alga, *Didymosphenia geminata*, commonly known as “Didymo” or “rock snot” (NYDEC 2010, PFBC 2010). This stalked diatom can dominate the periphyton community in streams and can foul the stream substrate, with implications for the entire ecological food web (e.g., Shearer et al. 2007, Gillis and Callifour 2010). A potentially even more serious threat is the discovery of the golden alga, *Prymnesium parvum*, within Pennsylvania (Renner 2009). This species of algae thrives at higher TDS concentrations, a particularly high risk in areas with extensive mining activity. And most alarmingly, blooms of *P.parvum* can cause widespread mortality among many aquatic life forms from the production of toxins (e.g., Reynolds 2009). The use of water diversion equipment in connection with well drilling throughout the Special Protection Waters region of the Delaware Basin will increase the likelihood that one or more invasive species, such as Didymo or *P.parvum*, will be transported to new areas where the invasives may cause important shifts in the ecological systems.

In conclusion, exploratory well drilling both heightens the risks via expanded human activity and creates novel environmental threats to water quality for both the tributaries and the mainstem Delaware River designated as Special Protection Waters. When combined, these individual risks lead to a cumulative probability of impacts that is not trivial. Should these risks be maximized through inadequate oversight and insufficient regard for the environmental hazards, I believe the potential exists for substantial impacts to water quality of Special Protection Waters. Because the risk of substantial effects directly attributable to activities associated with exploratory well drilling or operations is manifest, a regulatory regime is needed to: (a) reduce the risks to the extent possible; (b) institute pre-and post-development monitoring requirements in order to identify measurable adverse effects and institute measures to stop degradation before it becomes irreversible; and (c) ensure that operators responsible for adverse effects have the resources necessary and the legal obligation to mitigate them.

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Map 1. Marcellus Shale and Special Protection Waters Areas within the Delaware River Basin. Major rivers within the region are highlighted with separate color schemes, and significant tributaries are labeled.