Section 3
Hydrogeologic Investigation Results

The primary focus of the hydrogeologic investigation was to characterize the hydrogeology and the groundwater/surface water quality in the site vicinity to the extent necessary to support conclusions regarding the groundwater flow characteristics and potential constituent fate and transport characteristics. Based on the data collected by CDM and others, a hydrogeologic characterization was completed that described the site-specific geologic layers, provided initial estimates of the hydrogeologic properties, and described the groundwater flow patterns. In addition, CDM assembled and evaluated a water quality database to assess constituents in groundwater and surface water in the site vicinity. This database includes all applicable data from the sources identified in Section 2.5 of this report.

3.1 Site-Specific Geology

The geologic layers investigated at the site include the surficial aquifer, the Yorktown confining zone, and the Yorktown aquifer. **Figure 3-1** includes a boring log summary from monitoring well installation. These boring logs were used to identify the elevations of the geologic layers and provide the layer descriptions. Additional elevation data for these layers on a regional basis were obtained from regional literature (McFarland, 2006).

Surficial Aquifer – In the site vicinity, CDM divided the surficial aquifer into two zones: an upper clay zone that occurred from land surface to depths ranging from 1 to 15 feet bls and a sand zone that was beneath the clay zone. The average thickness of the clay zone was approximately 5.5 feet. Two primary lithologies were identified for this clay. The dominant lithology was a sandy to silty clay that was typically brown to gray. The less frequent lithology of upper zone was black, organic-rich clay. The remainder of the surficial aquifer from the base of the upper clay zone to the top of the Yorktown confining zone consisted primarily of sand, ranged in thickness from 28 to 61 feet, and was approximately 39 feet thick on average. The typical lithology consisted of fine- to medium- to coarse-grained sand. Structure contours drawn on the surface of the surficial aquifer sand zone are shown on **Figure 3-2**.

Yorktown Confining zone – The Yorktown confining zone was found to have variable lithologies, as indicated by the regional data. Most of the Yorktown confining zone consisted of clay with less dominated layers of primarily sand. The depth to the top of the Yorktown confining zone was from 29 to 61 feet bls and averaged approximately 44.5 feet bls. The thickness of this zone ranged from 30 to 51 feet and was approximately 41.5 feet thick on average. The clay in the Yorktown confining zone was typically sandy to silty and at several locations included shell fragments and mica. The sand was typically silty to clayey, fine- to medium- to coarse-grained and also contained shell fragments. Structure contours drawn on the surface of the Yorktown confining zone are shown on **Figure 3-3**.

Yorktown Aquifer – The Yorktown aquifer was found to consist entirely of sand layers that ranged from fine- to coarse-grained and was less typically silty. Shell fragments and mica were also common admixtures. The depth to the top of the Yorktown aquifer was from 76 to 96 feet bls and averaged approximately 88.5 feet bls. The thickness of this zone could not be determined from the 6 borings that reached this zone because these borings did not fully penetrate this zone. Structure contours drawn on the surface of the Yorktown aquifer are shown on **Figure 3-4**.

3.2 Groundwater Flow

Previous mapping of the surficial aquifer potentiometric surface at the site has been performed and all of these maps have indicated a general southeast groundwater flow direction. This flow direction is consistent with the regional expectations and the direction of the Pocaty River. **Table 3-1** includes a summary of groundwater level depths, potentiometric surface elevations, and surface water elevations used to construct potentiometric surface maps for the surficial aquifer and the Yorktown aquifer in the site vicinity.

Figure 3-5 is a potentiometric surface map for the surficial aquifer. To construct this map, CDM used water levels collected on September 15, 2009, from monitoring wells. Estimates of the surface water elevations along the ditch that borders the site to the south and an in the onsite ponds were estimated from average values reported for December 3rd and 10th of 2008 and for July 15, 2009 (MACTEC, 2009). From this figure, the overall groundwater flow direction is east. However, the groundwater flow patterns are influenced by the onsite ponds and the ditch on the south boundary of the site. The North Tributary appears to form the surficial aquifer's local hydraulic base level in the site vicinity with groundwater flowing toward the tributary and eventually discharging to the tributary as surface water.

Figure 3-6 is a potentiometric surface map for Yorktown aquifer. To construct this map, CDM used water levels collected on September 15, 2009, from monitoring wells. Surface water data were not used to construct this map because the deeper Yorktown aquifer is not hydraulically connected with the surface waters. From this figure, the overall groundwater flow direction is east-northeast. Water level elevations also decrease to the northwest toward MW-1C to elevations below sea level. Pumping in this direction is a good possibility and evidence of pumping in this unit was observed during the APT.

3.3 Groundwater and Surface Water Quality

The comprehensive water quality database in Appendix D includes a total of 161 water sample locations. The locations include groundwater from 48 site-specific monitoring wells and 80 residential wells that are located within close proximity to the site. From the 128 groundwater sample locations, over 4,100 analytical results are available. In general these results include metals and general water quality parameters that vary slightly among the samples. In addition to groundwater, 33 surface water locations are included in the database with a total of approximately 1,300 analyses.

3.3.1 Initial Data Screening

Table 3-2 includes summary level statistical data from the database. Normal probability plots of the database are included in **Appendix E**. The probability plots, or quantile plots, include the constituent concentration in micrograms per liter (ug/L) on the y axis and the x axis is the quantile of the distribution. CDM initially evaluated the data using percentile plots but the percentile plots appeared to bias the results toward possible "false positive" conclusions related to assessing potential water quality effects associated with the fly ash. The constituent quantile values were calculated using an Excel workbook application called PPLOT (Chappell, modified 2010). A quantile is a measure of relative standing and a description provided in EPA guidance (EPA, 2000) is provided below.

> "A quantile is similar in concept to a percentile; however, a percentile represents a percentage whereas a quantile represents a fraction. If 'x' is the p^{th} percentile, then at least p% of the values in the data set lie at or below x, and at least (100-p) % of the values lie at or above x, whereas if x is the p/100 quantile of the data, then the fraction p/100 of the data values lie at or below x and the fraction (1-p)/100 of the data values lie at or above x. For example, the .95 quantile has the property that .95 of the observations lie at or below x and .05 of the data lie at or above x."

Non detections are included at the reported detection limits. A steep rise in the quantile plot near the beginning of the line or near the end of the line typically indicates data outliers that are not consistent with the "population" distribution. Normally distributed data approximate a straight line on the normal plots and log-normal distributed data approximate a straight line on the log plots. The appearance of more than one straight line on a quantile plot can indicate multiple "populations" within the dataset or a population that is not normally or log-normally distributed.

Preliminary conclusions based on the summary statistics and the quantile plots are included in Table 3-2. This analysis was used as a screening tool to identify data sets to evaluate in more depth. From this screening analysis, 15 constituents of the 27 constituents were recommended for additional analysis. The 12 constituents excluded from additional analysis had insufficient detections to support additional analysis. Possible high- and low-concentration outliers were identified in the initial analysis and these outliers were removed from the database prior to further analysis as presented in the section below.

3.3.2 Detailed Constituent Analysis

Background constituent concentrations are assumed to present a "population" and based on the initial analysis the distribution are generally log-normal. A higher concentration "population" as compared to background could possibly represent exceedances of background associated with water quality effects from the site. For each constituent identified for further analysis in Table 3-2, additional quantile plots were prepared that segregate the data into one of the following three "populations."

- Baseline Data – These data points are assumed to be the least likely "populations" to be affected by the site and consist primarily of background concentrations. The baseline data were derived from the following locations: residential wells, offsite monitoring wells, upgradient monitoring wells, onsite monitoring wells completed at the base of the surficial aquifer, and offsite surface water samples. Although results from some of these data points are possibly influenced by the site, the influence should be small compared with the two site-related "populations" described below. The effect of including data points that are possibly influenced by the site in the baseline data is to make the analysis conservative toward minimizing false-positive identification of site effects on water quality.

- Onsite Ponds – These data points are assumed to be one of the most likely "populations" to be affected by the site and can be compared to the baseline data to assess possible background exceedances.

- Onsite "A" Wells – These data points consist of onsite monitoring wells completed in the upper-most portion of the surficial aquifer. These wells are assumed to be one of the most likely "populations" to be affected by the site and can be compared to the baseline data to assess possible background exceedances.

The data plots for these three "populations" are included in Appendix E, **Figures E-16** through **E-30**. Additional statistical information for these data sets, which excludes the previously identified outliers and non-detect results, is provided in **Table 3-3**. The statistical information includes the mean, or average, and the 95% confidence intervals of the mean. The bar plots of the confidence intervals include the central mean and the range associated with the confidence interval of the mean. A simple explanation of the confidence interval's significance is that a 95% confidence exists that the average or mean concentration of the subject population is within the confidence interval based on the data supplied. Where the mean value of the onsite pond data or the onsite "A" well data exceed the upper limit (UL) of the 95% confidence interval of the baseline data, a statistical exceedance in concentration of that "population" over the baseline "population" was assumed to exist. These results are further discussed below for each constituent.

3.4 Groundwater and Surface Water Quality Conclusions

Data collected by CDM and the others identified in Section 2.5 of this report were used to assemble the comprehensive water quality database and all of the data were used to complete the data analysis and formulate the following conclusions.

3.4.1 Constituent Concentrations

Aluminum – The mean for the onsite ponds exceeds the baseline UL. The quantile plots on Figure E-16 indicate that the distribution difference between the "A" wells and the baseline is small although the "A" wells quantiles have higher concentrations. Two samples collected from MW-8A were identified as high concentration outliers for aluminum. The onsite pond quantiles are clearly higher in concentration than the baseline on these plots. Aluminum concentrations in the onsite ponds and the onsite "A" wells are possibly influenced by the site.

Ammonia – The mean ammonia concentration for onsite "A" wells exceeds the baseline UL. However, the quantile plots on Figure E-17 indicate that the distribution differences between the "A" wells, the ponds, and the baseline are small beyond the lower quantiles. Ammonia concentrations in the onsite ponds are consistent with the baseline water quality. The onsite "A" wells are possibly influenced by the site based on the ammonia data.

Antimony – Antimony concentrations are assumed to not be affected by the site because of the low number of detections, approximately 17%.

Arsenic – The mean arsenic concentration for both the onsite "A" wells and the onsite ponds is below the baseline UL. The quantile plots on Figure E-18 indicate similar distributions from the onsite ponds and the "A" wells to the baseline. MW-3C was identified as high-concentration outlier for arsenic. MW-3C is not likely affected by the fly ash because it is upgradient and in a lower aquifer. The arsenic concentrations in the onsite ponds and "A" wells are consistent with the baseline water quality.

Barium – The mean barium concentration for the onsite ponds exceeds the baseline UL. The quantile plots on Figure E-19 indicate that the distribution difference between the onsite ponds and the baseline is small beyond the lower quantiles. PW-25 and MW-3A were identified as high-concentration outliers for barium and all are offsite or upgradient wells. Barium concentrations in the onsite "A" wells and onsite ponds are consistent with the baseline water quality.

Beryllium – Beryllium concentrations are assumed to not be affected by the site because of the low number of detections, approximately 26%.

Boron – The mean boron concentration for both the onsite "A" wells and the onsite ponds is below the baseline UL and the quantile plots on Figure E-20 indicate that the distribution difference between the onsite "A" wells, the onsite ponds, and the baseline is small. Boron concentrations in the onsite “A” wells and onsite ponds are consistent with the baseline water quality.

Cadmium – Cadmium is assumed to not be influenced by the site because of the low number of detections, approximately 18%.

Chromium – The mean chromium concentration for the “A” wells exceeds the baseline UL and the onsite ponds mean is below the baseline UL. The quantile plots on Figure E-21 indicate a similar concentration distribution from the onsite “A” wells to the baseline. The concentration differences are small as compared to the confidence interval and these differences are not significant. Chromium concentrations in the onsite “A” wells and onsite ponds are consistent with the baseline water quality.

Cobalt – Cobalt is assumed to not be influenced by the site because of the low number of detections, approximately 39%.

Copper – Copper is assumed to not be influenced by the site because of the low number of detections, approximately 17%.

Iron – The mean iron concentration for the onsite “A” wells exceeds the baseline UL. The mean iron concentration for the onsite ponds wells is below the baseline UL. The quantile plots on Figure E-22 indicate that the distribution for the onsite “A” wells is higher than the baseline and the onsite ponds have a distribution that is below the baseline. Iron in the onsite “A” wells is possibly influenced by the site.

Lead – The mean lead concentration for the onsite “A” wells and the onsite ponds are below the baseline UL. The quantile plots on Figure E-23 indicate that the distribution for the onsite “A” wells is higher than the baseline for the middle quantiles. The onsite ponds have a distribution that is consistent with the baseline. Lead concentrations in the onsite “A” wells and onsite ponds are consistent with the baseline water quality.

Magnesium – The mean magnesium concentration for the onsite “A” wells exceeds the baseline UL. The quantile plots on Figure E-24 indicate that the distribution for the onsite “A” wells is only higher than the baseline in the middle quartiles. The onsite ponds have a distribution that is lower than the baseline. Magnesium in the onsite “A” wells is possibly influenced by the site.

Manganese – The mean manganese concentration for the onsite “A” wells exceeds the baseline UL. The quantile plots on Figure E-25 indicate that the distribution for the onsite “A” wells is higher than the baseline and the onsite ponds have a distribution that is lower than the baseline. Manganese in the onsite “A” wells is possibly influenced by the site.

Mercury – Mercury is assumed to not be affected by the site because of the low number of detections, approximately 17%.

Molybdenum – Molybdenum is assumed to not be affected by the site because of the low number of detections, approximately 20%.

Nickel– The mean nickel concentration for the onsite "A" wells and onsite ponds exceed the baseline UL. The quantile plots on Figure E-26 indicate that the distribution for the onsite "A" wells is higher than the baseline and the onsite ponds have a distribution that is slightly higher than the baseline. MW-5A and -8A were identified as high-concentration outliers for nickel in two samples from each well. However, MW-5A is an offsite well. Nickel concentrations in the onsite "A" wells and the onsite ponds are possibly influenced by the site.

Nitrate – The mean nitrate concentration for the onsite "A" wells exceeds the baseline UL. The quantile plots on Figure E-27 indicate that the onsite "A" wells have insufficient detections for further analysis. The onsite ponds mean nitrate concentration is below the baseline UL. Nitrate concentrations in the onsite "A" wells are possibly influenced by the site.

Nitrite – The mean nitrite concentration for the onsite "A" wells exceeds the baseline UL. The quantile plots on Figure E-28 indicate that the onsite "A" wells have insufficient detections for further analysis. The onsite ponds mean nitrite concentration is below the baseline UL. Nitrite concentrations in the onsite "A" wells are possibly influenced by the site.

Selenium – Selenium is assumed to not be affected by the site because of the low number of detections, approximately 8%.

Silver – Silver is assumed to not be affected by the site because of the low number of detections, approximately 7%.

Sulfate – The mean sulfate concentration for the onsite "A" wells exceeds the baseline UL. The quantile plots on Figure E-29 indicate that the distribution for the onsite "A" wells is higher than the baseline. The onsite ponds mean sulfate concentration is below the baseline UL. Sulfate in the onsite "A" wells is possibly influenced by the site.

Sulfide – Sulfide is assumed to not be affected by the site because of the low number of detections, approximately 2%.

Thallium – Thallium is assumed to not be affected by the site because of the low number of detections, approximately 3%.

Vanadium – Vanadium is assumed to not be affected by the site because of the low number of detections, approximately 39%.

Zinc – The mean for zinc in the onsite "A" wells exceeds the baseline UL. The quantile plots on Figure E-30 indicate that the distribution for the onsite "A" wells is higher than the baseline and the onsite ponds have a distribution that is lower than the baseline. Zinc in the onsite "A" wells is possibly influenced by the site.

3.4.2 Constituent Spatial Distributions

Figures 3-7 and **3-8** include spatial plots of the data for the eight of the constituents concluded to possibly reflect water quality influences associated with the site. Plots were not prepared for nitrate and nitrite because of the low number of detections in onsite groundwater. The plots were prepared by posting the sample collection location with a symbol that is proportionate in size to the sample concentration. From these plots, the constituent spatial concentration distributions can be further assessed to identify potential distribution patterns associated with the site.

For aluminum, ammonia and magnesium, the spatial distribution of high concentrations do not present an obvious site-wide association although higher concentrations do appear near the southwest corner of the site. Constituents that do appear to have higher concentrations on the site include iron, nickel, and zinc. Areas that consistently include the higher concentrations are along the south boundary and eastern portion of the site. Both of these areas are in the direction of groundwater flow from the areas where fly ash was used for fill.