APPENDIX 9

Climate and Acid Sulfate Conditions

Water Levels and Drought

Although the groundwater gradient at the site is relatively flat, water level elevations have changed to a surprising degree during the period of monitoring. The fluctuations can amount to a rise or fall of up to four or six feet between semi-annual measurements. These changes will be explored in greater detail for individual wells of concern, and are significant in connection with oxidation of pyrite-bearing soils.

Precipitation has affected groundwater levels at the site. A long-term decrease in rainfall has caused a decline in average water levels over the period of monitoring, and superimposed on that trend are shorter periods of heavier or scarcer rainfall that produced a rise or fall in the water table of shorter duration. Both precipitation and water levels can thus be seen as a product of long-term and short-term factors.

The site water level record is based on measurements that are approximately six months apart. This interval is adequate to follow long-term fluctuations in the water table, but is certain to miss most high and low water levels associated with rain events and periods of little or no rainfall.

Pressure Transducer Study

Pressure transducers were used to obtain information about the extent of short-term water level fluctuations. InSitu miniTROLL® self-contained data probes were placed in two monitoring wells and at one surface water gauging location on May 11, 2006 to collect a continuous record of changes over a 40 day period. Gauging station SG-2 is located in the perimeter ditch close to monitoring well GWC-2, and these two locations were selected to study the relationship between groundwater and ditch levels. Background monitoring well GWA-3 was selected to compare water level changes in a smaller upland site, closer to probable groundwater discharge zones in adjacent swampland, with locations near the landfill.

Daily rainfall data at the Savannah Airport were obtained to compare the intensity of rain events with the water level records. To evaluate any groundwater fluctuations that might reflect tidal influence, tide data were collected for a station at the Highway 17 bridge over the Ogeechee River, located about 5.2 miles southwest of the Dean Forest Road site. That station was chosen for comparisons because it is located approximately the same distance inshore as the site.

The results of the pressure transducer study are documented in Appendix 13. Figure 1 of that appendix displays the entire water level record for all three transducers. Figures 2 through 5 show the same data in 10-day increments along with precipitation events. The change in water level from initial levels is shown rather than water level elevations.

There were minor rain events 3 days and 24 days into the recording period, and their effect is seen as short-duration rises in surface water with very little groundwater impact. Over 32 days into the record, on June 12, over three inches of rain associated with tropical storm Alberto caused a rise of about 1.75 feet in the ditch water level. That storm

produced a rise of over one foot in GWC-2, but did little more than arrest the continued decline in GWA-3.

Before the storm, GWC-2 was declining slowly but steadily at 0.25 feet per month. In contrast, GWA-3 was in a steep decline at 2.25 feet per month until water level had fallen about 1.5 feet, at which point the rate of decrease abruptly slowed to 1.35 feet per month. That change might be connected with some lithologic boundary, but not one that is shown in the log for this well. There is a transition from clayey sand to underlying sandy clay around elevation 4.1 feet, but the water level drop of 1.5 feet from an initial water level elevation near 3.45 feet would place the slope break around elevation 2.0 feet; possibly that is close to the water level in the surrounding swamp.

The very close correlation between changes in GWC-2 and SG-2 indicates a strong hydraulic connection between the ditch and the formation screened by this well. That appears to reinforce the conclusion that groundwater discharges to the ditch on the eastern side of the landfill. Water level in GWC-2 rose by 1.1 feet in the space of slightly more than one day during the storm; this is a surprisingly rapid response even under intense rainfall, and requires infiltration through about 8 feet of clayey sand in that time period. Larger and more rapid increases were seen at the ditch due to runoff. The decline from peak water levels in both well and ditch (see Appendix 13, Figure 5) followed almost identical paths, suggesting that the ditch was primarily fed by groundwater.

Under drought conditions, it appears that groundwater levels will decline slowly in upland areas farther from natural discharge sites, but in smaller or more isolated uplands such as that around GWA-3, groundwater discharge will cause rapid drops in water levels until elevations near that of surrounding lowlands. Prolonged, frequent, lower-intensity rainfalls will be likely to produce a more lasting water table rise than Alberto did. The data indicate that water level changes of up to two feet could occur within a month, implying the possibility of a much more complex record than indicated by semi-annual monitoring.

There are unexplained diurnal water level fluctuations in the records, especially at GWC-2 where the amplitude is around 0.3 feet. None of the oscillations are related to ocean tides or to earth tides as seen by comparison with the tide data in Appendix 13, Figures 7 through 10. Highs and lows occur at the same times every day rather than exhibiting the progressive change of time seen in tides which are correlated with lunar months.

All records begin at 4:30 pm, so the two peaks in the GWC-2 data occur around 1:00 am and 7:30 am, and the intervening low spans the 1:00 pm to 6:00 pm interval. The two low-amplitude peaks and troughs in the GWA-3 data superficially appear tidal but also show no progression in times. The temperature record for the data logger shows no daily changes that could explain this behavior. The single dip in ditch water level that occurs every day around 7:00 am might be related in some fashion to sampling activities, but the other diurnal fluctuations are much harder to explain.

Precipitation Record

Records of monthly rainfall can be used in several ways that supplement the existing water level data. A summation of precipitation over a period of time effectively integrates rainfall data and reduces "noise" in the record. This integrated record gives some idea of the current rainfall deficit or surplus, and thus implies longer-term decline or rise in water level. Long-term changes might appear to be adequately represented in the semi-annual water level data, but the specific date of monitoring could represent either an uncharacteristically high or low water level. Periods of protracted low precipitation would thus be a good indicator that average water levels are falling and also that shorter-term fluctuations may be reaching lower elevations in the formation.

The monthly precipitation data can be used in a different way, specifically to identify periods when water levels might have risen or fallen for a briefer period, perhaps weeks or months, prior to monitoring events.

Figure 32 (Appendix 1) presents the precipitation record from January 1978 to January 2006, based on data from the Savannah Airport. The record is displayed in two ways:

1. The monthly rainfall totals are shown.

2. The net precipitation for the 12 months prior to the indicated date is plotted. A 12-month time period was selected to eliminate seasonal rainfall differences; at every point, data from the previous four seasons is included. This is effectively an annual precipitation determined on a running monthly basis rather than an arbitrary January 1 to December 31 time basis, and will be referred to here as "total precipitation".

To some extent, use of an integrated total precipitation curve to indicate water level trends reflects the fact that rainwater may infiltrate to groundwater relatively rapidly, but a long time may be required for lateral flow to reach points of discharge when the horizontal gradient is low. The transducer record for GWC-2 is a good example of very slow decline during a period of low rainfall, punctuated by rapid rise after heavy rains.

The polynomial trendline for total precipitation shows an increase in average rainfall up to 1991-1992, and a decrease thereafter. The maximum values on the total precipitation curve remained high through 1998, and much of the decreased average seems to be a product of longer periods of low rainfall. For reference, the average annual precipitation at Savannah Airport for the period of record (1948-2005) is 48.6 inches.

Portions of the total precipitation curve that have remained below 40 inches per year for a significant period have been depicted in red in Figure 32. There is no particular significance attached to 40 inches per year; it was selected as an arbitrary benchmark. The three most recent periods of low total precipitation are of particular interest. They are shown in more detail in Figure 33, where the time scale has been shortened and altered to match the approximate April and October schedule of semi-annual monitoring.

The first noteworthy period of low total precipitation (September 1996 to July 1997) occurred about 11 years after the preceding event (in 1985) ended. In terms of acid sulfate soils, the rising groundwater table would halt further oxidation and allow pH levels to rise over time due to dilution and buffering. Therefore, the 1996-1997 event could have initiated a new round of pyrite oxidation and the resulting consequences, including pH decreases in groundwater.

The second period of low total precipitation (July 2000 to December 2002) is of interest for two reasons. Firstly, it follows the preceding period by only three years. Acidic groundwater might have persisted to some extent for that length of time, and thus a new round of acid and metals inputs might be cumulative. Secondly, this period of low rainfall (evident also in the monthly precipitation curve at the base of Figure 33) lasts for almost two and a half years. That is notably longer than any of the previous such events in Figure 32, and it could have driven average water levels progressively lower while also permitting even deeper formational drying and oxidation during shorter-term dips in the water table.

The third period of low precipitation (April 2004 to April 2005) is of short duration compared to its predecessor, but comes only one year and four months later. Once again, any persisting acid sulfate conditions and their consequences might have been emphasized during this event.

Precipitation and Groundwater Elevations

To confirm that the foregoing analysis is in fact relevant to changes in groundwater elevations, the water level history in the wells of concern have been plotted along with the total precipitation curve in Figure 34. When examining this chart, it is helpful to recall that the water level data are based on points six months apart. These measurements are effectively "snapshots" that may capture short-term fluctuations with the complexity of the monthly precipitation data overlain on the longer-term trends. Therefore, an exact correspondence is not to be expected.

The water level trends appear to reflect the main features of the total precipitation curve quite well, if not entirely consistently. Periods of higher total precipitation are accurately mirrored by higher water levels in all wells. The periods of low precipitation discussed previously appear to have caused corresponding water level declines, most strongly during the lengthy 2000-2002 interval. The overall trend in each of these wells is one of falling groundwater levels produced by the cumulative effect of three succeeding periods of low total precipitation.

GWC-2 may have had the lowest overall decrease in water levels; this is not surprising because it is located farther from discharge zones in surrounding swampland, as attested by the higher overall water level elevations. Average water levels in GWC-14 may have decreased by six feet or more. That suggests the presence of some form of groundwater discharge near this well, whether due to offsite pumping or a drainage feature. Water levels in AMW-1 fell precipitously in the past year due to drainage in the borrow area.

Apart from these added influences, the total precipitation curve seems to provide a good indicator of the potential for acid sulfate conditions in onsite PASS.

Even the exceptions may have explanations that can be deduced from the data presented. For example, four of the wells had a spike in water levels during the April 18, 2001 monitoring event. This occurred in the midst of the long period of low total precipitation. Looking at the monthly precipitation data in Figure 33, there was a spike in rainfall plotted at April 1, 2001 – actually representing the rainfall for the month of March, 6.65 inches. This was the highest for any month that year. If those rains fell late in the month, the higher water level in early April would be a good example of a short-term change superimposed on the long-term decline in water levels. When measurements are semi-annual, encountering these events is a matter of chance.

Groundwater pH

Before considering data on groundwater pH at the site, it could be helpful to review some of the possible consequences of water table changes in the presence of potential acid sulfate soils as examined in Appendix 8. In brief, lower average groundwater levels could produce partial drying and exposure to oxygen. The specific periods of low water levels responsible for oxidation might not be detected in the semi-annual monitoring, but the probable time frame could be inferred from the total precipitation curves discussed previously.

The extent of the oxidation would be much less in the subsurface than was observed on exposed soil surfaces in the borrow area, and much of the pyrite would remain unreacted. The first stage of pyrite oxidation would produce excess acidity and release some metals that were adsorbed on soil particles. Additional oxidation stages might continue to release more acidity over an extended period of time.

Rainfall events during drought periods cause a temporary water table rise, and that brings groundwater into contact with oxidized zones. The result is a release of sulfuric acid, aluminum and trace metals to groundwater. Thus, a decrease in pH and increased metal concentrations may occur at times when groundwater elevations have increased.

Repeated rises and falls in the water table produce complex reactions involving mineral deposits, breakdown of complexes, and pH fluctuations. Periods of somewhat higher groundwater pH may be accompanied by relatively higher concentrations of metals that were initially released by low pH conditions. When average water levels rise again, groundwater flow eventually brings pH back to higher levels through dilution and buffering, and metals are adsorbed by clays. (Figures 50 through 53 in Appendix 2)

Sitewide pH Trends

Figure 35 presents pH trends for six wells of concern. The yellow lines that form a background to the data are the pH records for all of the wells at the site, and provide a

frame of reference without identifying each individual well. Several features in this plot are worth mention:

1. The pH in all wells was initially very high, possibly due to grout contamination before the wells were adequately developed. The pH levels then decreased in unison to around 5-6, then increased to 6.5-8, and then most began to decrease again between spring and fall of 1995. These early data are somewhat suspect. Wells were redeveloped in 1994 and continued to benefit from development in the course of subsequent sampling, so the pH data prior to 1996 may not be representative.

2. The pH in GWC-11 reached a lower level (3.4) than any other site wells between April 1997 and April 1998. Referring to Figures 33 and 34, this time frame corresponds to a period of increasing total precipitation and increasing water level following a period of low precipitation and possibly unrecorded times of very low water level. GWC-11 is relatively close to areas of discharge in surrounding swamp lowlands and the borrow area. Therefore, water level at this well could have decreased very rapidly, perhaps as fast as the two feet per month documented by the transducer study at GWA-3, another site close to discharge areas. Those lowest periods may not be represented by the water level data. The abrupt decrease in pH is probably due to rising water contacting zones that have been oxidized, releasing sulfuric acid. Another sharp decrease in pH in April 2003 is also associated with a rise in water level following a period of low water levels.

3. In contrast to the behavior of GWC-11, pH at GWC-2 and GWC-3 reached the lowest levels (2.2 to 2.4) in October 2001, a time of lowest recorded water levels and during a period of protracted low total precipitation. The reason for this difference could be lithology. The water table at all the other sites of concern resides in sandy clays. At GWC-2 and GWC-3, the saturated sediments are clayey fine sands. After water declines to a horizon with mostly unoxidized pyrite, the sand may dry out more rapidly, oxidation may proceed more rapidly, and rainfall may infiltrate the soil and effectively wash sulfuric acid downward to the water table. Possible also are brief, intense rain events that may raise the water table temporarily such as that seen in the transducer study at GWC-2. After October 2001, pH in GWC-2 has remained low (under 4.2) and has fluctuated, probably in connection with short-term water level changes.

4. AMW-2 and GWC-5 had slightly higher pH in October 2001, a time of low water levels. GWC-11 had a much higher pH in October 2001, as did GWC-1, GWC-8, GWC-18 and GWC-20, with pH exceeding 7 in all those wells. The cause is not clear, but this effect was certainly not limited to one area – specific wells on all sides of the landfill displayed pH increases on that date, with some reaching higher levels than any time after the pre-development samples.

pH Probes

Site investigations included subsurface sampling to construct vertical and horizontal groundwater pH profiles near three areas of concern. Differences in pH may provide indirect evidence about the source of dissolved metals. Between June 1 and 3, 2005, pH probes were attempted at 30 locations near GWC-2 and GWC-3 on the eastern landfill border, near GWC-5 on the southern landfill border, and near GWC-10, GWC-11, AMW-1 and AMW-2 on the western landfill border. Probes at 27 of the locations were successful. The locations of the pH probes are shown in Figure 36.

Standard Geoprobe equipment was initially used. A one-foot section of ¾ -inch diameter stainless-steel screen attached to the bottom of the probe rods was pushed to the sample depth. Polyethylene tubing was then inserted to the bottom and a sample was collected using a peristaltic pump. This process proved to be slow and difficult, and equipment broke down further hampering progress. That technique was abandoned after the third location.

Hollow-stem augers were used for the remaining pH probes. A hole was drilled to the sample depth, the augers were pulled up about 12-inches and polyethylene tubing with a stainless steel screen attached was inserted through the augers to the bottom of the boring. The screen in this application was approximately ¼-inch diameter stainless steel mesh. A peristaltic pump was used to collect a sample, and pumping rates were kept low to minimize mixing of water between strata. This process was repeated at each sample interval.

The volume pumped was typically less than ¼ gallon unless the screen clogged. When that happened, the pump was reversed to flush the screen, or the tubing was removed and cleaned manually before re-insertion. Only one sample was collected at some locations due to persistent clogging issues.

At each interval, several samples were collected and pH measurements made to check for stabilization. The observed pH changes with depth suggest that representative samples were obtained. Each boring was backfilled with bentonite after completion.

Soils were visually inspected in the course of the pH probe investigation. Soil samples were placed in a plastic bag and changes in coloration were noted after approximately 24 hours. At least one soil sample, from Probe 5 on the east side of the landfill near GWC-2, revealed yellow and rust-colored oxidation staining after the 24-hour period comparable to that documented in the borrow area. The color change was more intense after 96 hours. One of the probe water samples from the area of GWC-2 contained clay-sized sediment after filtration with a 0.1-micron filter. However, the sample was observed to clarify within an hour, likely indicating the flocculating influence of dissolved aluminum in the water. This has parallels to the borrow area observations.

The results of pH probes are shown in Figures 37 through 39. Multiple pH measurements are shown above a line indicating the approximate elevation of sample collection. The

construction diagrams and logs for nearby wells are included for comparison purposes, as are the range of historic water levels in those wells. Two pH readings and dates are shown inside the well diagrams; these are data from the monitoring events (April and October 2005) that preceded and followed the pH probes.

Several observations can be made about the data as a whole.

1. With only one exception, pH levels display a clear and consistent depth trend at every location. The lowest pH occurs in the shallowest groundwater and the highest pH at the deepest levels. (The exception is Probe 8 where higher pH is found in the shallowest sample.)

2. The increase of pH with depth is highest near GWC-2. In the four probes nearest this well (Probes 1, 4, 5 and 7), the pH increases by an average of 1.1 units over 10 feet. If Probe 8 is excluded due to possibly anomalous shallow pH, there are seven probes on the eastern side of the landfill where three samples were collected at five foot intervals; the average pH increase with depth for all these is 0.9 units per 10 feet.

3. The increase of pH with depth appears to be less near GWC-5 on the southern landfill border (0.6 units over 10 feet, based on one probe) and near the western border (an average of 0.3 units per 10 feet, based on two probes).

4. If the two pH readings at an adjacent monitoring well are used to derive an interpolated pH for the time of the pH probe investigation, the well pH is typically lower or comparable to the shallowest pH probe result. Considering the depths of the well screen and probe depths in each case, it appears that groundwater near the top of the saturated zone might have a lower pH than that observed in the shallowest probes, at least on the eastern and western sides of the landfill.

5. At similar depths, there is no consistent relationship between pH and distance from the landfill. On the eastern side, probes nearest GWC-2 show lower pH toward the landfill; from Probes 8, 9 and 10 southward to GWC-3, pH is lower away from the landfill; south of GWC-3, pH is lower near the landfill. On the southern side, three pairs of probes show lower pH closer to the landfill and one pair shows higher pH near the landfill. On the western side, probes near GWC-10 have slightly lower pH close to the fill, while probes near GWC-11 have markedly lower pH farther from the fill. Outside the ditch, probes near AMW-1 show lower pH farther from the fill.

Several conclusions can be reached from these observations. Lower pH at shallower depths is consistent with oxidation of pyrite; some sulfuric acid would be washed into the shallowest water by precipitation but most would probably enter groundwater as the water table rises and falls within the zone of oxidation. Mixing would account for low but increasing pH at greater depths.

Finally, the soil observations near GWC-2 seem to be similar to those associated with confirmed acid sulfate soils observed in the borrow area on the other side of the landfill. Along with pH decreases at wells in various parts of the site in response to precipitation, this evidence points toward areas of acid sulfate soil at numerous locations near the landfill.