Section 8
Conclusions

Amended fly ash was used as fill in the development of the Battlefield Golf Course. This study was performed to assess the current and likely future water quality in groundwater beneath the site and in offsite locations to determine whether groundwater is currently, or could become, adversely impacted by constituents originating from the fly ash. CDM collected existing data for the site, completed a hydrogeologic investigation, and developed a groundwater model to assess current and future water quality. This report is strictly focused on groundwater and the conclusions provided herein do not address potential issues associated with constituents in surface water, soil, or air. Nor does this report address ecological or human health toxicological issues that may be associated with the site.

8.1 Current Water Quality Conditions

CDM identified ten constituents in shallow groundwater onsite that are elevated as compared to the baseline data set. These constituents include aluminum, ammonia, iron, magnesium, manganese, nickel, nitrate, nitrite, sulfate, and zinc. With the exception of nitrite, all of these constituents have been shown to be present in the fly ash and were detected by leaching tests performed on the fly ash. Analyses for nitrite have not been performed on the fly ash. It is likely that these constituents are elevated because of the site. However, none of these constituents presents current groundwater plumes that can be reasonably mapped by concentration and they have apparently irregular spatial distribution patterns. This is likely because sufficient time has not elapsed following fill emplacement for the water quality effects to become fully recognizable. Onsite monitoring wells MW-5A and -8A were qualitatively identified as high-concentration outliers based on aluminum and nickel and the cause for these high concentrations should be evaluated.

8.2 Groundwater Flow

CDM developed a 3-dimensional numerical groundwater flow model to investigate local groundwater flow patterns and to enable a more sophisticated basis for an analysis of potential offsite constituent migration. The data used to support the flow model development, primary assumptions, and model results are summarized below. A complete description of the model and associated assumptions are included in Section 6.

To develop an assessment of the local hydrology, and generate appropriate input parameters for the numerical groundwater flow model, CDM performed several qualitative and quantitative analyses, including an APT analyzed with AQTESOLV and further evaluated with the groundwater model. The evaluation suggests that the hydraulic conductivity of the surficial aquifer is in the range of approximately 30 to 70 ft/day.

The groundwater flow model was developed to simulate saturated groundwater flow beneath the site and surrounding area. The groundwater flow model includes four hydrogeologic units, listed from top to bottom:

- Surficial silt-clay semi-confining layer approximately 5-feet thick that underlies the fill at the site;
- Surficial Aquifer – fine- to coarse-grained sand and gravel interbedded with fine-grained sediments approximately 50- to 60-feet thick in the site vicinity;
- Yorktown Confining Zone – heterogeneous semi-confining zone approximately 20- to 30-feet thick in the site vicinity that separates the underlying Yorktown aquifer from the overlying surficial aquifer; and
- Yorktown Aquifer - heterogeneous unit approximately 40- to -60 feet thick composed of sand with interbedded silt/clay.

The groundwater flow model boundaries selected include the Intracoastal Waterway to the north, the North Landing River and Currituck Sound to the east, the Northwest River to the south and southwest, and swampland and unnamed tributaries to the Northwest River to the west.

Approximately 63 known residential wells in the site vicinity are used for water supply. The well depths for 17 if these wells are known and the wells were assigned to these depths in the groundwater flow model. The remaining 46 residential wells that do not have available well depth data were simulated as pumping from the surficial aquifer as a conservative measure. All residential wells were assumed to pump continuously at the average residential water usage rate of 0.45 gpm based on typical City of Chesapeake water use rates.

The groundwater model was calibrated using groundwater heads measured in monitoring wells in 2008 and 2009 and an APT conducted by CDM in 2009. The groundwater flow model sensitivity to recharge and the hydraulic parameter assignments for K_h and K_v was assessed and the model was found to be sensitive to these two variables. As a result, two alternative flow models were developed incorporating the range of parameter value assignments considered appropriate for the site.

The relatively low hydraulic conductivity of 30 to 70 ft/day derived from the APT required the use of a recharge rate of 3.1 in/yr that was lower than expected based on regional values. A higher hydraulic conductivity of 100 ft/day was required to achieve calibration at the more typical recharge rate of 10.1 in/yr. Therefore, the higher-flow USGS model assumptions were simulated in addition to the APT results. This resulted in two simulated flow fields for the groundwater flow model that represent the most likely range of possible groundwater flow rates beneath the site and the surrounding area.

The regional groundwater flow in the surficial aquifer is toward the southeast and the Atlantic Ocean with localized variations in this flow direction being caused by surface water features. Numerous local surface water features on and near the site complicate patterns of groundwater flow in the shallow surficial aquifer, including onsite ponds, and a network of drainage ditches, including one that is located along the southern and southeastern border of the site.

Based on water level elevations, CDM assumed that onsite ponds SG-3, -9, -10, -11, -12, -16, and -17 have good connection with the shallow groundwater and onsite ponds SG-1, -2, -19, -6, -7, and -8 have poor connection. Furthermore, because SG-3 and SG-16 discharge to surface drainage ditches, they are assumed to behave essentially as groundwater drains.

Onsite, groundwater flow model simulations in the surficial aquifer, as well as groundwater and surface water data from the network of monitoring wells, indicate that groundwater from beneath the footprint of the site area primarily discharges to the ditches along the southern and southeastern site boundary. Local pumping from residential supply wells does not appear to have an appreciable impact on local groundwater flows, except in their immediate vicinity.

In summary, the groundwater flow model was found to be most sensitive to the recharge rates and hydraulic conductivity assumptions with regard to flow model calibration and the range of values considered acceptable by CDM were used to effectively bracket the range of flows. The pumping effects from the residential wells on the groundwater flow field beneath the site were found to be negligible. This is primarily because the groundwater flowing beneath the site primarily discharges to the intervening drainage ditch that is south and southeast of the site boundary and this discharge occurs for both the APT flow model and the high flow model. Should the hydraulics of this drainage ditch change in the future this discharge could change. Features such as a downstream dam or siltation and ditch infilling at the site would likely decrease the groundwater discharge from the site.

The geographic locations of the individual residential wells within the properties were not available for inclusion in the model. As a result, CDM used the approximate center of the properties for each of the residential wells. The results of the overall site-wide model are not highly sensitive to the location on each individual property. However, if a residential well were located very close to the ditch, it is possible that a portion of the groundwater pumped from the well could be derived from beneath the ditch and in the future that groundwater may contain constituents derived from the fly ash.

8.3 Future Water Quality Conditions

Future water quality conditions beneath the site and in offsite locations were assessed with the aid of a numerical transport model. The results of this groundwater modeling effort indicate that water quality in the surficial aquifer beneath the fly ash fill will be affected by the site. In order to assess the future magnitude of the water quality affects, the model variables and assumptions that are sensitive to the model results were considered for ranges of reasonable values. Representing a range of values was appropriate because the currently available data did not provide a basis for transport model calibration. CDM concludes that sufficient time has not passed since fly ash emplacement for a definable plume to develop that would provide a basis for transport model calibration. While not calibrating the groundwater model for observed contaminant transport could increase the range of the most-probable results simulated for contaminant transport, not calibrating the model does not invalidate the transport model. CDM concludes that the future groundwater quality will likely fall within the approximate range simulated by the model. However, predicting a constituent concentration at a given location for a future date is not a reasonable expectation for the model, primarily because contaminant transport calibration data do not currently exist.

The groundwater flow model formed the basis for simulations of groundwater transport simulations. The groundwater transport model requires inputs for the mass of constituents being added to the groundwater. The EPA HELP model was used to develop the water infiltration rates through the fly ash fill and these infiltration rates were used to develop the mass loading inputs. Arsenic and nitrate were selected as the constituents for the transport model. These constituents were selected on the basis of being present in the fly ash, being present in leachate from tests performed on the fly ash, being regulated constituents having drinking water MCLs, and their mobility in groundwater.

Arsenic has a low drinking water MCL of 10 ug/L and was present in fly ash leachate samples. It should be noted however that the ambient background concentration of arsenic in groundwater can also exceed the MCL. Arsenic typically has a moderate mobility and would be expected to leach from the fly ash for a longer period of time than nitrate. Nitrate does not have a drinking water MCL but has a state standard of 5,000 ug/L and was present in fly ash leachate samples. Nitrate has a high mobility and would be expected to leach from the fly ash relatively quickly as compared to the other constituents in the fly ash. Simulations using these two constituents should effectively represent the range of effects on groundwater that can be expected from the fly ash.

Data from TCLP leaching tests performed on samples of fly ash and samples from borings in the emplaced fly ash at the site suggest the potential for groundwater contaminants in the fly ash to leach into precipitation and irrigation water that infiltrates from the surface and percolates through the fly ash fill to the saturated groundwater system. Potential differences may exist between the TCLP leaching data and the actual leaching at the site. However, CDM conservatively used the mass leached from fly ash by the TCLP test to represent the total leachable mass from the fly ash for one scenario. CDM reviewed the chemical data from laboratory analysis of samples of fly ash, as well as pre-construction analyses used in design and planning to assess potential future water quality impacts resulting from the use of the fly ash in golf course development. For mass loading purposes, CDM used an arsenic value of 43 mg/kg arsenic in fly ash. This value is calculated from the average concentration of 59 mg/kg from most recent investigations less the 95% confidence interval of the mean of 16 mg/kg.

The estimated footprint of the areas receiving fly ash totals approximately 92.4 acres. The estimated total mass of stabilized ash used to construct the golf course was 1.5 million tons, projected by URS (2001b) and cited by MACTEC (2009). CDM conservatively assumed that no fly ash was placed in low-lying areas or ponds. In addition, CDM assumed that fly ash was not placed along the site boundaries such as in the southwest corner. No current data are available defining the precise locations of fly ash fill. The transport simulations were performed for 5 years to simulate current conditions and for 20 years and 200 years to simulate future conditions.

The conclusions for future water quality represent static site-wide conditions that are assumed to not change in the future. Examples of site conditions that could change in the future and cause these conclusions to change include items such as deterioration of the soil cover over the fly ash, low plant transpiration rates over the fly ash, and changes in the hydrology of the drainage ditches surrounding the golf course.

8.3.1 HELP Model Infiltration Rates

A range of estimated infiltration rates to groundwater through fly ash fill was developed based on the layer properties for the soil cover, fly ash, and underlying soil. Eight scenarios were evaluated for infiltration rate determination and evaluated for sensitivity. In these scenarios, the soil cover thickness was evaluated at 6 and 18 inches and the evaporative zone depth was evaluated at 6, 10, and 18 inches. The hydraulic conductivity of the soil cover was evaluated at three values as well. The next lower layer in the HELP model was the fly ash fill and this layer was included with a single hydraulic conductivity value of 5×10^{-5} cm/sec and a variable thickness based on available information regarding the thickness across the site. The lower layer beneath the fly ash fill was included as a relatively low permeability layer having conductivity between 8.27×10^{-7} cm/sec and 6.4×10^{-7} cm/sec. This layer was excluded in one scenario because it may be discontinuous. These data input ranges for the HELP Model were derived from the previous model prepared by URS and additional information obtained by CDM.

The resulting infiltration rates ranged from approximately 7 to 20 in/yr. The model results were most sensitive to those elements of the model related to the soil cover parameters, including hydraulic conductivity, thickness, and depth of the evaporative zone. Based on the HELP Model results, a range of infiltration from 7.5 to 15.8 in/yr appears reasonable and this range excludes the infiltration rate calculated with the lower layer being absent. Assuming that the lower layer is present at all locations is a conservative assumption because water levels indicate that it may be absent beneath certain onsite ponds. It should be noted that these infiltration results do not include infiltration associated with irrigation of the golf course. Therefore, it is reasonable to assume that the fly ash fill is exposed to infiltration rates that are higher than those representing the reasonable range. Should the soil cover become eroded and thinned in the future or if the vegetative cover becomes stressed, the infiltration rates will likely increase.

8.3.2 Arsenic Migration

A range of estimated arsenic to groundwater mass loading rates over time for the transport model simulations was developed based on the following assumptions: It was assumed that the arsenic concentrations in the leachate will exhibit first-order decay and the relationship between the arsenic concentration in the fly ash and its concentration in leachate is linear, and expressed by K_d. A range of K_d values was evaluated for arsenic. Instantaneous equilibrium between the liquid and solid phases is assumed. The simulated steady-state groundwater flow field and the estimated arsenic loading rate were used to simulate potential future transport of arsenic in the groundwater over a period of 200 years. The groundwater transport simulations represent advection of arsenic with flowing groundwater, adsorption of arsenic to the soil, and dispersion of the arsenic plume. Because arsenic has a strong tendency to adsorb to soil particles, its transport in the subsurface is much less rapid than the groundwater velocity. Field data are not available to calibrate the transport model, so a range of transport parameters and loading rates was simulated.

After a simulated period of approximately 20 years, the model results indicated very minor impacts to the surficial aquifer were observed. Because the arsenic depletion rate in the fly ash is expected to be low, the model predicts that water quality impacts in shallow groundwater beneath the site would persist for 200 years or more. Simulated arsenic concentrations in the upper surficial aquifer at the conclusion of the 200 year arsenic transport simulations were 0.1 mg/L to 2 mg/L, with the higher concentrations reflective of a conservatively high estimate of mass leaching into the aquifer. The model did not indicate that appreciable arsenic from the site will migrate offsite beyond the ditch during that period. The model indicated that arsenic would ultimately discharge to the drainage ditch just south and east of the golf course. There was no arsenic migration to the Yorktown aquifer in the simulation result.

8.3.2 Nitrate Migration

Transport of nitrate is not significantly retarded, and it is expected to migrate through the aquifer at approximately the same rate as groundwater. It was assumed that the nitrate concentrations in the leachate exhibit first-order decay and the relationship between the nitrate concentration in the fly ash and its concentration in leachate is linear, and expressed by K_d. CDM also conducted simulations of nitrate transport from the fly ash in the groundwater. Nitrate was simulated as a conservative substance, without significant adsorption or degradation, and thus migrated much faster than the arsenic.

The nitrate transport simulations indicated that the impact to the upper surficial aquifer beneath the site is possible within the first 5 years following equilibration of the water infiltration and leaching process. The maximum simulated nitrate concentration in groundwater is 50 to 500 mg/L. Because nitrate is much more soluble than arsenic, the source mass in the fly ash was estimated to be largely depleted from the source within approximately 20 years. The model results show that nearly the entire simulated nitrate mass had discharged to the drainage ditch south of the golf course within 20 years.

Hydraulic connections between the onsite ponds and the underlying surficial aquifer would provide a preferred pathway through the 5-foot thick silt/clay layer at the base of the fly ash for constituents in the fly ash leachate to migrate into shallow groundwater. Due to the characteristics of the local groundwater flow field, the model simulations suggest that preferred pathways, if present, are not expected to impact water quality at offsite receptors, although the direct connection of the ponds to the surficial aquifer would decrease the length of time required for leachate constituents to be observed in shallow groundwater directly beneath the site.

8.4 Future Land Use Considerations

The groundwater flow and transport model simulations of future conditions can become invalid if the assumptions related to leaching from the fly ash and the site-wide hydrology change because of future land use changes. Examples of the type of changes that could occur and some of the effects of these changes are depicted on **Figure 8-1** and described below.

One prominent feature that effects the conclusions of the model centers on the drainage ditch located to the south and southeast of the site. Based on the investigation data, this ditch serves as the receiving water body for groundwater that passes beneath the site and therefore limits the extent of groundwater migration to the south. The current ditch channel appears to be sufficiently deep to allow groundwater to discharge efficiently to the ditch and to flow unrestricted downstream based on the observed potentiometric surface data. These conditions must be maintained or improved into the future in order for the ditch to remain a limiting factor on groundwater migration to the south.

Examples of possible future changes in the ditch include infilling of the ditch by sediments and blockages/restrictions of the ditch flow by debris or constructed features. Infilling of the ditch channel could occur from sediments being transported from upstream and settling in the ditch near the site. Construction activities could also contribute to ditch infilling. The ditch must also be capable of supporting downstream flow into the future to remain effective. Flow restrictions are possible from man-made dams, undersized culverts, or debris deposited during storm events or by beavers. A period of severe drought could also lower the water table surface in the surficial aquifer and cause groundwater to no longer discharge to the ditch. Under this circumstance, groundwater beneath the site would continue to migrate beyond the ditch to offsite locations.

The infiltration rates through the soil cover over the fly ash could also be increased in the future, which will increase the rate of constituent loading to the groundwater system and cause the constituent concentrations to increase quicker and to higher concentrations than those simulated by the model. Decreases in the soil cover thickness to less than two feet can cause an increase in the infiltration rate. The soil cover thickness could be decreased by erosion and construction/landscaping activities on the golf course. The model also assumes that the infiltration rate is offset in part by evapotranspiration. Should the vegetation growing in the soil cover over the fly ash become stressed or vegetation with low transpiration rates be used, more precipitation can infiltrate through the soil cover and increase the leaching rate. Because the turf is assumed to require irrigation, this will increase the infiltration rate as well, although the vegetation will benefit. As a result, a balance should be maintained between irrigation requirements, using turf species with appropriate transpiration qualities, and keeping the vegetation healthy. Since April 2008, bare areas of soil cover and eroded soil areas have been observed on the golf course.