Section 5
Hydrologic Analysis

Specific hydrologic analyses and investigations were conducted to increase the understanding of the site hydrology and water budget and help quantify the model parameters and calibration targets for the groundwater flow modeling presented in Section 6. These analyses included:

- Review of stream flow data and hydrologic reports to help estimate the average groundwater recharge rate in the model area;
- Investigation of the influence of drainage infrastructure on regional and local groundwater flow;
- Investigation of data indicating the possible influence of the onsite golf course ponds on the shallow groundwater system;
- Numerical simulations to estimate infiltration and leachate production rates from the ash fill for development of source terms for groundwater transport modeling (Section 5.2);
- Critical review of leachate production rate estimates for the fill areas generated by HELP model simulations performed by URS (2001b); and
- Generation of an updated estimate of the likely range of average infiltration and leachate production rates using HELP model simulations with revised input parameters.

5.1 Recharge, Drainage and Ponds

Interaction between groundwater and surface water is an important feature of both local and regional hydrology. Available stream flow data was reviewed to help estimate regional average groundwater recharge in the study area. The regional USGS data for southeastern Virginia (**Figure 5-1**) show that average measured stream flow typical of the area is in the range of 0.7 to 1.1 cubic feet per second per square mile (cfsm), equivalent to 9.5 to 14.9 inches/year (in/yr). This represents a combined total of both groundwater-derived base flow and direct runoff. In stable systems base flow and recharge can be assumed to be approximately equivalent. Using base flow separation techniques, average net recharge for the Virginia coastal plain as a whole is estimated to be approximately 10 in/yr based on analysis of measured stream flow (Heywood and Pope, 2009). Actual recharge is spatially variable depending on soil properties, land slope, drainage, and land use.

The Chesapeake area is characterized by low-lying swamp lands and a high water table, and the land in the vicinity of the site is primarily used for agriculture. An extensive network of drainage ditches is plainly evident from inspection of aerial photographs, and major ditches are included in maps illustrating surface water features. Throughout the region, drainage facilities are extensively employed to manage water levels and prevent high groundwater conditions from adversely impacting agriculture and other land uses. Groundwater is discharged into these drains and this water is then conveyed by ditches to downstream courses.

A network of staff gauges has been installed in ditches on and nearby the site area. In addition, the USGS maintains a regional network of staff gauges and associated data can be accessed on-line (http://waterdata.usgs.gov/nwis).

Local influence of the ditches on groundwater flow near the site is evident from the water level data measured in the ditches and nearby groundwater monitoring wells. Hydraulic gradients toward the ditch are noted both horizontally and vertically in the observed water level data. Water levels in monitoring wells immediately adjacent to the drainage ditch to the south of the site are consistent with readings from staff gauges installed in the ditch indicating hydraulic communication between the groundwater and the surface water in the ditch.

A number of ponds were constructed onsite as golf course features by excavating in the unsaturated zone and into the saturated zone. Water level data from staff gauges sited in onsite ponds were also qualitatively examined in the context of water levels measured in nearby "A" wells. Although the MACTEC report indicated that the depths of the ponds were measured, tabulated measurement data appear to be absent; however, two measured depths are noted on cross-section figures 4 and 5 (MACTEC, 2009). These figures indicated that Pond SG-12 is 10.7 feet deep, and Pond SG-9 is 18.9 feet deep. Pond SG9 is connected to Pond SG-10 via a short canal, and thus the depth is assumed to be similar in Pond SG-10. Pond depths are not drawn to scale in the MACTEC cross-section figures. These cross-sections also suggest that Ponds SG-8 and -3 are considerably shallower (depth data are not posted), although they are also illustrated as having depths extending below the bottom of the silt/clay layer and in direct hydraulic communication with the more permeable sand zone in the surficial aquifer. Water level fluctuations within the ponds were evaluated for consistency with neighboring pond behavior (and, where available, data from shallow groundwater wells). The size of the ponds was also considered, with the larger ponds assumed to possibly be deeper than smaller ponds.

Based on this analysis, CDM concluded that the following ponds are likely to have moderate to good hydraulic connection with surficial aquifer: ponds SG-3, -9, -10, -11, -12, -16, and -17. Conversely, the following ponds are likely to have a more limited hydraulic connection with surficial aquifer: ponds SG-1, -2, -19, -6, -7, and -8. Ponds SG-3 and -16 have drainage ditches that lead from the ponds to the main site drainage ditch. The rise of the water surface level of these ponds is thus limited by an outlet structure. The water levels in these ponds varied by less than 0.2 feet, except during a dry period in July 2009, when the pond levels had receded.

5.2 Leachate Production Rates (HELP Model)

CDM was tasked with evaluating a project-specific, Integrated Pathway Model (URS, 2001b). A baseline component of the input data for the Integrated Pathway Model was a HELP Model simulation of the site resulting in an estimate of infiltration rates through the ash fill in the unsaturated zone. The HELP model is a quasi-two dimensional, deterministic model (Schroeder, 1994) developed by the EPA to help landfill designers estimate the magnitudes of components of a landfill's water budget and the amount of leachate produced by the landfill. The HELP model determines runoff, evapotranspiration, percolation, and lateral drainage to obtain water budgets. CDM performed a review of the HELP model simulation conducted by URS for the Integrated Pathway Model.

Table 3.4 in Section 3.2.1 of the URS report documenting the Integrated Pathway Model (URS, 2001b) listed the assumptions used for the model input data. Three layers were simulated at the Battlefield Golf Course site: Layer 1 represents the soil cover; Layer 2 represents the fly ash fill; and Layer 3 represents the underlying silt/clay layer. As a starting point, CDM attempted to recreate the URS HELP model run and simulate the results reported. Several inconsistencies were noted between input files included in the report appendix and tabulated data in the body of the report, including the depth of the ash fill, and the hydraulic conductivity value used for the silt/clay layer at the base of the fill. Using the corrected values gleaned from the model output files in the report appendix, CDM was able to recreate the URS HELP model simulation and obtain the results reported by URS of 18.8 in/yr of recharge. This was the value used by URS as an initial estimate of the local rate of recharge entering the groundwater flow model.

CDM conducted several more simulations to evaluate the sensitivity of the model to various assumptions. These included:

- Omitting the representation of a low-hydraulic conductivity silt/clay layer (Layer 3) at the base of the ash fill. This simulation yielded an infiltration estimate of 18.84 in/yr, indicating that the HELP model estimate of infiltration is insensitive to hydraulic conductivity assignments of Layer 3. In the URS HELP model simulations (URS, 2001b), the silt/clay layer (Layer 3) underlying the ash fill was assigned a value of 8.2E-07 centimeters per second (cm/s), or 0.0023 ft/d, based on data from boring B1B.

- A review of fly ash samples (URS, 2001b, and MACTEC, 2009) yielded a geometric mean saturated hydraulic conductivity value of 6.4E-06 cm/s. Using this site-specific value, a 20.3 in/yr rate of recharge was calculated by the HELP Model.

- Increasing the simulated thickness of the soil cover on the landfill (Layer 1) from 6 inches to 18 inches to improve model agreement with soil boring data reported by MACTEC (2009) yielded an annual infiltration rate of 19.9 in/yr.

- Increasing both the simulated thickness of the soil cover (Layer 1) and the evaporative zone depth from 6 to 10 inches yielded an annual mean infiltration rate of 15.8 in/yr. Increasing the evaporative zone depth from 6 to 18 inches yielded a rate of 12.7 in/yr. The recommended range of evaporative depths provided in HELP model documentation is approximately 10 to 42 inches (Schroeder, et. al., 1994) for southeastern Virginia. It was assumed that at the site, the root zone would not exceed the depth of the soil cover.

- The top cover material applied above the ash fill was described by MACTEC (2009) as "brown to dark brown and gray, stiff to firm, clay and silt soils." A sensitivity simulation, whereby the hydraulic conductivity value originally cited in the URS report (2001b) of 8.2E-07 cm/s for onsite silt/clays tested from boring B1B (URS, 2001b) was applied to the soil cover (Layer 1), and the simulated soil cover thickness and evaporative zone depths were both set at 18 inches, yielded an annual mean infiltration rate of 7.15 in/yr.

- Applying the hydraulic conductivity value used in the groundwater model layer representing the silt/clay, 0.05 ft/d (1.76E-5 cm/s) to the soil cover (Layer 1) generated an infiltration rate of 7.55 in/yr.

The HELP model simulations did not appear to be sensitive to adjustments in parameters describing the silt/clay layer underlying the ash fill (Layer 3), but were found to be sensitive to the hydraulic conductivity, depth, and evaporative depth assignments in the soil cover (Layer 1), all of which reduced model estimates of infiltration through the landfill areas. As a result of this analysis, the estimated infiltration through the emplaced fly ash at the golf course is reasonably expected in the range of approximately 7.5 – 15.8 in/yr. The estimate of infiltration (leachate production) through the unsaturated zone in areas of ash fill was an important parameter in calculating mass loading rates for the transport model, as described in Section 7.2.1.