Permitting Seeps from Coal Ash Impoundments with Consideration of Natural Conditions


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ABSTRACT

In 2015, the U.S. Environmental Protection Agency finalized technology-based effluent limitations guidelines and standards for wastewater discharges from steam electric power plants. The final rule set federal limits for metals and other effluent parameters that power plants are permitted to discharge in primary sources of wastewater. These primary sources of wastewater include coal ash management basins and flue gas desulfurization. In addition, the Coal Combustion Residuals (CCR) rule addresses risks from coal ash disposal. As a result of these two rules, steam electric power plants are faced with new National Pollutant Discharge Elimination System (NPDES) permit limits that may be difficult to consistently achieve. This difficulty may be especially true for parameters that, in many cases, reflect natural geological and hydrogeological conditions. An NPDES permit may designate discharge of wastewater that has migrated from an ash impoundment via infiltration into groundwater. The composite chemistry of this wastewater/groundwater mixture can be dominated by natural processes and interactions with soil, rock, and biota in the subsurface before discharging as an ash basin seep. Theses natural processes often influence the chemistry of ash basin seeps in ways that cannot be controlled by the power generator. Parameters especially subject to excursions due to natural conditions include effluent pH and hardness. These parameters can be influenced by natural geochemical processes, and regional groundwater conditions. Power companies may choose to pursue a consent order for relaxation of effluent limits associated with such ash basin seeps. Consent order applications often require scientific verification that potential non-compliance is not related to improper operation and maintenance of existing wastewater treatment processes. This paper provides a description of geological and hydrogeological conditions in North Carolina that can influence key effluent parameters like pH and hardness, and provides a recent example of a consent order application for NPDES variance based on those conditions.
INTRODUCTION

The U.S. Environmental Protection Agency’s (EPA) Steam Electric Power Generating Effluent Guidelines Final Rule set federal limits on the amount of metals and other effluent parameters that power plants are permitted to discharge in primary sources of wastewater. Typical sources include fly and bottom ash, flue gas desulfurization and mercury control, and gasification of fuels such as coal and petroleum coke. In addition to the Coal Combustion Residuals (CCR) rule that established nationally applicable minimum criteria for the safe disposal of CCR (coal ash) in landfills and surface impoundments, steam electric power plants are also faced with new National Pollutant Discharge Elimination System (NPDES) limits that may be difficult to consistently achieve, especially for parameters that reflect natural geological and hydrogeological conditions.

In some cases, water from CCR surface impoundments (ash basins) has seeped into groundwater, which then migrates to downgradient discharge points, where seeps must be permitted under NPDES. While migrating through the subsurface, the wastewater interacts with soil, rock, biota, and stormwater in ways that cannot be controlled by the permit holder. Power companies may opt to pursue a consent order for relaxation of effluent limits associated with ash basin seeps permitted under NPDES. Consent order applications may require documentation that compliance with certain discharge limits may not always be achievable due to naturally occurring conditions (e.g., geochemistry) that are not influenced by the wastestream and is beyond the control of the permittee. Parameters especially subject to excursions due to natural conditions include effluent pH and hardness. These parameters can be influenced by natural geochemical processes, and regional groundwater conditions. This paper provides a description of geological and hydrogeological conditions in North Carolina that can influence key effluent parameters like pH and hardness, and provides a recent example of a consent order application for NPDES variance based on those conditions.

METHODS

Consent Orders

In the state of North Carolina, a "Consent Order" or "Special Order by Consent" is defined as a type of special order where the regulatory agency enters into an agreement with the entity responsible for water or air pollution to achieve some stipulated actions designed to reduce, eliminate, or prevent air or water quality degradation. One of the requirements for submitting a complete application for a special order is a third-party evaluation documenting that the potential non-compliance is not related to improper operation and maintenance of the existing wastewater treatment system (e.g., a CCR surface impoundment or ash basin).
A third-party evaluation was conducted on behalf of an electric power generator request for relaxation of effluent parameters pH and hardness, because these parameters are often influenced by natural conditions.

**North Carolina Physiographic Provinces**

North Carolina is divided into three distinct physiographic provinces: Blue Ridge, Piedmont, and Atlantic Coastal Plain. The Blue Ridge Province is in western North Carolina and includes the city of Asheville. The Blue Ridge Province is characterized by vegetated, mountainous terrain ranging from 1,500 feet above mean sea level at the base of the escarpment to an altitude of over 6,000 feet at the highest peaks.

The Piedmont Province is in central North Carolina and extends from North Carolina’s northern border with Virginia to North Carolina’s southern border with South Carolina. The Piedmont Province is generally characterized by mature, rolling hills underlain by crystalline rock. The cities of Charlotte, Winston Salem, and Raleigh are located within the North Carolina Piedmont Province.

The Coastal Plain Province extends from the Piedmont Province eastward to the Atlantic coast. The North Carolina Piedmont and Coastal Plain Provinces are separated by the geologic fall line where hard, erosion resistant crystalline rock of the Piedmont dips below relatively soft sedimentary rock and depositional materials east of the fall line. The fall line forms an irregular path that runs approximately parallel to the coast from Virginia to South Carolina. Greenville and Fayetteville North Carolina are located in the Coastal Plain Province, east of the fall line.

Following are general descriptions of the geology and hydrology that characterize North Carolina’s Blue Ridge, Piedmont, and Coastal Plain physiographic provinces.

**North Carolina Blue Ridge Geology and Hydrogeology**

The Blue Ridge Province is dominated by the Blue Ridge geologic belt. The Blue Ridge belt is an extensive thrust sheet that is bound by the Piedmont geologic belt on the southeast and the low angle thrust faults that created the Valley and Ridge physiographic province in eastern Tennessee to the northeast. Episodes of folding and faulting occurred in Blue Ridge Province along with several periods of metamorphism with igneous intrusion. Uplift subsequently occurred during the Cenozoic Era and exposed the rocks for subsequent weathering and erosion. Weathering and erosion have resulted in fracturing of the bedrock in the form of stress-relief fractures and expansion of existing fractures.

Groundwater in the Blue Ridge Province is grouped into two hydrogeologic terranes; a gneiss-granite terrane with an interquartile yield from about 8 to 32 gal/min and a schist-sandstone terrane with an interquartile yield from 10 to 61 gal/min. The USGS Provincial Aquifer-System Analysis deferred to isolating hydrogeologic terranes rather
than aquifers and confining units due to complexity of the geology in the Blue Ridge Province\textsuperscript{5}.

Soil/saprolite regolith and the underlying fractured bedrock represent a composite water-table aquifer system\textsuperscript{6}. Two major factors that can influence the behavior of groundwater in the Blue Ridge Province include the thickness (or occurrence) of saprolite/regolith and the nature of underlying bedrock. Thickness of the regolith is directly related to topography, type of parent rock, and geologic history. Topographic highs tend to exhibit thinner soil/saprolite zones while topographic lows exhibit thicker soil/saprolite zones. In general, gneiss and schist have thicker soils and moderate to relatively high fracture densities as opposed to unaltered igneous rocks such as granite\textsuperscript{5}. Schist and gneiss can be susceptible to weathering, thus making efficient sources for transition zone media. Transition zone media can range from pea-sized to gravel-sized fragments of partially weathered rock (PWR) and generally contains a decreasing amount of clay content with depth. Transition zones may facilitate vertical movement of groundwater to underlying fractured rock or serve as a horizon for relatively rapid lateral groundwater movement along the top of unweathered bedrock\textsuperscript{6}.

The behavior of groundwater in the Blue Ridge Province is also influenced by the amount of precipitation, seasonal water table fluxes, and flow boundaries. The province typically receives 4.0 to 4.5 inches of precipitation per month, which serves as the source for groundwater recharge. Natural seasonal variability in the water table is apparent with seasonal highs and lows during the winter and fall months, respectively. Flow boundaries can be marked by topography. Ridges act as a groundwater divide whereas streams serve as boundaries. It is rare for groundwater to pass beneath a perennial stream and travel to another area of discharge\textsuperscript{6}.

\textit{North Carolina Piedmont Geology and Hydrogeology}

The Piedmont Province is several hundred feet higher in North Carolina than in neighboring South Carolina and Virginia due to the Cape Fear Arch, an uplift feature that trends roughly along the Cape Fear River and continues through the Piedmont into the Appalachian Mountains. The resulting geomorphology results in river flow to north or south instead of east\textsuperscript{7}.

The upper portions of rocks in the Piedmont are typically fractured and weathered and are covered with unconsolidated material known as regolith. The regolith includes residual soil and saprolite zones and, where present, alluvium. Saprolite is formed by in-situ chemical and physical weathering of bedrock. It is typically composed of clay and coarser granular material and reflects the texture and structure of the parent rock. The degree of weathering decreases with depth and partially weathered rock is commonly present near the top of the bedrock surface. The transition zone from the regolith and the partially weathered rock and competent bedrock is often gradational and difficult to differentiate.
In general, groundwater flow systems in the Piedmont Province are comprised of two interconnected layers, or mediums: (1) residual soil/saprolite and weathered fractured rock (regolith and partially weathered rock) overlying (2) fractured crystalline bedrock\textsuperscript{8,9}. The regolith layer is a thoroughly weathered and structureless residual soil that grades into saprolite. Saprolite is underlain by partially weathered/fractured bedrock that extends downward until competent bedrock is encountered. This mantle of residual soil, saprolite, and weathered/fractured rock (transition zone) is a hydrogeologic unit that serves as the principal storage reservoir and provides a granular medium through which the recharge and discharge of water from the underlying fractured rock occurs\textsuperscript{10}. A transition zone at the base of the regolith is present in many areas of the Piedmont. The zone consists of partially weathered/fractured bedrock and lesser amounts of saprolite that grades into competent bedrock and has been described as “being the most permeable part of the system, even slightly more permeable than the soil zone”\textsuperscript{9}. The zone thins and thickens within short distances and its boundaries may be difficult to distinguish. Where present, the zone may serve as a conduit of rapid flow and transport of groundwater\textsuperscript{9}.

Fracture apertures, connectivity, etc. control groundwater movement and storage capacity within the fractured crystalline bedrock. The bedrock is broken and displaced by faults and shear zones, some of which extend for miles. Joints, rock breaks without accompanying displacement, are common and the joints typically occur in groups oriented in preferred directions. Weathering and erosion can result in stress-relief fractures. In addition, weathering and erosion can expand existing fractures. It is through these fractures that groundwater flows. Planes and bedding of metamorphic foliation, as well as breaks and folds in these rocks, are areas of higher permeability\textsuperscript{5}.

Groundwater recharge in the Piedmont Province is derived entirely from infiltration of local precipitation. Groundwater recharge occurs in areas of higher topography (i.e., hilltops) whereas groundwater discharge occurs in lowland areas bordering surface waterbodies, wetlands, and floodplains\textsuperscript{6}. Average annual precipitation in the Piedmont ranges from 40 to 50 inches with a minimum of about 30 inches and a maximum of about 80 inches. Mean annual recharge in the Piedmont Province ranges from about four to ten inches per year\textsuperscript{5}.

\textit{North Carolina Coastal Plain Geology and Hydrogeology}

The Coastal Plain Province is comprised of stratified marine and non-marine sedimentary rocks deposited on a crystalline basement. Coastal Plain aquifers are comprised of permeable sands, gravels, and limestone separated by confining units of laterally extensive silt and clay rich layers.

Where present, the Lower Cape Fear and Upper Cape Fear aquifers are the lower-most (deepest) marine sediment. The Upper Cape Fear aquifer is overlain by the Black Creek Aquifer and the Black Creek Aquifer is overlain by the Pee Dee Aquifer\textsuperscript{11}. Shallow confined and unconfined aquifers of local origin and extent overlay the Pee Dee
Aquifer. Surficial (unconfined) aquifers receive recharge from precipitation in upland areas of the Coastal Plain. This recharge water is stored in the surficial aquifer as the groundwater migrates toward local discharge points (lakes, rivers, streams, etc.). A portion of the groundwater in surficial aquifers migrates vertically to recharge semi-confined aquifers. On average, only a fraction of the surficial aquifer recharge reaches the semi-confined aquifers due to the substantial amount of time it takes for groundwater to reach these units. Potable water for municipalities is generally extracted from the deeper confined aquifers.

**Natural pH and Hardness in Groundwater**

We have monitored groundwater at several CCR sites represented by the geological and hydrogeological conditions described above. pH and hardness in background monitoring wells indicative of natural conditions are listed below.

**pH:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Blue Ridge</th>
<th>Piedmont</th>
<th>Coastal Plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg pH (s.u.)</td>
<td>5.5</td>
<td>6.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Min pH (s.u.)</td>
<td>4.2</td>
<td>4.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Max pH (s.u.)</td>
<td>8.9</td>
<td>11.8</td>
<td>10.0</td>
</tr>
<tr>
<td>Background Groundwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samples</td>
<td>122</td>
<td>388</td>
<td>331</td>
</tr>
<tr>
<td>Background Groundwater</td>
<td>8</td>
<td>37</td>
<td>11</td>
</tr>
<tr>
<td>Wells</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

NPDES permitted discharge limit for pH was 6.0 to 9.0 s.u. before limit was modified by consent order.

**Hardness:**

<table>
<thead>
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<th>Parameter</th>
<th>Blue Ridge</th>
<th>Piedmont</th>
<th>Coastal Plain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg Hardness (mg/L)</td>
<td>16</td>
<td>175</td>
<td>42</td>
</tr>
<tr>
<td>Min Hardness (mg/L)</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Max Hardness (mg/L)</td>
<td>72</td>
<td>706</td>
<td>212</td>
</tr>
<tr>
<td>Background Groundwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samples</td>
<td>113</td>
<td>374</td>
<td>315</td>
</tr>
<tr>
<td>Background Groundwater</td>
<td>8</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>Wells</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

NPDES permitted discharge limit for hardness was 100 mg/L before limit was modified by consent order.

Groundwater hardness was calculated using the concentration of total calcium and total magnesium measured in groundwater per the following equation:
Total Hardness (mg/L as CaCO$_3$) =
Calcium Hardness (mg/L as CaCO$_3$) + Magnesium Hardness (mg/L as CaCO$_3$) =
2.497 x Calcium Conc. (mg/L as Ca$^{2+}$) + 4.116 x Magnesium Conc. (mg/L as Mg$^{2+}$)
(Source: http://www.water.ncsu.edu/watershedss/info/hardness.html, accessed on July
12, 2016)

These types of data and the geological and hydrogeological information above Illustrate
that site groundwater may not satisfy certain NPDES permit discharge limits and could
be the primary reason why pH or hardness concentrations in permitted seeps do not
always satisfy limits imposed on these discharge parameters. In the following
example, a third-party review of primary and secondary literature and site-specific
background groundwater data were used to document pH levels and hardness
concentrations in site groundwater that has not been influenced by ash basin
wastewater. The third-party submitted this documentation with the consent order request to the state agency.

RESULTS

pH

Natural waters contain various salts, acids, and bases that contribute H$^+$ and OH$^-$ ions in
varying ways, depending on specific conditions. pH is governed to a large extent by the
interaction of H$^+$ ions arising from the dissociation of carbonic acid (H$_2$CO$_3$) and from
OH$^-$ ions produced during hydrolysis of bicarbonate. The pH of natural waters can
range between the extremes of $< 2$ to 12.

A compilation of groundwater-quality data collected as part of a United States
Geological Survey (USGS) study in cooperation with North Carolina Department of
Environmental Quality (NCDEQ) provides a basis for understanding the ambient
geochemistry related to the geological setting of the Piedmont and Blue Ridge
Physiographic Provinces of North Carolina$^{13}$. All geozones in the study, including those
that comprise the area geology, had multiple wells with groundwater sample results
outside the pH range of 6.5 to 8.5, most of which were less than 6.5. This illustrates that
natural groundwater can be characteristically acidic and that pH values of 6.0 or less
are not uncommon.

Chemical adjustment of pH is usually required at the facility because ponded water in
the ash basins can exhibit pH above 9.0. Alkaline pH’s is not uncommon for ponded
waters in the region because waterborne algae consume carbon dioxide during
photosynthesis. The removal of carbon dioxide from ponded water can increase the pH
above 10 s.u. It stands to reason that pH excursions below seep discharge limits for pH
cannot be attributed to ponded ash basin wastewater which is characteristically alkaline.
Hardness

Water hardness is frequently used as an assessment of the quality of potable water. The hardness of a water is governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate and with sulfate, chloride, and other anions of mineral acids. Naturally-occurring calcium and magnesium can dissolve in groundwater as it moves through soil and rock, thereby increasing groundwater hardness under the appropriate conditions.

The basic ionic compositions of bedrock groundwater in the region are generally classified as a calcium-sodium/bicarbonate or calcium-magnesium/bicarbonate water type. Review of background monitoring wells at the facility indicated that calcium and magnesium ion concentrations ranged up to approximately 83 mg/L and 3 mg/L, respectively. Thus, total hardness of background groundwater conditions at the facility (unaffected by the ash basins) could exceed the effluent limitation of 100 mg/L (e.g., 185-233 mg/L as CaCO₃). Total hardness of the groundwater seeps in excess of 100 mg/L could be attributed to natural groundwater conditions.

Geology of the area is comprised of mafic gneisses, amphibolites, and metagabbros among other metamorphic rock types. Mafic (dark colored) rock, especially gabbro, tends to be low in silica content relative to most rocks. The low silica content limits or, prevents (in the case of gabbro) the formation of quartz (SiO₂). Silicate minerals would include olivine, pyroxene, amphibole, and feldspars. Each of these minerals can incorporate substantial calcium and magnesium into the crystal structure. In addition, the transition zone between overlying saprolite and bedrock beneath is likely the most transmissive groundwater flow unit in the subsurface. The combination of relatively high groundwater flow rates and relatively fresh rock in the transition zone yields a chemically active environment prone to liberation of calcium and magnesium to solution as the primary minerals are altered to oxides and clay minerals. This hydrogeologic setting, with or without anthropogenic features like ash basins, is well suited for generation of groundwater with elevated hardness during the natural chemical weathering processes that convert rock to soil. Finally, the highly transmissive transition zone is the most likely source of surface seeps. All these factors combine to produce conditions conducive to elevated hardness in groundwater.

CONCLUSIONS

Coal-fired power generating facilities may anticipate future violations of limits on pH and hardness in permitted seep discharges from ash basin. The outfalls are designated in the NPDES permit as discharges of wastewater that has migrated from the impoundment (ash basin) via infiltration into groundwater that discharges via aboveground seeps. In the example given above, natural geochemical process and typical conditions of the region indicate that such permit violations may occur irrespective of operation and maintenance of the wastewater treatment system (ash basin). Groundwater pH values below 6.0 are normal for the region, and total hardness
of groundwater in excess of 100 mg/L can occur based on review of the facility’s background monitoring well data. There is no evidence that possible future permit violations of these parameters would be linked to operation and maintenance of the wastewater treatment system (ash basin). Natural geological and hydrogeological conditions should be considered when imposing effluent limitations on permitted ash basin seeps influenced by subsurface features.

REFERENCES


