Expert Report on the Relationship Between Land Use and Stream Condition (as Measured by Water Chemistry and Aquatic Macroinvertebrates) in the Delaware River Basin

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22 November 2010

Contribution Number 2010011

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I. Link between land use and water chemistry – Although differences among sites can be a reflection of underlying geology, soils and vegetation covering the land, changes in land and water use also can change the concentrations of major ions, nutrients, and organic compounds, and introduce elements or compounds to a waterway that were not there naturally.

The link between water chemistry and underlying geology, soils and vegetation is well known, and covered in most limnology and stream ecology texts (e.g., Wetzel 2001 and Allan and Castillo 2007). Our research in the drinking water watersheds of New York City, which include the East and West Branches of the Delaware as well as the Neversink River and lower Hudson River tributaries (SWRC 2008), identified a number of differences in water chemistry among groups of sites that illustrate the variation in water chemistry (i.e., base cations) that occurs naturally. The gray dashed line in Figure 1 is a regression that describes the relationship between base cations (e.g., calcium, magnesium, sodium, potassium) and alkalinity (acid neutralizing capacity, primarily bicarbonate) for sites in the Catskill Mountains that are forested (>97% forest cover in the EBD, WBD, NRD) and do not have known point sources. It shows the consistent, positive relationship between alkalinity and base cation concentration - base cation concentration increases as alkalinity increases. The range of values along this line reflects differences in underlying geology, soils, and vegetation that occur naturally between basins and sub-basins across the Catskill Mountains (e.g., consistently low concentrations in the Neversink River, higher and variable concentrations in the West and East Branches of the Delaware River). Data points above the gray dashed line in Figure 1 reflect increases in cation concentration relative to alkalinity that is presumably a result of anthropogenic land and water uses such as salts used to deice roads, fertilizers applied to fields or lawns, or treated sewage discharged to land or waterways.

When examining changes in differences in water chemistry among sites, we have found that one of the best single predictors of these changes is often % forest cover in the watershed. As the percentage of upstream forests is reduced (i.e., converted to other land uses and covers), we have observed higher values for a number of parameters that are a reflection of changes in cations and anions such as conductivity, sodium, potassium, calcium, magnesium, and chloride as well as changes in nitrogen and phosphorus (Figure 2). We have also observed higher concentrations of elements or compounds that are directly or indirectly waste products or residuals from human activity or human-related land uses. For example, sulfate is often associated combustion engine exhaust, motor oil, and tires, and its concentration tends to be higher when road density is higher (Figure 3).

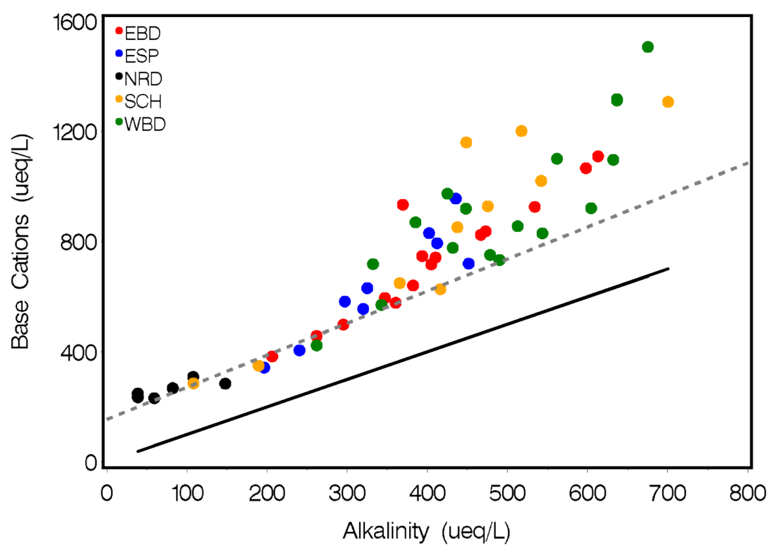

Fig. 1. Plot of alkalinity and base cation concentration for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch (EBD) and West Branches (WBD), and the Neversink River (NRD) as well as sites in Rondout (NRD), Esopus (ESP) and Schoharie (SCH) Creeks. The gray dashed line is a regression between base cations and alkalinity for forested sites (>97% forest cover in the EBD, WBD, NRD) that do not have known point sources. The solid black line is the 1:1 line.

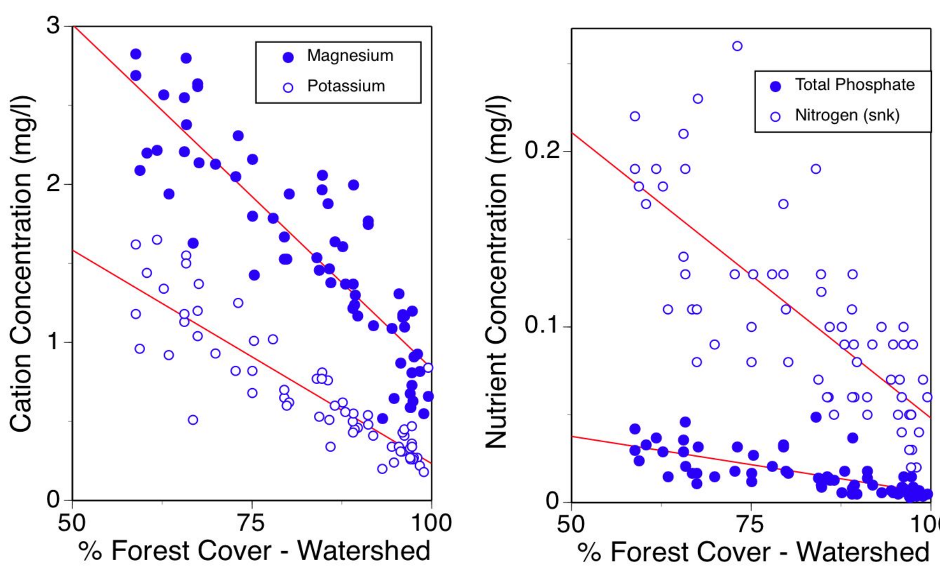

Fig. 2. Plot of cation (magnesium and potassium) and nutrient (total phosphorus and nitrogen) concentrations versus % forests cover at the watershed scale for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

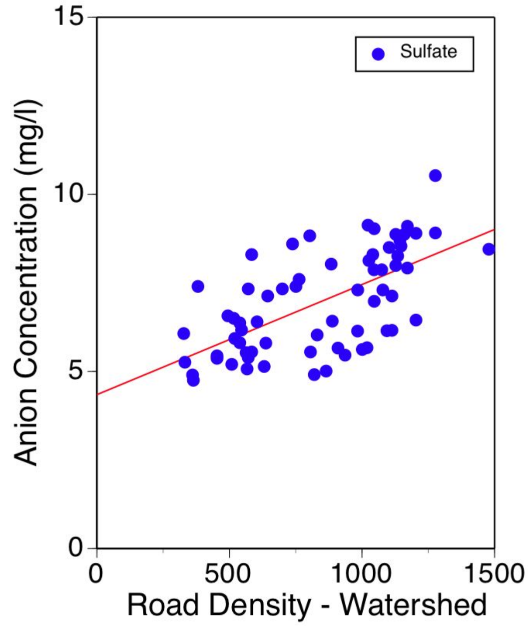

Fig. 3. Plot of anion (sulfate) concentrations versus road density at the watershed scale (m per 100 sq. km) for streams draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

II. Stream macroinvertebrates as indicator of water quality

Stream macroinvertebrates (primarily insects, but also other invertebrates such as aquatic worms, crayfish, and molluscs) have provided water quality assessment programs with valuable insight for more than 100 years (Rosenberg and Resh 1993). The presence or conspicuous absence of certain macroinvertebrate species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs that rely on periodic water chemistry samples. Local, state, and federal agencies have developed a wide variety of stream bioassessment protocols that rely on macroinvertebrates. Stream macroinvertebrates are commonly used and widely accepted tools in water quality monitoring programs for a number of reasons.

(1) Most river and stream ecosystems have relatively diverse aquatic insect assemblages (100-200 species), with species from several different orders [e.g., Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Coleoptera (beetles), Diptera (true flies)]. Each of these species is to some degree evolutionarily unique; as a result, each potentially possesses different tolerances to changes in environmental conditions. Thus, together, the aquatic insects are a sensitive measure of environmental change and stress.

As an example of stream macroinvertebrate biodiversity, we sampled seven high quality tributaries to the Delaware River near the Water Gap in 2008 and 2009 (Stroud Water Research

Center, unpublished data). Among the seven sites, we identified 236 different macroinvertebrate species or taxonomic groups (i.e., identified to genus or higher taxonomic level and therefore may have represented more than one species), and the number at any one site ranged from 97 to 150 species. Many of these species are known to be pollution sensitive such as the mayflies, stoneflies and caddisflies (i.e., Ephemeroptera, Plecoptera, Trichoptera, or EPT). Among the 236 different species or taxonomic groups identified in the Water Gap tributaries, 105 (44%) were EPT species. The species in these insect orders are often grouped together and used as a pollution indicator (e.g., the number of EPT species, also known as EPT Richness). Because these seven Water Gap tributaries were clean streams draining well forested watersheds with limited anthropogenic activity, each supported a variety of these pollution-sensitive EPT species (43-53 per site) that together represented 37-46% of the macroinvertebrate species identified at a site.

Similar taxonomic richness was observed among Catskill Mountain tributaries in the headwaters of the Delaware River when we sampled 3-6 times between 2000 and 2005 (SWRC 2008, unpublished data). For example, across 15 tributary and main stem sites for the East Branch of the Delaware River, we identified 285 different macroinvertebrate species or taxonomic groups, 117 (41%) of which were pollution-sensitive EPT species. Individual sites had between 84 and 154 species, including 35-60 EPT species (34-47%). Similarly, we identified 287 different macroinvertebrate species or taxonomic groups (including 108 (38%) that were pollution-sensitive EPT species) across 17 tributary and main stem sites for the West Branch of the Delaware River, and 183 different macroinvertebrate species or taxonomic groups (including 73 (40%) that were pollution-sensitive EPT species) across four tributary and main stem sites for the Neversink River.

The same samples used above to describe the biodiversity for stream macroinvertebrate can also be used to describe abundance. For example, the Water Gap tributaries had an average macroinvertebrate density of 6,091 individuals/m^2 (Stroud Water Research Center, unpublished data). The upper Delaware River sites supported higher densities: 21,923 individuals/m^2 among the 15 West Branch sites, 20,981 individuals/m^2 among the 17 East Branch sites, and 15,606 individuals/m^2 among the 4 Neversink sites (SWRC 2008). Thus, the Delaware River and its tributaries support a diverse and abundant macroinvertebrate community that includes many pollution-sensitive species.

III. Response of stream macroinvertebrates to changes in land and water use

In general, concentrations of selected ions, nutrients, and organic compounds increase as forests are converted to other land uses. Concentrations of anthropogenic compounds (e.g., herbicides, insecticides, heavy metals, oil-derived compounds) that are associated in these new land and water uses also increase. For the Delaware River basin, examples of these relationships can be seen in Figures 1, 2, and 3, above.

Parallel changes in macroinvertebrate faunas have also been observed as forests are replaced by other land uses (which often is accompanied by different water uses such as domestic, commercial, and industrial consumption and waste and storm water runoff). Many streams in the

Delaware River basin drain watersheds that are almost completely forested and are high quality (Figure 4), but they already show evidence of stress (e.g., changes in relative abundance but without local macroinvertebrate species extinctions) in response to local changes in land and water use (Figure 5). More intensive changes in land cover and water use are generally accompanied by the loss of pollution-sensitive macroinvertebrate species (Figure 6). In some cases, local land and water use changes have already resulted in moderate to severe impairment of the macroinvertebrate species (i.e., a loss of 50-75% of the pollution-sensitive species). In many cases, the cause of stream degradation is a current activity such as erosion from recently plowed fields or outflow from a poorly functioning wastewater treatment plant. In other cases, present degradation reflects past land use decisions, including how and where changes were implemented, sediment and erosion control practices, and management of wastestreams. For example, most of the anthracite coal field in the Schuylkill River basin have not been actively mined for decades yet many of the streams in contact with the waste piles or mine outflows are currently some of the severely impaired in the basin because they still have excessive acid and metals in the water (Figure 8).

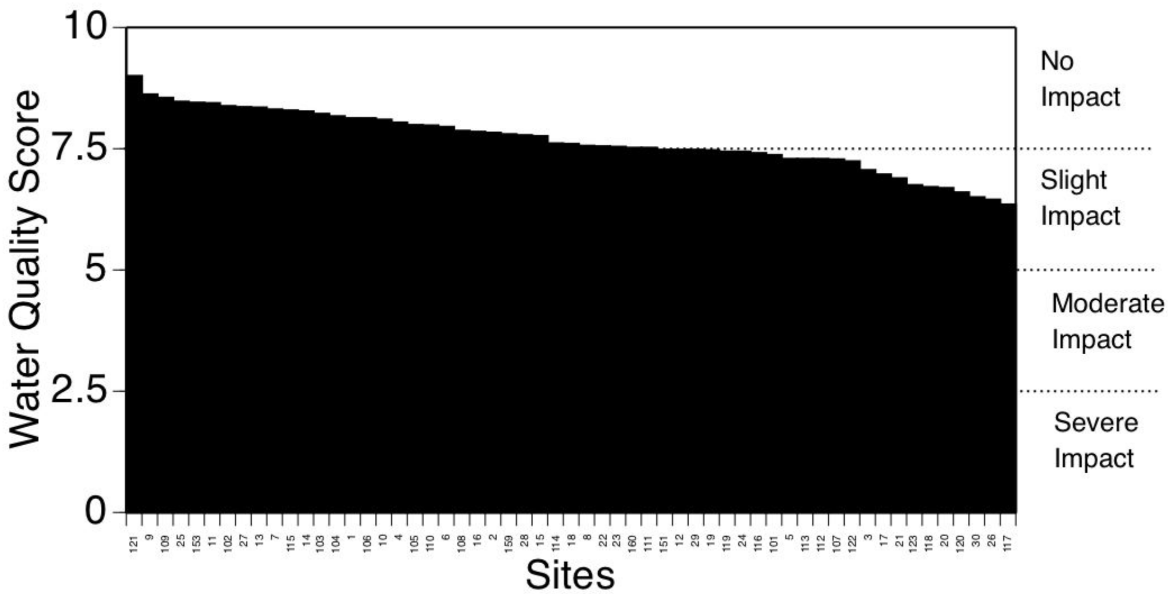

Fig. 4. Plot of Water Quality Score (sorted from highest to lowest) for 57 stream sites draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

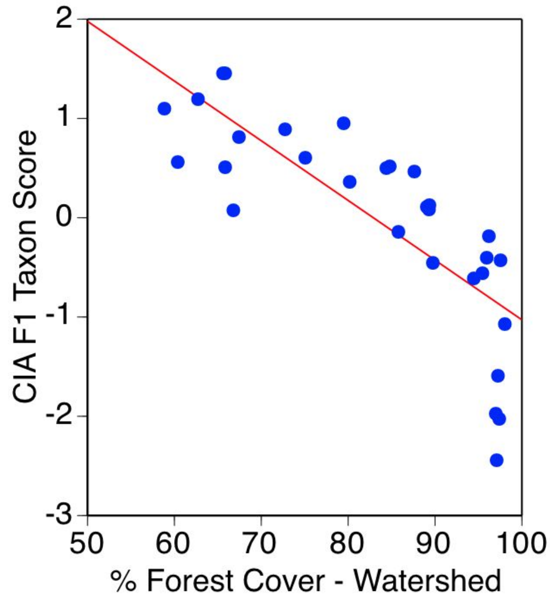

Fig. 5. Plot of macroinvertebrate community structure (as expressed by Co-Inertial Analysis Factor 1) versus % Forest Cover at the watershed scale for 30 stream sites draining the Catskill Mountains. This includes Delaware River sites in the East Branch and West Branches, and the Neversink River as well as sites in Rondout, Esopus and Schoharie Creeks.

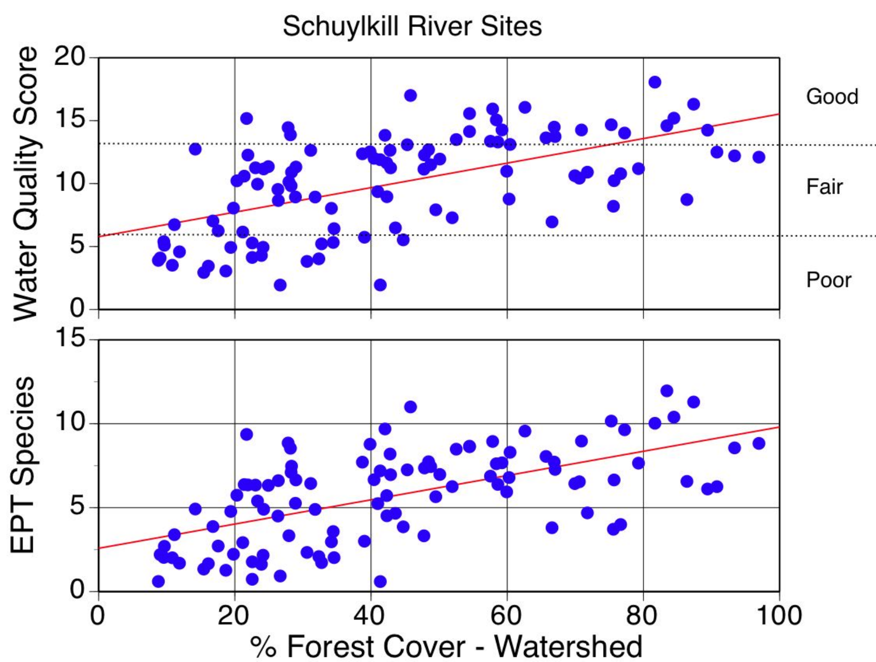

Fig. 6. Plot of macroinvertebrate community structure (as expressed by MAIS Score and EPT Richness) versus % Forest Cover at the watershed scale for 104 sites in the Schuylkill River basin, the largest tributary to the Delaware River.

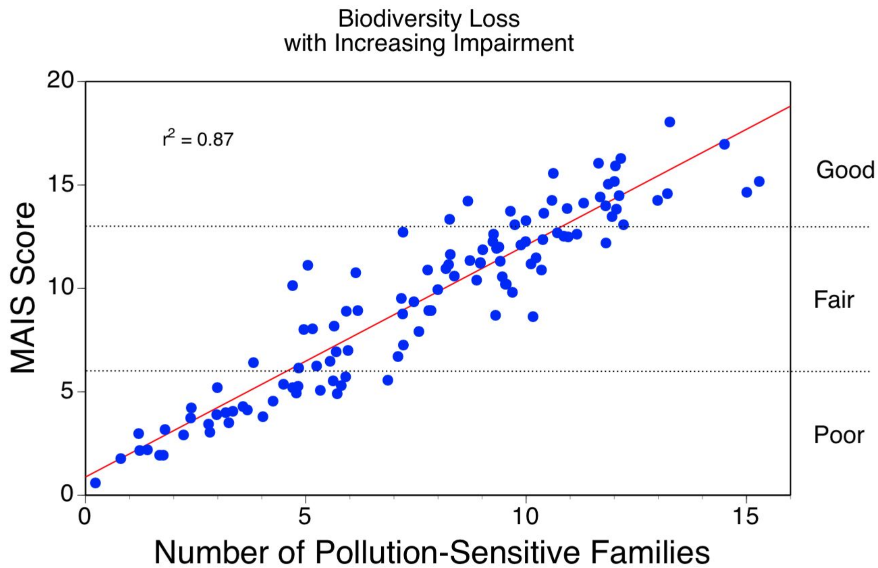

Fig. 7. Plot of macroinvertebrate community structure (as expressed by MAIS Score) versus the number of pollution-sensitive macroinvertebrates in the Schuylkill River basin, the largest tributary to the Delaware River.

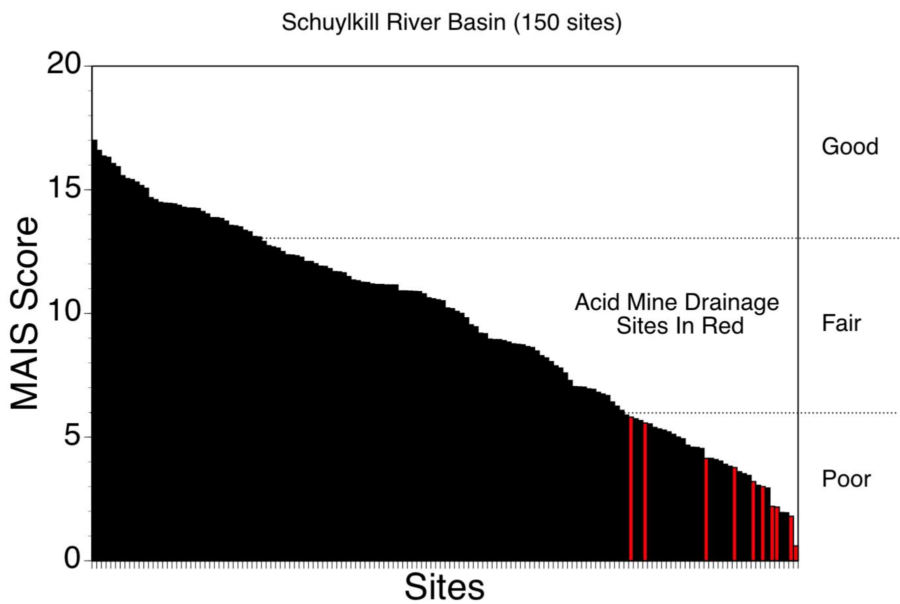

Fig. 8. Plot of MAIS Scores for 150 sites in the Schuylkill River basin, sorted from highest to lowest score. Sites with clear evidence of acid mine drainage are shown in red.

IV. Stream and watershed changes associated with Marcellus Shale exploration and development

The potential for stream degradation associated with Marcellus Shale exploration and development depends on the location and intensity of changes in land cover and water use that may then result in changes in changes in stream habitat, water quality and/or water quantity. Because many of these watersheds are well forested, Marcellus Shale exploration and development are going to result in replacing forests with other land uses. Changes in land and water use may result from the construction, expansion, and maintenance of drill sites, roads, stream crossings, and pipelines as well as additional infrastructure in support of the new industry (e.g., new or modified sites, roads, stream crossings, pipelines, and power lines). This can lead to stream degradation if it results in changes in local hydrology (flood maxima and low base flow, sediment erosion in the stream corridor and in upland areas, warming of the waterways (from reduced shading) as well as the presence or increase in naturally occurring chemicals (silt, salts, naturally occurring radioactive material), chemicals resulting directly from drilling and fracking process, and potential pollutants associated with additional developed lands (directly and indirectly associated with exploration and production) or more intensive use of previously developed lands (e.g., more traffic and people resulting in more road salt, heavy metals, oil-derived compounds).

The effects from land use changes (e.g., converting forest to agricultural, industrial, commercial, or residential uses) on water chemistry and macroinvertebrate communities are well established in areas both within and outside of the Delaware Basin. Based on these scientific studies, impacts to water chemistry and aquatic communities could potentially result from land use changes associated with Marcellus shale exploration and development (e.g., replacing forests with infrastructure associated with or in support of the new industry). As a result, careful review and regulation of land use changes associated with all shale gas well development activity, including exploratory well development, appears warranted to minimize the extent to which the sensitive aquatic resources in the Delaware River basin are affected.

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