Potential Groundwater Impacts of the Proposed Carolinas Cement Company Facility Near Castle Hayne, North Carolina

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March 20, 2014

EXECUTIVE SUMMARY

GeoResources, Inc. was contracted by North Carolina Coastal Federation to consider potential groundwater impacts of the proposed Carolinas Cement Company (CCC) mining and cement manufacturing facility near Castle Hayne, North Carolina. Hydrogeological conditions and opinions regarding potential groundwater impacts are described as follows, and opinions are those of Curtis A. Consolvo, GeoResources, Inc.

The site for the proposed CCC facility is the former Ideal Cement Company site on the south bank of the Northeast Cape Fear River in northern New Hanover County. Open-pit mining to a depth of approximately 80 feet is proposed, requiring estimated groundwater withdrawal rates of 10 to 16 million gallons per day.

Based on review of local and regional hydrogeology and proposed groundwater withdrawals for open-pit mining, the potential effects of the proposed facility on groundwater resources are summarized as follows:

Drawdown impacts on local wells and regional groundwater supplies

- Mine dewatering to the proposed depth (approximately 80 feet) will impact water levels/potentiometric surfaces of the surficial, Castle Hayne and Peedee aquifers. These impacts have the potential to adversely affect local wells and regional groundwater supplies. The Peedee aquifer is the principal source of groundwater supply for large public and industrial supply wells, and a broad, far-reaching cone of depression should be anticipated based on hydraulic characteristics for the aquifer (generally highly transmissive and semi-confined to confined). Drawdown impacts to the overlying Castle Hayne aquifer will be more localized, perhaps impacting local wells and potentially reducing recharge rates to the Peedee aquifer for the affected area.

- Drawdown impacts will be difficult to reliably estimate or model for both Castle Hayne and Peedee aquifers because of local and regional complexities in hydrogeologic framework conditions and highly variable hydraulic properties. Efforts to do this should include extensive test well drilling/logging and test pumping to better define the hydrogeologic framework complexities between the site and surrounding region and to evaluate drawdown trends across framework transitions and between Castle Hayne and

Peedee aquifers, with varying degrees of hydraulic separation being likely in the vicinity of the proposed site. The extent to which the Northeast Cape Fear River will act as a recharge boundary will need to be evaluated, and any plans for discharging to artificial recharge features, such as mined-out pits, will need to be considered.

- The proposed site for the CCC facility is located approximately 6 miles north of the Cape Fear Public Utility Authority's (CFPUA's) nano-membrane water treatment plant (Nano Plant) and associated well field, which began operation in 2009. The extent that drawdown impacts between the well field and the proposed CCC site might coalesce will be difficult to estimate because of hydrogeologic framework transitions and widely varying hydraulic properties. The well field utilizes both Castle Hayne and Peedee aquifers, and for Peedee wells, the potential for regional water level declines has been a concern for the CFPUA and other water supply systems in the region. Additional withdrawals from the Peedee aquifer at the CCC site would further increase the potential for regional declines.

- Extensive measures have been taken by the CFPUA in planning and developing the Nano Plant well field to ensure the sustainability of Castle Hayne and Peedee aquifer water supplies. Wells are aquifer-specific, enabling control of withdrawal rates by aquifer, and pumping schedules have been designed to minimize drawdown impacts. Controls such as these do not seem feasible for mine dewatering in the event that regional levels are found to be adversely affected.

Contaminant migration

- The proposed CCC facility is located adjacent to the site of an abandoned quarry and former processing facility for chromite ore, where pump-and-treat remediation of chromium-contaminated groundwater has been on-going since 1975. Long-term monitoring indicates that extraction wells have been effective in establishing capture zones and reducing contaminant concentrations over time. Contaminant releases have also occurred at the site of the proposed CCC facility, with remediation efforts to remove petroleum-impacted soils and groundwater. Dewatering at the proposed CCC site and resulting impacts to groundwater elevations may substantially alter contaminated groundwater flow.

- Environmental evaluations at the adjacent site have characterized an aquitard (low-permeability bed) occurring within Castle Hayne limestone that separates "upper" and "lower" aquifers, with higher contaminant concentrations in the upper aquifer. Drawdown impacts from the proposed CCC site may be more pronounced in the lower aquifer (due to higher transmissivity and lower storativity), potentially increasing the hydraulic gradient across the aquitard and the likelihood of further contaminating the lower aquifer.

Sinkhole development

- Sinkholes have resulted from past mine dewatering at the proposed CCC site, occurring at distances up to 4,600 feet from mine walls. Deeper and more expansive mining is proposed by CCC. Additional sinkhole development should be anticipated and may be more pronounced and/or farther-reaching.

Surface water features and wetlands

- Impact to water levels in the Northeast Cape Fear River will likely be negligible. Hydraulic gradients underlying some portion of the River will be affected, but associated reductions in groundwater discharge to the River in the vicinity of the proposed site will likely be far outweighed by the overall scale of groundwater contribution to baseflow and also surface water flow/other factors affecting river levels.

- Water levels in smaller drainage features and/or wetlands may be affected by reductions or reversals of underlying hydraulic gradients, with groundwater contribution being reduced or eliminated. Features more isolated or elevated from larger surface water features/the Northeast Cape Fear River will likely be more vulnerable to impacts.

- The water quality of groundwater pumped from the mine will reflect characteristics typical for Castle Hayne and Peedee aquifers, with higher pH and hardness than typically occurs in surface waters, in addition to other differences that may occur locally. As such, there is a potential for mine dewatering discharge to impact surface water quality.

Saltwater encroachment

- Saltwater occurrences in Castle Hayne and Peedee aquifers are far-removed from the proposed CCC site, both by distance and intervening wells/well fields. The proposed facility could have an impact to the extent that additional withdrawals from the Peedee aquifer may contribute regionally to cumulative drawdown effects, and water systems affected could include those more vulnerable to saltwater encroachment.

- Saltwater upconing impacts are not likely to occur beneath the proposed site. A deep saline aquifer is present, but it is overlain by a thick confining unit.

Of the potential impacts listed, the potential for affecting Peedee aquifer water levels (potentiometric surface) on a regional scale should be a primary concern. The Peedee aquifer is a principal source of water supply, and the potential for declining water level trends is already a concern for water systems in the region. Reliable estimates or modeling to predict impacts will be difficult due to hydrogeologic complexities and framework transitions and the extent to which the Northeast Cape Fear River may act as a recharge boundary. Preventative or mitigative measures seem feasible for some potential impacts, such as reconfiguring contaminant extraction wells or filling/repairing sinkhole damages; however, reversing drawdown impacts to Peedee aquifer levels will require reductions in withdrawal rates, and this does not seem a viable option for purposes of maintaining pumping levels for open-pit mining.

BACKGROUND

GeoResources, Inc. was contracted by North Carolina Coastal Federation to review hydrogeological information and consider potential groundwater impacts of the proposed Carolinas Cement Company (CCC) mining and cement manufacturing facility near Castle Hayne, North Carolina. Pertinent hydrogeological information and professional opinions regarding potential impacts follow, and opinions are those of Curtis A. Consolvo, L.G., GeoResources, Inc.

PROPOSED SITE AND FACILITY

The intended location for the CCC facility is the former Ideal Cement Company site on the south bank of the Northeast Cape Fear River in northern New Hanover County. Open-pit mining to a depth of about 80 feet is proposed (Kimley-Horn, 2006) on a 1,868-acre site (U.S. Army Corps, 2008). Pumping rates necessary for dewatering the mine have been estimated at 10 to 16 million gallons per day (mgd), based on mentions by CCC representatives at public meetings, such as the public scoping meeting held July 1, 2008 by the U.S. Army Corps of Engineers (described to GeoResources, Inc. by the North Carolina Coastal Federation).

HYDROGEOLOGIC SETTING

The site for the proposed CCC facility is located in a region underlain by sediments and sedimentary rock of formations listed as follows, in descending order: undifferentiated surficial deposits, Castle Hayne limestone, the Peedee formation, and the Black Creek formation (Bain, 1970). The associated freshwater-bearing aquifers are the surficial, the Castle Hayne, and the upper Peedee aquifers (Lautier, 1998). Small yields are available for small irrigation and domestic supplies from the surficial aquifer throughout New Hanover County (Bain, 1970). The confining unit between the surficial and Castle Hayne aquifers is discontinuous in New Hanover County (Lautier, 1998). The Castle Hayne aquifer is generally productive, and yields of individual wells in the county depend largely upon the degree to which the porosity and permeability have been increased by solution (Bain, 1970). Distribution and thicknesses of the Castle Hayne are irregular as a result of erosion and solution of the upper surface and its deposition on an eroded surface of the Peedee (Bain, 1970). The uppermost sandstone in the Peedee formation is the principle fresh-water aquifer in New Hanover County (Bain, 1970).

The upper Peedee aquifer is underlain by a thick confining unit of silt and clay, separating the upper Peedee from a deep, saline, Peedee aquifer (Bain, 1970). The saline aquifer occurs at an approximate depth of 270 feet at the proposed CCC site (estimated from map by Bain, 1970 and an assumed land surface elevation of 25 feet). Mining depths of approximately 80 feet have been proposed for the CCC facility (Kimley-Horn, 2006). These depths would expose surficial, Castle Hayne, and upper Peedee formations, based on formation depths interpreted from a composite section by Harris and others (1986) of quarry walls at the Ideal Cement quarry (located at the same site). The Castle Hayne aquifer varies from unconfined to semi-confined conditions throughout the county. Mapping by Bain (1970) indicates that clay generally overlies

Castle Hayne limestone to the south/southeast of the proposed site versus sand to the west/northwest (the proposed site is located approximately where Bain places a line delineating regional differences). The Castle Hayne aquifer is separated from the Peedee aquifer by a clay layer in most areas of New Hanover County (LeGrand, 1982). The proposed site is located at the approximate north/northwestern limit of a large region where the Peedee is overlain by clay, which increases in thickness to the south (based on mapping by Bain, 1970). The variability in degrees of confinement for both Castle Hayne and Peedee aquifers is exemplified by the ranges of storage coefficient estimated by Lautier (1998) in New Hanover and Brunswick counties: .00006 to .0097 for the Castle Hayne aquifer and .00002 to .1 for the Peedee aquifer.

Transmissivity values for northern New Hanover County have recently been reported by McSwain and Nagy (2011), who report values on the basis of falling within ranges of: less than 2,500 $feet^2$/day, 2,500 to 4,999 ft^2/day, 5,000 to 7,499 ft^2/day, 7,500 to 9,999 ft^2/day, and greater than 9,999 ft^2/day. Reported values for the Peedee aquifer vary from less than 2,500 to greater than 9,999 ft^2/day. Castle Hayne aquifer values fall between 2,500 to greater than 9,999 ft^2/day, with most between 5,000 and 7,499 ft^2/day. Many of the reported values, and nearly all Castle Hayne aquifer values, are from the well field associated with the Cape Fear Public Utility Authority's (CFPUA's) nano-membrane water treatment plant (Nano Plant). Peedee aquifer values range as widely within the well field as for the entire study area (northern New Hanover County), with values ranging from less than 2,500 to greater than 9,999 ft^2/day. This reflects the high degree of variability for Peedee aquifer hydraulic properties, supported also by the (afore-mentioned) range of storage coefficient values estimated by Lautier (1998): .00002 to .1. Bain (1970) and also McSwain and Nagy (2011) report transmissivity values for three former Ideal Cement wells (at the proposed CCC site) that were open to both Castle Hayne and Peedee aquifers, with well depths between 160 and 164 feet (all cased to a depth of 23 feet). Bain (1970) lists transmissivities of 10,000 gallons per day per foot (gpd/ft) for two of the wells and 20,000 gpd/ft for the third well (values equivalent to 1,337 and 2,674 $feet^2$/day). No transmissivity values are reported by Bain (1970) or McSwain and Nagy (2011) for the region between the Nano Plant well field and the proposed CCC location.

A composite section for Ideal Cement quarry walls prepared by Harris and others (1986) indicates the base of the Castle Hayne limestone contacting the Peedee formation at a depth of approximately 56 feet. Land surface elevations range from about 20 to 30 feet for upland portions of the site (estimated from U.S.Geological Survey 7.5-minute quadrangle maps: *Mooretown, North Carolina*, 1997 and *Scotts Hill, North Carolina*, 1980). A composite section for the adjacent Martin Marietta Aggregates quarry (Diamond Shamrock site) was prepared by Baum and others (1985). Comparing the two sections from the two adjacent sites suggests similar stratigraphy. At the Diamond Shamrock site, the top of the Peedee formation occurs at a depth of approximately 40 feet, with upland portions of the site ranging in elevation from about 15 to 25 feet (estimated from diagrams by CRA Geological Services, 2010). Based on land surface elevations and reported depths to the Peedee, the top of the Peedee occurs at similar elevations between the two sites, ranging from -15 to -36 feet.

Extensive hydrogeological evaluations have been conducted at the Diamond Shamrock site in association with contaminant incidents. Two distinct aquifers (upper and lower) have been characterized that do not correlate with aquifers recognized regionally. The aquifers are separated by a dense, well-cemented, limestone aquitard, occurring within the Castle Hayne limestone at thickness of 2 to 9 feet across the site (Dames and Moore, 1981). This correlates with a dense, siliceous limestone described by Bain (1970) at the Ideal Cement quarry. Bain (1970) mentions that local well drillers call this "cap rock" and describes Castle Hayne units above and below, explaining that the overlying shell hash unit is mined for the manufacturing of cement at the Ideal Cement Company. The lower aquifer has been characterized at the Diamond Shamrock site as including lower Castle Hayne limestone commingled with upper Peedee sand/sandy limestone (Dames and Moore, 1981 and CRA Geological Services, 2008).

Water levels in upper versus lower aquifer wells at the Diamond Shamrock site indicate a downward hydraulic gradient, with typical water-level depths of about 10 to 15 feet for the upper aquifer versus depths of about 25 to 30 feet for the lower aquifer (outside of areas proximate to active recovery wells). Generally similar levels have been reported by Dames and Moore (1981), Woodward-Clyde (1990), and CRA Geological Services (2010). Dames and Moore (1981) determined a vertical hydraulic conductivity for the aquitard of 3.7×10^{-7} feet/minute.

POTENTIAL IMPACTS

Drawdown impact on local wells and regional groundwater supplies

Mine dewatering to proposed mine depths of approximately 80 feet (Kimley-Horn, 2006) will impact water levels/potentiometric surfaces of the surficial, Castle Hayne and Peedee aquifers. These impacts have the potential to adversely affect local wells and regional groundwater supplies. These are the three freshwater aquifers supplying wells throughout New Hanover County, and the uppermost sandstone in the Peedee formation is the principal fresh-water aquifer in the County (Bain, 1970).

Efforts to predict or model the extent of distance-drawdown impacts will be complicated by three hydrogeologic conditions: 1) local "upper" and "lower" aquifers within the Castle Hayne limestone that do not correlate with regionally recognized aquifers, 2) the location of the proposed site occurring within a transition zone, where both Castle Hayne and Peedee aquifers become more confined and more hydraulically separated to the south, and 3) the likelihood that the Northeast Cape Fear River will act to some extent as a recharge boundary, which could lessen drawdown impacts (especially to the north), though correspondingly higher withdrawal rates could be expected for achieving/maintaining intended mine dewatering levels. In addition, hydraulic properties of the Castle Hayne aquifer and especially the Peedee aquifer are highly variable on a regional basis, further undermining the reliability of distance-drawdown estimates or simulations.

Past dewatering operations at quarries in the vicinity of the proposed CCC site have a history of affecting residential wells in the area. Dewatering of the Castle Hayne Quarry was associated with problems at ten wells, as described in letters between Martin Marietta Aggregates (1979) and the North Carolina Division of Environmental Management (1980). The quarry depth was 35 feet, with a mine area of 1,212 acres (according to listings on the permit application by Superior Stone Co., 1972). Deeper mining (to approximately 80 feet) is proposed for the CCC facility (Kimley-Horn, 2006) on a 1,868-acre site (U.S. Army Corps, 2008). The deeper pumping levels and the larger area may cause more extensive well impacts. Pumps may need to be lowered and/or wells replaced.

More regionally, wells may be impacted in terms of yield potential and long-term sustainability. Large wells requiring substantial drawdown for high production rates are especially at risk. Additional wells or alternative sources of supply may be needed to maintain production rates. A map by Lautier (1998) is helpful for identifying large wells in the region, indicating locations where more than 10,000 gallons was pumped from a well (or multiple wells at one site) in any single day for the period from June, 1993 through September, 1994. The map indicates four sites within a distance of 6 miles of the proposed CCC site. The map does not include well sites in Pender County (to the north and east of the proposed site), and it predates the CFPUA Nano Plant well field, located 6 miles to the south.

Groundwater withdrawals at the proposed CCC site will result in cones of depression developing in the local “upper” aquifer (unconfined surficial sands/upper Castle Hayne units) and “lower” aquifer (lower Castle Hayne unit commingled with upper Peedee sand/sandstone). A broader cone of depression can be expected for the lower aquifer based on higher transmissivity and lower storativity (as characterized by Dames and Moore, 1981). The lateral extent of the aquitard separating upper and lower aquifers is unknown. Drawdowns imposed upon these local, hydrogeologic framework conditions will translate to drawdown impacts in the regionally recognized aquifers (surficial, Castle Hayne, and Peedee), and predicting effects across framework transitions will be challenging.

Based on maps by Bain (1970), clay becomes increasingly present at the top of the Castle Hayne to the south and east of the proposed CCC site. Also to the south, a clay confining unit separates Castle Hayne and Peedee aquifers. The site location is approximately at the thin, northern limit of the clay, which thickens to the south. The CFPUA’s Nano Plant well field is located approximately 6 miles south of the proposed CCC site, where the Castle Hayne and Peedee are two distinct aquifers (W.K. Dickson, 2010). Estimating the extent to which combined drawdown impacts will develop between the proposed CCC site and the Nano Plant well field will be complicated by these regional differences in aquifer characteristics.

Planning phases for the Nano Plant well field included regional modeling of drawdown impacts (CFPUA, 2011). Modeling results suggest drawdown impacts for the Peedee aquifer will reach the location of the proposed CCC site. If results are close to being representative of actual conditions, then relatively minor drawdown impact at the proposed CCC would cause cones of depression to coalesce. Simulations of well field drawdown by BPA Environmental and Engineering (1995) for withdrawal rates of 5 mgd from Peedee aquifer wells indicated about 3 feet of drawdown at the proposed CCC location. Edwin Andrews and Assoc. (1996) simulated drawdowns for withdrawals from both Castle Hayne and Peedee aquifers wells at rates of 8.4 mgd and 10.4 mgd, respectively (with modeled well locations extending somewhat north of subsequent as-built wells) and concluded that withdrawals of 10.4 mgd from the Peedee aquifer plus 8.6 mgd from the Castle Hayne aquifer would be reasonable. The modeling results suggest about 5 feet of drawdown in each aquifer at the location of the proposed CCC facility.

Conceptual designs for the Nano Plant well field initially targeted the Peedee aquifer, based on better water quality and the Castle Hayne aquifer being more susceptible to surface pollution and sinkhole development (CFPUA, 2011). Public comments were received as part of a subsequent Environmental Assessment, and comments included much concern regarding impacts to Peedee aquifer levels and the sustainability of the aquifer as a regional source of water supply (Arcadis and W.K. Dickson, 2003).

Well field designs that followed were based on utilization of both Castle Hayne and Peedee aquifers via separate wells (at paired locations) to supply the 6-mgd Nano Plant (CFPUA, 2011). The CFPUA began operating the new well field in 2009, which includes 10 Castle Hayne and 15 Peedee wells (CFPUA, 2011). The Castle Hayne wells have been associated with the risk of sinkhole development and also affecting nearby pond levels. Water level impacts to ponds at the nearby Country Haven Development have recently been reported, with recommendations for decreasing production from Castle Hayne wells, especially those nearest the ponds (GMA, 2013). Recent statements from a CFPUA official have indicated a long-term goal of less dependence on the Castle Hayne aquifer and increased utilization of the Peedee aquifer (Port City Daily, 2013). Further reliance upon the Peedee aquifer by the CFPUA reinforces the need for concern that mine dewatering at the proposed CCC site may increase the potential for regional water-level declines.

The planning and development process for the Nano Plant well field included many measures to help ensure long-term sustainability, including: plans for alternative supplies (via system interconnections and development of aquifer storage and recovery), registration requirements for large (private) wells, and mitigation protocols to address potential impacts, such as sinkholes and private wells affected (CFPUA, 2011). Also, operational designs utilize pumping schedules coordinated between individual wells to meet system needs while minimizing drawdown impacts, as described in a Groundwater Protection Plan by WK Dickson (2010). The Plan recommends tracking water-level trends via perimeter monitoring wells that "*would be used to detect possible changes in the groundwater supply from the proposed Titan Cement Plant to the north, and salt water intrusion from the east*".

Monitoring water-level trends will be of critical importance should CCC plans go forward. Efforts to reliably predict or model drawdown impacts for the proposed CCC facility and the extent to which cones of depression might be expected to coalesce between the CCC facility and the Nano Plant well field will be challenged by hydrogeologic complexities at the proposed CCC site and transitions that occur over the 6 miles separating the two sites. Even with extensive drilling/logging and aquifer testing in the region between the two sites to better define framework conditions and how effectively drawdown impacts might extend across these, much uncertainty will remain, and real impacts should be monitored as they develop. If/when trends of concern become evident, there will be the means for making adjustments/responding at the Nano Plant well field, while at the CCC facility, there will not be similar means for controlling withdrawal rates by aquifer or reducing rates below those found necessary to maintain open-pit mining operations.

Contaminant migration

The proposed CCC site is located adjacent to the site of an abandoned quarry and former processing facility for (imported) chromite ore (NUS Corp., 1989). The site is referred to herein as Diamond Shamrock (also known as Occidental Chemical). Chromic acid and sodium bichromate were the principal products (Dames and Moore, 1981). From 1971 to 1975, an estimated 1,072 tons of chromium were released via leaking underground storage tanks and faulty drainage trenches and piping (EPA, 1995). Remediation of dissolved chromium in groundwater was initiated in 1975 (CRA Geological Services, 2010).

Groundwater monitoring and remediation activities have continued at least until 2010 (most-recent report reviewed), when a maximum detected chromium concentration of 9,700 milligrams per liter (mg/l) was reported for the upper aquifer (see previous Hydrogeologic Setting section for descriptions of "upper" and "lower" aquifers). This includes monitoring and recovery wells. Concentrations for most wells ranged from a few mg/l to several hundred mg/l. A maximum concentration of 2.0 mg/l was reported for lower aquifer monitoring/recovery wells (CRA Geological Services, 2010).

Over a 6-month reporting period in 2010, approximately 3,200 pounds of chromium were removed from the upper aquifer and 40 pounds from the lower, with similar amounts removed over the previous 6 months (CRA Geological Services, 2010). Pumping rates for upper aquifer extraction wells were typically less than one gallon per minute (gpm), with higher rates (about 2.5 to 5 gpm) reported for several wells (CRA Geological Services, 2010). Pumping rates reported for lower aquifer extraction wells were much higher, generally ranging from about 5 to 15 gpm. Water-level maps indicate one cone of depression has been established in the upper aquifer and two in the lower aquifer. CRA Geological Services (2010) also reported that for well locations outside capture zones, dissolved chromium was detected in one (shallow aquifer) monitoring well, at a concentration of 0.77 mg/l. A 64-gpm overall groundwater extraction rate was reported, with the groundwater treated on-site and discharged via NPDES permit.

Water levels reported by CRA Geological Services (2010) indicate that water table elevations for the upper aquifer are generally 15 to 20 feet and are near zero in lowest areas of the cone of depression for contaminant capture. Potentiometric surface elevations for the lower aquifer are generally less than 5 feet and about -30 feet near lowest areas of one cone of depression and about -15 feet near lowest areas of the other cone of depression.

Based on comparison of chromium concentration maps by CRA Geological Services (2010) with locations of existing quarries at the proposed CCC site, distances to contaminant plumes are approximately 4,700 feet for the upper aquifer and 4,000 feet for the lower aquifer (quarry locations interpreted from U.S. Geological Survey, 7.5-minute quadrangle maps: *Scotts Hill, North Carolina*, 1997 and *Mooretown, North Carolina*, 1980).

The depth to the bottom of a water-filled quarry at the Diamond Shamrock site is about 10 to 20 feet below the aquitard separating upper and lower aquifers (estimated from cross-section diagram by CRA Geological Services, 2010). Water filling the quarry is indicated at an elevation of zero, or about 10 to 15 feet above the aquitard. Capture zone maps by CRA

Geological Services (2010) for upper and lower aquifers suggest that contaminants are not reaching the quarry.

Contaminant releases have also occurred at the site of the proposed CCC facility. An unknown amount of petroleum was released from underground storage tanks that were removed in 1989 (Arcadis, 2009). Remediation efforts have included removal/treatment of impacted soils and aggressive fluid vapor recovery to remove measurable free product detected in monitoring wells, and starting in 2007, petroleum absorbent socks were utilized in monitoring wells for continued removal of petroleum products (Arcadis, 2009).

The extent to which dewatering at the proposed CCC facility would affect contaminants from on-site sources or contaminant plumes and capture zones at the adjacent Diamond Shamrock site or beyond is unknown. For the Diamond Shamrock site, Woodward-Clyde (1990) reported that "*groundwater flow in the lower aquifer is towards the east-southeast away from the river and is largely controlled by quarry operations located approximately one mile east of the site*". The report summarizes that "*groundwater gradients have been locally reversed toward the recovery wells*". Groundwater withdrawals at the proposed CCC site can be expected to impact water levels and hydraulic gradients at the adjacent Diamond Shamrock, potentially lowering depths to contaminated groundwater and altering flow rates/directions.

A possible consequence of impacting hydraulic gradients is an increased rate of leakance/downward migration of contaminated groundwater across the aquitard that occurs within the Castle Hayne limestone at the Diamond Shamrock site. The aquitard separates upper and lower aquifers, with higher contaminant concentrations in the upper aquifer (Dames and Moore, 1981 and CRA Geological Services, 2010). The lower aquifer has been characterized as having substantially higher transmissivity and lower storage coefficient (Dames & Moore, 1981). Distance-drawdown impacts from the CCC site may be more pronounced in the lower aquifer, potentially increasing the (downward) hydraulic gradient and leakance rates across the aquitard.

Sinkhole development

New sinkholes should be anticipated as a result of dewatering at the CCC site. The extent of sinkhole development will be difficult to predict. Past dewatering operations at the nearby Castle Hayne Quarry has been associated with the development of sinkholes. Martin Marietta prepared a map of sinkholes in the vicinity of the Castle Hayne Quarry, indicating depressions of varying shapes and sizes (one appears to be approximately 70 feet long by 30 feet wide) at distances up to 4,600 feet from the quarry perimeter (Martin Marietta, 1981). "Newly mapped small sink holes" are also shown, and these appear to occur in two clusters at distances of approximately 950 and 1,900 feet from the quarry. The map was submitted to the North Carolina Division of Natural Resources and Community Development under a cover letter that describes plans to record any new depressions and check for additional movement in existing sinks (Martin Marietta, 1981).

The floor elevation for the Castle Hayne Quarry is described in the letter as approximately 37 feet below mean sea level (Martin Marietta, 1981). For comparison, the floor elevation for open-pit mining at the proposed CCC facility would be approximately 55 feet below sea level, based upon an intended depth of approximately 80 feet (Kimley-Horn, 2006) and an estimated land surface elevation of 25 feet (estimated for upland portions of the site from U.S.Geological Survey 7.5-minute quadrangle maps: *Mooretown, North Carolina*, 1997 and *Scotts Hill, North Carolina*, 1980). Also, the proposed 1,868-acre site for the CCC facility (U.S. Army Corps, 2008) is larger than the Castle Hayne Quarry, which has a 1,212-acre mine area listed on the permit application (Superior Stone Co., 1972). A deeper dewatering level and larger mining area suggest that sinkhole development may be more pronounced and/or farther-reaching for the proposed CCC facility.

Heath (1997) describes the process of sinkholes developing where Castle Hayne limestone is directly overlain by permeable sand layers in overlying surficial deposits as follows: "*Water percolating downward through the sand layers retains most of the carbon dioxide it dissolved when passing through the soil zone and thus retains its capacity to dissolve the shells and limestone in the Castle Hayne. This results in the formation of solution openings which, when large enough or where affected by ground-water withdrawals, result in collapse of the overlying deposits and the formation of sinkholes.*"

As part of groundwater evaluations for planning phases of the CFPUA Nano Plant well field, one of the conclusions by Edwin Andrews and Assoc. (1996) was that sinkholes would not develop with the initial Peedee well field, but that Castle Hayne aquifer pumping will result in "*sinkhole development similar to that found in the Castle Hayne area due to quarry dewatering*." The CFPUA recognized this in establishing protocols for responding to sinkhole development in the vicinity of the well field (CFPUA, 2011). Similarly, sinkholes should be anticipated in the vicinity of the CCC site.

Surface water features and wetlands

Mine dewatering at the proposed CCC facility will reduce the hydraulic gradient supporting groundwater contribution to surface water features. The impact to Northeast Cape Fear River levels will likely be negligible, considering the overall scale of groundwater contribution to baseflow and the scale of surface water flow/other factors affecting river levels. Greater impacts can be expected for smaller drainage features, where larger proportions of the overall groundwater contribution are reduced or eliminated. Water levels in wetlands may be lowered as a result of reducing or reversing hydraulic gradients that support groundwater contribution to wetland areas and to drainage features flowing to wetlands. Surface water features and wetlands that are more isolated or elevated from open surface water flow or the Northeast Cape Fear River will likely be more vulnerable to impacts.

The water quality of surface water features receiving discharge from mine dewatering may be affected, as water quality for the Castle Hayne and Peedee aquifers is typically higher in pH and hardness versus surface water, in addition to other water quality differences that may occur locally. As such, there will be potential for impacting surface water quality via discharge from the mine.

Saltwater encroachment

Saltwater occurrences in Castle Hayne and Peedee aquifers are far-removed from the proposed CCC site by distance and intervening wells/well fields. The proposed facility could impact saltwater encroachment to the extent that additional withdrawals from the Peedee aquifer may contribute regionally to cumulative drawdown impacts and to impacts associated with wells/well fields more vulnerable to saltwater encroachment. The extent to which drawdown impacts could affect regional trends or coalesce with drawdown associated with distant pumping centers will be difficult to predict (for reasons described earlier this section, under *Drawdown impacts on local wells and regional groundwater supplies*).

There is little potential for saltwater upconing below the proposed site, based on hydrogeologic framework conditions. A thick, silt and clay confining unit occurs between the uppermost Peedee aquifer and a deeper (Peedee) saline aquifer (Bain, 1970). The depth to the saline aquifer is about 270 feet, based on a map by Bain (1970) and an assumed land surface elevation of 25 feet for the proposed CCC site.

CONCLUSIONS

Complexities in the hydrogeologic setting for the proposed site will make it difficult to reliably estimate or model groundwater impacts. Regionally, hydraulic properties for the Castle Hayne and Peedee aquifers are highly variable and the degree of hydraulic separation between these aquifers increases to the south/southeast of the site, as does the presence of clay overlying the Castle Hayne. Hydrogeologic complexities at the proposed site include an aquitard occurring within the Castle Hayne limestone and the potential for recharge boundary effects from the Northeast Cape Fear River.

Water-level impacts for the Castle Hayne aquifer will likely be more localized versus a broader cone of depression developing for the Peedee aquifer. The CFPUA Nano Plant well field is located six miles south of the proposed site, and the potential for combined drawdown impacts (coalescing cones of depression) for the Peedee aquifer should be a primary concern. For the Castle Hayne aquifer, drawdown effects may impact local wells and also reduce recharge rates to the underlying Peedee aquifer for the affected area.

Efforts to reliably estimate or model drawdown impacts should include extensive test well drilling/logging to better define the hydrogeologic framework transitions. Pumping tests should be utilized to evaluate drawdown trends across these transitions and between Castle Hayne and Peedee aquifers. Even with the best efforts to estimate drawdown impacts, some degree of uncertainty should be expected. If proposed mining goes forward and adverse drawdown trends develop beyond expectations, slowing/reversing trends will require a reduction in withdrawal rates, which does not seem a viable option for purposes of maintaining a dewatered mine. Water-level impacts may be mitigated to some degree by minimizing footprint areas for active mining or selectively avoiding higher-permeability depths/areas of the site, if feasible. Artificial recharge features may also be utilized, such as via discharging to mined-out pits/slots, but withdrawal rates will need to be correspondingly higher, and the potential for effectiveness seems limited in view of the overall goal to maintain pumping levels below open-pit mining depths.

Dewatering impacts may affect contaminant migration from on-site (petroleum-contaminated) sources or at the adjacent (chromium-contaminated) Diamond Shamrock site. The impacts to groundwater levels and hydraulic gradients will potentially alter flow rates/paths for contaminated groundwater. The effectiveness of extraction wells utilized at Diamond Shamrock (to establish capture zones in upper and lower aquifers) may be impacted. Drawdown impacts at the adjacent site may be more pronounced in the lower aquifer, due to higher transmissivity and lower storativity, potentially increasing the hydraulic gradient between the aquifers and the likelihood of further contaminating the lower (and more transmissive) aquifer.

Sinkhole development will likely result from proposed dewatering. Sinkhole occurrences at distances up to 4,600 feet have been associated with past mine dewatering at the same site. More expansive and deeper mining is proposed by CCC. Additional sinkhole development should be expected and may be more pronounced and/or occur over a larger area.

Impact to water levels in the Northeast Cape Fear River will likely be negligible. Hydraulic gradients underlying some portion of the River are likely to be affected, but the associated reductions in groundwater contribution to the River will be slight in comparison with the overall scale of groundwater contribution to baseflow and effects of surface water flow and other factors affecting river levels.

Water levels in smaller drainage features and/or wetlands may be affected by reduced groundwater contribution due to reductions/reversals of underlying hydraulic gradients. Impacts will be more likely for surface water features/wetlands that are isolated or elevated from larger surface water features/the Northeast Cape Fear River.

Water quality characteristics for groundwater pumped from the mine will likely reflect water quality typical of Castle Hayne and Peedee aquifers, with higher pH and hardness than typically occurs in surface waters. Other differences are also likely, depending upon local conditions. Water quality differences will mean a potential for surface water to be impacted by discharge from mine dewatering.

The proposed facility is far-removed from saltwater occurrences in the Castle Hayne and Peedee aquifers. However, impacts could occur to the extent that additional withdrawals from the Peedee aquifer may contribute regionally to drawdown associated with wells/well fields where saltwater encroachment is a concern.

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