APPENDIX 6

Geological Assessment

Regional Geology

The most current reference for understanding geological materials at the site and within Chatham County appears to be provided by Georgia Geological Survey Bulletin 131 "Geology of the Oligocene, Miocene and Younger Deposits in the Coastal Area of Georgia" (R. E. Weems and L. E. Edwards, U.S. Geological Survey, 2001).

Information in that publication indicates that surficial deposits at the Dean Forest Road site belong to the Satilla Formation. The Satilla is described as a heterogeneous mixture of sands, silts and clays with color ranging from pale yellowish-brown to gray and dark greenish-gray. These sediments were deposited in coastal lagoons, as barrier islands, and in shallow marine environments during the late Pleistocene, and are older than 130,000 years. The Satilla Formation is expected to be present down to an elevation of around 30 to 40 feet below sea level on the basis of projections from two published cross-sections, one of which passes a short distance to the west of the landfill. Basal elevations of formations appear to be very uniform for great distances.

Underlying the Satilla in this region are sandy deposits of the Miocene-age Ebenezer Formation. The Ebenezer is typically a fine to very fine well-sorted sand of pale olive, yellowish-gray, or grayish yellow-green color. Portions of this formation may have been deposited in an open marine environment. The Ebenezer Formation is expected to be around 70 to 80 feet thick at the site, and the elevation of its base should be around 100 feet below sea level.

Together, the Satilla and Ebenezer formations define the surficial aquifer in Chatham County and vicinity. The surficial aquifer is underlain by the upper Berryville Clay member of the Coosawhatchie Formation, composed primarily of silty and sandy clay. Its thickness would be around 40 to 50 feet thick at the site, and it serves as the confining unit for the underlying Upper Brunswick aquifer.

Previous site studies have stated that the property is underlain by the Cypresshead Formation (Pliocene) with an occasional veneer of Satilla materials. However, the above-cited report indicates that the Cypresshead disappears well south of Chatham County, having been removed by erosion, and that materials characterized as Satilla are present at the surface throughout most of the coastal region.

Based on the above information, none of the monitoring wells and borings on the landfill property would have encountered any formation except the Satilla. The descriptions of site materials in boring logs, plus recent observations in exposures and trenches, fit the profile of that formation. The heterogeneity seen throughout the property is characteristic of the depositional environments described for the Satilla, and is pertinent to observations about hydrogeological factors affecting water quality.

The geologic setting of the Georgia coast during the Pleistocene is discussed in many publications, including Weems and Edwards (2001). An understanding of this framework, along with typical barrier island morphology, can assist the interpretation of sediment descriptions in well and boring logs, and may provide a basis for reasonable expectations about the nature of deposits in various portions of the site.

The Holocene (recent), Pleistocene and Pliocene sediments that are present at the surface are “terrace deposits” that formed at times when the sea level was higher than at present. During the Pleistocene, numerous glaciations and interglacial periods affected the volume of water in the oceans and consequently sea level. “Highstand” deposits were formed when water levels were at their highest and most stable. Sedimentary deposits that formed when sea levels were rising and inputs of new sediment are relatively low are termed “transgressive”, while “regressive” deposits formed as sea level decreased.

Pleistocene deposits at less than 100 feet elevation are said to generally preserve ancient landforms such as barrier islands, partly infilled coastal lagoons, and planar bodies of well-sorted sand.

During transgressive periods, sediments are deposited on top of landforms that lie farther inland. For example, a barrier island and all its associated environments may migrate landward, resulting in beach sands being deposited over back-barrier marshes and lagoonal deposits, and the lagoon migrating landward and depositing silty and clayey material over older shoreline complexes. Along with reworking of older deposits, this can produce a very complex mixture of materials.

A recent reference (Foyle et al, 2004) states the following:

> “Geomorphic analysis of lower coastal plain topography…suggests that early Pleistocene highstand shorelines now located 40-50 km inland from the coast were dominated by wave rather than tidal processes. Lower elevation paleoshorelines closer to the modern coast indicate that a tide-dominated regime has persisted since at least 100 ky BP [thousand years before present]. The former wave-dominated paleoshorelines are characterized by cuspate (deltaic) headlands and long curvilinear barriers (e.g. the Talbot and Penholoway paleo-barriers…) that developed at the mouths of large Piedmont-draining rivers such as the Savannah and the Altamaha.”

The Dean Forest Road site is approximately 30 to 35 km from the coast, and is not early Pleistocene, so it does not represent the older highstand conditions. Its deposits are younger than the Penholoway. However, the Satilla sediments are older than 130,000 years before present and the site is sufficiently far inland that the depositional environment may have been either wave-dominated or mixed-energy.

At present, the Georgia coast is characterized by broad, “drumstick” barrier islands formed predominantly by tidal processes, stable inlets, and offshore ebb-tidal sand deposits. However, the above analysis suggests that sediments at the Dean Forest Road site could have been formed under different conditions characterized by narrower barriers, appearance and disappearance of inlets, and flood-tidal sand deltas within the lagoons.

The above framework will be applied to the site geology in the subsequent section, but it is worth noting that materials seen near the surface in one area of the site are very likely to have deeper counterparts elsewhere that formed under similar environmental conditions and possess similar properties.

Site Geology

Geologic Cross-Sections

Appendix 11 contains logs of onsite monitoring wells. Figure 3 shows the location of five cross-sections prepared from those descriptive logs. Several additional borings interior to the landfill are also shown on that figure that were drilled by a different firm; the available logs proved difficult to correlate with those for nearby monitoring wells, and thus called into question whether they belonged to the borings whose locations are indicated here.

Geologic cross-sections A-A′ through E-E′ are shown as Figures 4 through 8. Horizontal and vertical scales are the same for all sections, as is the range of elevations, thus allowing direct comparison.

As has been noted, the site materials are heterogeneous and they consist of mixtures of sand, silt and clay. Different individuals may classify a given sample as either a sandy clay or a clayey sand, while others may give preference to the silt fraction of the fines. Some of the older descriptions do not present the same degree of accuracy as those of the Unified Soil Classification System (USCS), wherein the approximate percentages of components are estimated according to specified field procedures and possibly significant trace components are included. Consequently, the logs make it difficult to distinguish between a sand with 15% clay and one with 40% clay. However, from a practical viewpoint, such fine distinctions may not be meaningful if the sediment is quite variable over short distances. In those cases, a boring only 20 feet away could present materials warranting very different characterization.

The relative distinctions between sandy clay and clayey sand, for example, may reflect gradational changes rather than different depositional environments or discrete units that can be correlated over distances of hundreds or thousands of feet. In addition, the color of site sediments does not seem to consistently relate to lithology, although color appears to have some significance over short distances – hence the inclusion of that descriptor in selected portions of the cross-sections. Color may have greater importance in distinguishing the degree of oxidation, and that will be used in this report to suggest possible sources for environmental factors related to metals detected in monitoring wells.

Despite all the above considerations, the logs seem to permit a greater degree of correlation than initially apparent. The cross-sections as presented do not employ graphical symbols, but rather present the descriptions contained in the logs along with generalized classifications between wells. This approach was used because fine distinctions can be more important in this environment than in situations where there are gross differences in lithology.

In general, the cross-sections indicate that clayey sands predominate near the surface over most of the landfill area. Deeper sediments are mostly sandy clays in the southern half of the landfill, but sandy sediments near the surface become thicker and extend to greater depths near well GWC-1 on the eastern boundary of the landfill. This appears to constitute a wedge of coarser material limited to the eastern side.

The deeper sandy clays apparently pinch out or grade to sandier material toward the northern boundary of the fill, where the entire section becomes clayey sand apart from lenses of sandy clay toward the eastern and western borders. The underlying sandy clay may extend to the surface near GWUL-25, in the east-central part of the fill, and also near GWC-8 in the southwest corner, but comprises most of the section below elevations of 8 to 10 feet along the southern boundary. An underlying clayey sand makes its appearance near the south-central portion of the western boundary as seen in section D-D′.

Six borings were drilled to the west of the landfill cells in May 1998 as part of a site acceptability study that was revised and completed by Hussey, Gay, Bell & DeYoung in November 2000. The locations of those borings are shown as B-1 through B-6 in Figure 9, and logs are included in Appendix 11 of the present report. In conjunction with logs of the background monitoring wells, these data indicate that sandy clay is generally present near the surface down to an elevation of near sea level near GWA-5 and GWA-6, with the basal elevation of the clay becoming higher and thickness shallower to the south. The clay eventually disappears near borings B-5 and B-6. A thin layer of sand overlies the clay at B-1 but not at other locations farther east and south. Beneath the clay stratum are silty and clayey sands that probably extend to an elevation of 15 feet or more below sea level.

Although the distances are too great for accurate correlation, it is possible that the sandy clay near the ground surface in the western area is congruent with the deeper sandy clay seen in sections B-B′ and C-C′, while the underlying sand in the western area may be the equivalent of the apparent sand ridge seen in the deeper portions of section D-D′. This would seem to agree with the general trend of eastward-sloping units formed under transgressive conditions on the coastal plain.

Other Geological Observations

In the course of the present investigation, sediments were inspected in detail (1) in a trench excavated for a force main on the eastern side of the southeastern landfill quadrant, (2) on exposures near the southeast corner of the southeast landfill quadrant, and (3) within the borrow area directly to the west of the southern half of the landfill.

The force main trench was inspected to a depth of seven feet, at a point where it passed 20- to 25 feet from monitoring well GWC-2 (Photos 25 and 26 in Appendix 3). Only the upper two feet was silty sand; the rest of the exposed material was either a stiff, hard clay or moderately stiff sandy clay. This is in contrast to the log of GWC-2, which indicates clayey sand throughout. The trench contractor stated that the southern half of the trench, from the southeast corner to south of GWC-3, was quite sandy and the northern portion very stiff clay. This suggests a good deal of spatial variability near GWC-2.

The southwest landfill quadrant was being excavated during the study and its contents had been removed. As seen in Photos 1 and 2, the upper zone of the exposed silty fine sand had been oxidized and leached, while the lower portion was only partly oxidized. Peroxide field testing, to be discussed in a subsequent section, confirmed the visual observations.

A large portion of the 25 to 30 acre borrow area was being dewatered and intensively mined for cover material during this study. This area is about 5 to 15 feet lower in elevation than the southwest quadrant floor. The combination of falling water table and excavation exposed reduced sediments to oxidizing conditions, and the consequences will be discussed in greater detail in Appendix 8. However, it will be noted here that sediment characteristics and fossils gave indications about possible depositional environments.

Deposits at higher elevations within the eastern part of the borrow area are predominantly tan-colored sand. Much of that sand is medium to coarse-grained, and layers of well-rounded gravel are also present. Grain orientation within the gravel layers is often chaotic, with longer axes sometimes vertical rather than horizontal, and the sorting is very poor. These characteristics indicate high-energy, rapidly flowing water. Interbedded with the sands and gravels are occasional layers of gray clay. Examples of these materials may be seen in Photos 3 and 4.

Farther down in the section, the sediments are mostly dark gray to black clayey and silty fine sands with occasional sandy clay. As seen in Photos 5 and 15, an oxidation boundary was visible in places that corresponded to the vertical change in sediment characteristics. The overlying coarser material was probably within the range of water table fluctuations and became oxidized, while the less-permeable clayey material beneath resisted dewatering during periods of low groundwater and remained predominantly reduced. At other locations, a less sharply defined oxidation boundary existed within a single soil type.

At one location within the range of the dark gray sand/silt/clay materials, a medium to coarse tan sand was found. This had steeply inclined bedding and indications of cross-bedding as seen in Photo 7. Dark fine-grained material occurred higher and lower in the section, and the bedded sand appeared to disappear laterally to the north and south. This may represent a short-lived channel of some sort.

A dark fine to very fine sand was present at still lower elevations. It displayed very consistent properties wherever it was found. It is subangular, very uniformly sorted, contains trace to little silt and clay, and is dark gray to greenish-gray when unoxidized. With exposure to air, it becomes reddish orange. When saturated, this sand frequently exhibited thixotropic properties, i.e. it became more fluid with increasing duration of an applied force, such as shaking a sample in the hand or the prolonged pressure of footsteps. Much of it was prone to liquefaction and behaved as a “quicksand”.

In the eastern part of the borrow area, this dark sand was found from approximately five feet above the water table to several feet or more below the water table as ascertained by hand auger borings. In the central part of the borrow area it appeared to be present as high as 10 feet or more above the water table.

It should be noted that the water table in the borrow area was depressed below previous levels due to draining and pumping, and careful hand level measurements using nearby monitoring wells as reference points indicates that it may have been as low as two feet above sea level.

During this study, a vertical section of the sediments near the eastern end of the borrow area was exposed by cutting into and scraping much of the surface with a mattock. This encompassed approximately 15 feet of vertical elevation difference, from the water table to the elevation of monitoring well AMW-2. Photos 8 through 12 illustrate portions of this section. Removal of eroded material from the slopes and oxidation products from the surface revealed the general upward progression of materials, from green-gray saturated sand, through dark clayey sands and occasional sandy clays, and finally coarser sands and gravels deposited nearer to the present ground surface.

Within the lowest sand unit, a well-defined horizon contained abundant shells within a restricted lateral area, while horizons above and below were entirely devoid of shells or any carbonate materials. The shell zone may be seen in Photo 19. A description of some fossils found within the shell horizon within the borrow area is contained in Appendix 12, along with preliminary environmental interpretations.

The shell assemblage mostly consisted of clams and snails that are presently characteristic of intertidal to shallow subtidal environments, and two of the most abundant (Macoma and Quahog clams) are also known to tolerate a range of salinities. Some shells were very delicate, and many clams still had their upper and lower valves joined (Photo 20). This appears to imply a very quiet setting or rapid burial.

Several vertebrate fossils were seen in the shell horizon, the most notable being the atlas (first cervical vertebra) and a portion of a scapula belonging to a young whale (Photos 21 and 22). These remains are quite heavy and do not appear to have been washed into the fine sediments, so the animal may have become trapped within a lagoon.

Interpretation of Site Geology

All of the borrow area observations noted above are compatible with a backbarrier lagoon environment and transgressive shoreline.

The lowest-lying dark sands are fine to very fine grained and very uniformly sorted, i.e. the range of grain sizes is small, and they typically appear to contain 5 to 15% silt. This might possibly represent intertidal flat and/or flood-tidal delta deposits. The latter form when tides transport sediment through a tidal inlet; the current becomes slower and more dissipated as it moves over a flood ramp and thus is capable of producing a very uniformly-sorted deposit. Low marshes and estuarine deposits appear unlikely candidates because they tend to be composed principally of silt.

Flood tidal sands would be more characteristic of narrow, wave-dominated barrier islands than those of the present Georgia coast, but it appears that such conditions may have prevailed when the Satilla was deposited. Those fine sands appear to reach higher elevations toward the western part of the borrow area, which is consistent with deposition during a rising sea level.

Apart from a distinct shell horizon, fossils do not appear in the dark sands. Examination of many samples with a stereoscopic microscope did not reveal any microfossils. That is likely to indicate that conditions were unfavorable for most bottom-dwelling organisms, probably due to low oxygen content near the bottom. The shell horizon may indicate proximity to an ancient inlet channel that afforded a flow of oxygenated water from the ocean until the channel migrated elsewhere.

The extreme uniformity of the deep sand and absence of apparent bedding in most places appears to be typical of sands in temperate zone lagoons. Chemosynthetic sulfur bacteria are abundant in anaerobic sediment layers, and nematode worms, which can withstand low oxygen levels, consume the bacteria and redistribute the sediment. Whether those conditions pertain to the site deposits is not known; however, the high concentrations of inorganic sulfur in those sands that will be discussed subsequently increase the likelihood.

In the eastern part of the borrow area, the material at higher elevations becomes more clayey on average and acquires sand and gravel layers . That could be seen as consequences of westward migration of a barrier island. The clayey material may represent the incursion of back-barrier marshes. The coarse, irregular, poorly-sorted sand and gravel mixtures may be thin washover fans deposited during storms. The very rounded nature of the sand and gravel indicates that they have been on an active beach for some time before they found their way onto the dark, fine-grained sediments.

The coarser, bedded sands that are present near the surface could be associated with the remnants of a barrier island that migrated farther westward as sea level rose, or may simply indicate a greater frequency of washovers that eventually buried the backbarrier marsh. The silty sands at higher elevations, seen on the excavation wall in the southeast landfill quadrant, may have been deposited during a later cycle of sea level rise.

In a transgressive sequence, boundaries between sediment types deposited in specific environments (facies) typically slope downward in the direction of the ocean. Therefore, the same materials should be present under the landfill, but at greater depths. Farther to the east, however, subsequent transgressive sequences are likely to be present on top of that which is seen in the borrow area. These later sequences are very likely to present environments and deposits similar to those seen in the borrow area.

The site cross-sections and other well and boring logs within and around the landfill, west of the landfill, and south of the landfill indicate local variability but great similarity in the types of sediments present, primarily oxidized and unoxidized clayey sands and sandy clays. Therefore, the same depositional environments seen within the borrow area, most likely those of a backbarrier lagoon, are likely to be present at various locations throughout the entire site.