Hsu, Benjamin

From:	Madden, Melissa
Sent:	Wednesday, July 18, 2018 11:56 AM
To:	Hsu, Benjamin; Chamberlain, Justin
Subject:	FW: WACS No. 41193 - Southeast County Landfill, Hillsborough County, Florida - Supplemental Liquid Level Assessment Reports
Attachments:	PZ Effectiveness Criteria 3 FINAL.PDF; Hillsborough_Technical_Memo_V4B4 (1)_KEG_AO.pdf

Please feel free to contact me with any questions or concerns.

Thanks, Melissa

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Subject: WACS No. 41193 - Southeast County Landfill, Hillsborough County, Florida - Supplemental Liquid Level Assessment Reports

Good Afternoon,

Re: Supplemental Reports & Updated Corrective Actions Plan
Southeast County Landfill – WACS 41193
Hillsborough County, Florida

Please find attached to this email three documents;

i) The University of Florida Report – Evaluation of the readings from the piezometers and assessment of the system pumping efforts.
ii) The Report from Susan Pelz – Pelz Environmental, Inc. – Completion of the Criteria #3 evaluation of the piezometers and readings.

As a brief summary of the technical reports provided above, the following overall findings have been provided;

1) There is liquid within the piezometers and the way it is being measured, with a standard water level indicator appears to be consistent and within a few tenths of foot of using other methods – transducers or sonic water level measurements.

2) The piezometer were flushed, are open, and do not appear to be clogged.

3) The liquid levels within the piezometer have remained static even though supplemental pumping continues from the Phase II areas. Since the levels have remained static, the levels may have reached an equilibrium point with the design of the system and liquid level removal rates.

4) The measurement of the liquid level within a piezometer does not correlate to a continuous phreatic (standing water level) that extends across the entire footprint of the landfill or within Phase I,II, and III.

5) The Series II piezometers can be effected by leakage around or adjacent to the borehole. This was confirmed by modeling and by the fact “measured” levels in the piezometer do not match the field conditions encountered during excavations.

6) Three separate excavations (one ~1,100 LF along the eastside of Phase II; one ~100 LF along the Phase III/VI, one ~100 LF along Phase II/III) had liquid levels measurements in the piezometers that were not encountered in the field. The “measured” levels in the piezometers would have indicated a standing liquid level in the sand layers; however, this was not encounter when the area was excavated.

7) If the liquid levels at the location of the piezometers was representative of condition at that specific location, then based upon slug and drawdown tests, the levels measured at these locations would potentially take more than a year to lower or would potentially require installation of dewatering points in very close proximity, within 100 ft., to have an effect these individual piezometer locations.

8) The County will continue to follow the current Corrective Action plan (continue with measurements of the piezometers, supplemental pumping, and quarterly GW sampling).

9) The County has successfully found and jet cleaned out two additional access laterals to the main collection header running through Phase II, III, and Phase VI to Permanent Pump Station B (the primary leachate removal point for Phase I-VI. One additional lateral was found one the Phase II/III boundary and one along the Phase III/Phase VI boundary. The County is evaluating these location for inclusion into the CAP or as within the Alternative Procedure.

10) Even with the heavy rains in June and July, the levels remained static with a slight increase (a few tenths of a foot and within the margin of error of measuring the liquid levels – See Criteria #1 finding Pelz Env) in the last part of July (Refer to Monthly Reports). We feel the system is functioning and keeping levels rising significantly.

11) Quarterly Water Quality Reports for the May sampling event is being compiled and will be sent to the Department for review.

We look forward to discussing the findings mentioned above and have an opportunity to explain this complex topic during our August 2 meeting.

Thank you

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Investigation of Landfill Leachate Removal at the Hillsborough County Southeast Landfill

Prepared for:

Hillsborough County Board of County Commissioners
Solid Waste Management Division

Prepared By:

Department of Environmental Engineering Sciences
Engineering School of Sustainable Infrastructure & Environment
University of Florida

UF | Environmental Engineering Sciences
UNIVERSITY of FLORIDA

Timothy G. Townsend, PhD, PE (Professor and Principal Investigator)
Steven J. Laux, PE (Professor and Co-Investigator)
Kevin Winslow (Graduate Research Assistant)
Jaeshik Chung (Graduate Research Assistant)

July 10, 2018

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EXECUTIVE SUMMARY

Hillsborough County (County) has been investigating the cause of a February 2016 groundwater exceedance event that was measured in several groundwater-monitoring wells along the east side of the Hillsborough Southeast County Landfill (SCLF) Phase I-VI disposal area. County staff has indicated that, based upon initial investigations, the exceedance event was most likely caused by a discharge of leachate from the Phase II disposal area. The County has implemented several supplemental leachate removal efforts to prevent further discharge and has been attempting to monitor the effectiveness of these efforts using piezometers to measure leachate levels in the landfill. There was an initial decline in leachate levels in some piezometers in the first quarter of 2017 after supplemental pumping began in December 2016. However, liquid levels in the piezometers in May 2018 were about the same as they were in May 2017, despite over 10 million gallons of supplemental pumping having occurred during this period.

Piezometers were initially installed by drilling a 6.25-inch borehole from the surface of the landfill through the waste mass into the underlying leachate collection system. A 2-inch diameter PVC pipe was then placed in the borehole (the pipe has perforations that correspond with the sand layer), and a sand pack was placed between the pipe and borehole wall. These piezometers are referred to in this report as “Series 1 piezometers.” The County determined that Series 1 piezometer leachate levels were being influenced by leachate from saturated perched zones in the overlying waste mass that was percolating downward through the piezometer sand pack. A modified piezometer was developed, designated as a Series 2 piezometer, where the sand pack in the upper portion of the LCS sand layer was replaced with a bentonite/grout mixture in an attempt to prevent seepage down the piezometer.

Because of the high liquid level readings measured in the Series 2 piezometers, the County installed dewatering pumps in landfill gas (LFG) wells and condensate traps, installed vertical dewatering wells, and a supplemental leachate collection trench along the east side of the Phase II area. After several months of pumping the levels dropped, but now have remained static.

The County retained the University of Florida to evaluate and provide an independent assessment of the piezometer readings and leachate removal efforts. This report documents the outcome of this investigation.

Long-term leachate pumping records for the Phase I-VI area were compared (on a gallons/acre/day basis) to leachate pumping rates of adjacent landfill cells (Sections 7-8 and Section 9). It was determined that per-acre leachate removal from the Phase I-VI area is consistently greater than, on a per-acre basis, than the leachate removal rates from Sections 7-8 and 9. These comparisons also indicate that leachate pumping rates in the Phase I-VI area fluctuate over time in a pattern similar to Sections 7-8 and 9, except during 2016 and 2017 where pumping rates in Phase I-VI increased more significantly than those of Sections 7-8 and 9. This comparison indicates that the leachate collection system is functioning and is at least as productive as the other landfill cells on this site, and indicates that recent supplemental pumping and piezometer drilling has increased leachate removal.

Phase I-VI leachate removal records and landfill leachate collections system configuration information were used to calculate theoretical maximum leachate levels based on leachate collection system configuration. These theoretical levels were significantly lower than the leachate levels measured in the Series 2 piezometers. Excavations performed in the Phase I-VI area adjacent to a piezometer found unsaturated conditions throughout the entire thickness of the sand drainage layer despite a liquid level being recorded in the adjacent piezometer.

It can be concluded from the information above that the Phase I-VI leachate collection system is at least as productive as the other landfill cells on this site and that liquid levels in the Series 2 piezometers are greater than calculated theoretical leachate collection system liquid levels. This report also explains why piezometers installed by drilling through the waste mass may not be a reliable method to measure actual liquid levels over landfill bottom liners.

Experience has shown that liquid in a landfill tends to migrate and accumulate in gas wells and piezometers that are installed in the landfill. Previous research has shown that drilling into a landfill disrupts the anisotropy of the waste, resulting in increased downward migration of liquid in the borehole. Although the boreholes around the Series 2 piezometers were sealed with grout and bentonite to prevent this from occurring, experience has shown that the heterogeneity of the waste does not allow an effective seal to prevent the downward migration of liquid.

The liquid then seeps downward in the borehole to the leachate collection system, where it causes localized mounding around the piezometer. This phenomenon, which is illustrated in this report using the two-dimensional finite element groundwater model SEEP/W, leads to higher “apparent” leachate level readings in the piezometers than the modeled level that is present in the sand drainage layer adjacent to the piezometer. It can be concluded that water levels measured in piezometers that have been installed through a waste mass into a landfill leachate collection system are influenced by liquids in the waste mass, and therefore do not necessarily represent liquid levels that would otherwise be in the leachate collection system or a continuous phreatic surface throughout the landfill.

1.0 INTRODUCTION

1.1 Summary of Issue

Hillsborough County has been investigating the cause of a groundwater impact that occurred at the Hillsborough Southeast County Landfill (SCLF). This event was the detection of elevated levels of total dissolved solids (TDS), chloride, and sodium in a monitoring well in the southeast corner of the landfill, east of Phase II in February and April of 2016. It was assumed that the groundwater impacts were caused by leachate that seeped from the side of the landfill above the top of the bottom liner system. Two possible mechanisms are hypothesized to have caused this. One possibility is the leachate collection system (LCS) was functioning poorly, resulting in an accumulation of leachate to the point where it overtopped the highest point of the landfill perimeter berm. The other possibility is that perched leachate present in the above-grade Municipal Solid Waste (MSW) regions of the landfill migrated laterally to the side slope because of anisotropic conditions within the waste. The leachate would have then seeped from the sides of the landfill and entered the underlying surficial groundwater. To evaluate the effectiveness of the LCS, the County installed piezometers at several locations through the waste mass and into the underlying sand drainage layer to monitor the leachate levels over the liner. The University of Florida was asked to examine the data collected from the piezometers and observe field investigations to evaluate if the piezometer readings are a representative indicator of actual leachate levels in the LCS.

1.2 Purpose and Organization of this Document

The purpose of this study is to evaluate whether the piezometers liquid level readings are representative of actual leachate levels in the landfill. This document is organized into eight sections. Section 2 provides some background information on the site, such as the overall layout, the leachate collection system (LCS) design, and corrective actions taken to-date.

An analysis of the site data is conducted in Section 3. This section compares normalized leachate generation rate in Phases I-VI to nearby landfills, estimates the leachate impingement rate in Phase I-VI, and summarizes the 2017 piezometer readings. Section 4 includes calculations of the maximum expected leachate levels in various locations of the Phase I-VI area based on actual impingement rates (determined in Section 3), LCS pipe spacing and bottom liner slopes. These levels are then compared to liquid levels measured in the Series 2 piezometers.

Section 5 presents the results of an excavation that was performed in the landfill (near one of the Series 1 piezometers) down to the bottom liner to compare actual liquid levels in the LCS to the Series 1 piezometer reading.

Section 6 provides a discussion on the observed piezometer readings and limitations of a piezometer's ability to measure leachate levels in a landfill LCS without influencing the reading. Computer simulations, performed using a two-dimensional finite-element model (SEEP/W), are presented in Section 7 to illustrate the concepts discussed in Section 6 (leachate flow in an anisotropic landfill and impact piezometer installation has on that flow). Conclusions and recommendations are provided in Section 8.

2.0 BACKGROUND

2.1 Overview of Site

The SCLF is comprised of two separate landfills: these are referred to as Phases I-VI and the Capacity Expansion Area (Sections 7, 8, and 9). A site map is shown in Figure 2-1. Sections 7, 8, and 9 were constructed more recently with a double liner system that conforms to current landfill liner standards (Chapter 62-701, FAC). Phases I-VI, were designed and constructed in the early to mid-1980s (before the current landfill design requirements were established) and do not have a synthetic bottom liner (the perimeter berm has a Hypalon geomembrane). Instead, the liner system for this landfill is composed of a thick layer of waste phosphatic clay. The thickness of the clay liner varies at different parts of the landfill, but averages about 5 feet, with the thickest clay located near the center of the landfill. Leachate is collected at the bottom of the landfill through a series of gravel trenches and pipes. More details on the LCS design is provided in Section 2.2. The current working face of this landfill is located in the eastern portions of Phases IV and VI. Between 2001 and 2007, annual piezocone tests were conducted by Ardaman & Associates at the site to measure the elevation, thickness and shear strength of the clay liner at different locations. These tests were performed by drilling through the waste to the underlying liner system.

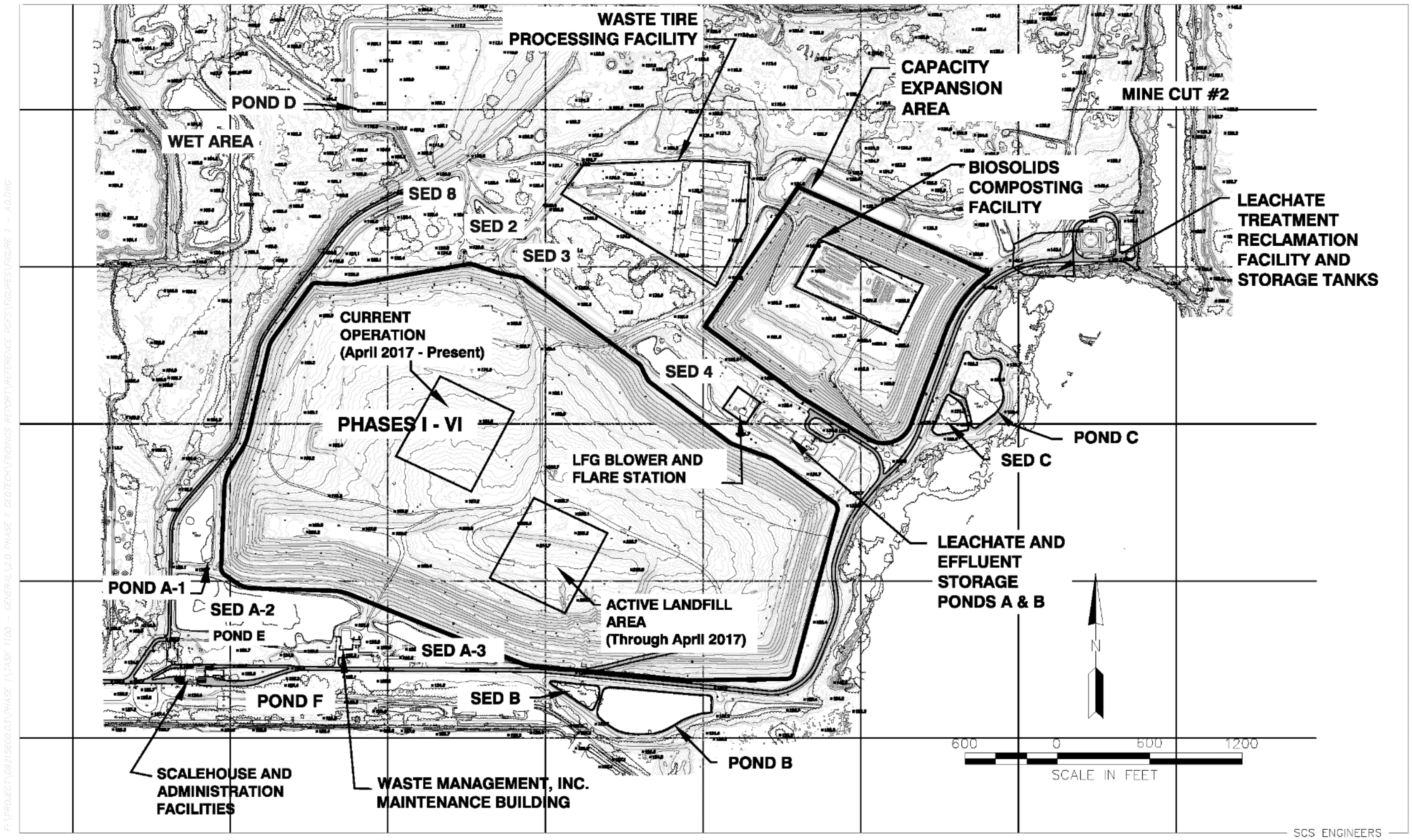

Figure 2-1. Site layout of SCLF. Phases I-VI are located in the southwest corner of the site near the scalehouse. Sections 7-9 (capacity expansion area) are located to the northeast of Phases I-VI. Figure was taken from the SCS corrective action plan from June 2017.

2.2 Design of the Leachate Collection System in Phases I-VI

The leachate collection system was designed in the early 1980s by Camp Dresser & McKee, in accordance with the landfill design standards that were in place at that time. A sand drainage layer was constructed over the top of the clay liner to drain leachate that percolates to the bottom of the landfill. The thickness of this layer ranges from 3 feet to 8 feet. A series of leachate collection trenches composed of gravel (in some cases, pipes are encased in the gravel) are spaced throughout the sand drainage layer. A cross section of one of these trenches is shown in Figure 2-2. The trenches have dimensions of approximately 2 feet by 2 feet and are covered above and below with a filter fabric. No filter fabric was placed along the sides of the trench. Leachate that enters the sand drainage layer eventually flows into the leachate collection trenches. From the gravel trenches, the leachate enters a leachate collection pipe (shown in Figure 2-3), which leads to a sump located in Phase VI. From the sump, collected leachate is pumped to the main leachate pump system (MLPS).

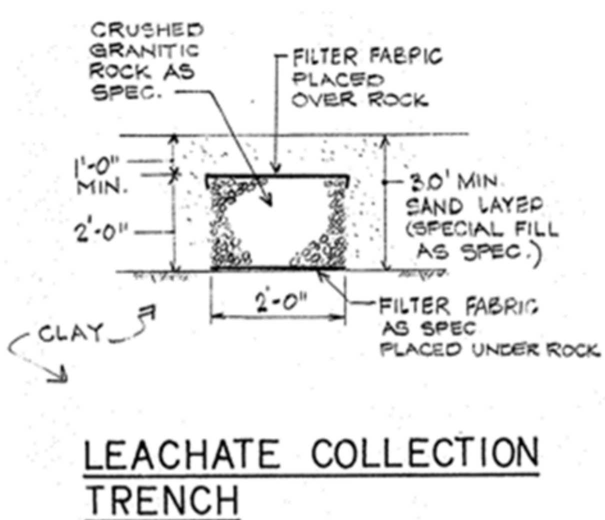

Figure 2-2. Cross section of the original CDM design of the gravel leachate collection trench.

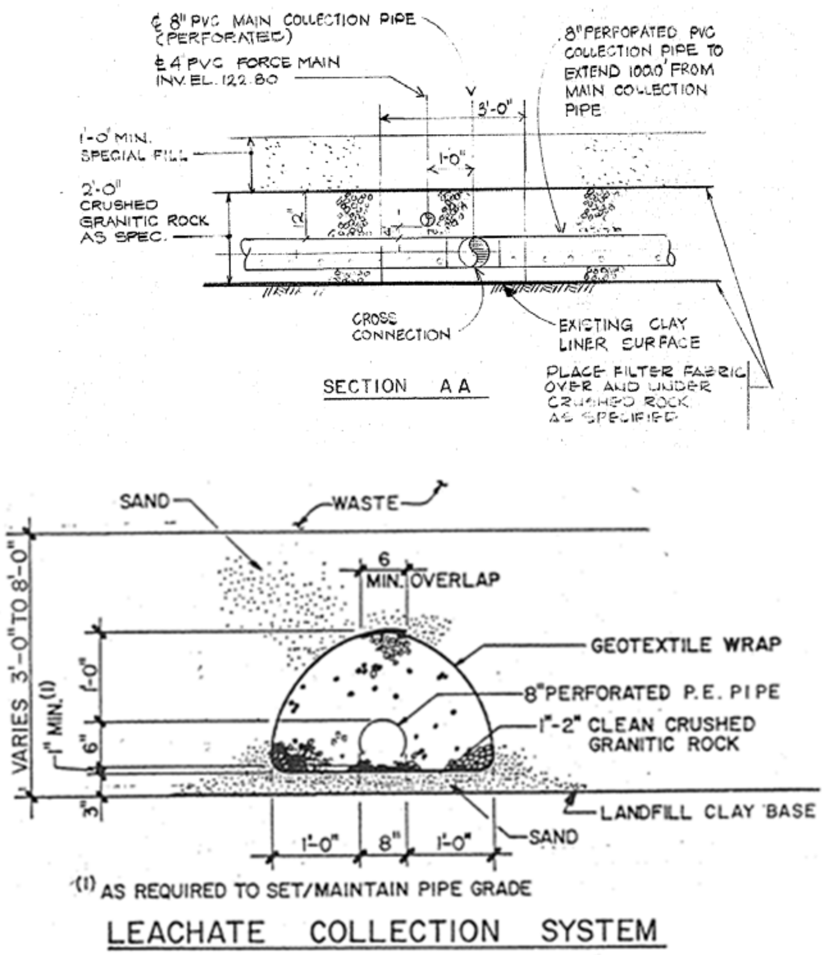

Figure 2-3. Cross sections of the original CDM design of the LCS pipes. Upper cross section shows Phases I through IV LCS PVC pipe surrounded with crushed granite and geotextile on top and bottom. Lower cross section shows Phases V and VI LCS PE pipe with crushed granite and geotextile wrap.

Figure 2-4 depicts the layout of the LCS in Phases I-VI. The system is comprised of a network of gravel collection trenches (green) and collection pipes (blue). The LCS slopes down to a low point in Phase VI (Pump Station B) where the leachate is pumped to a location outside the landfill.

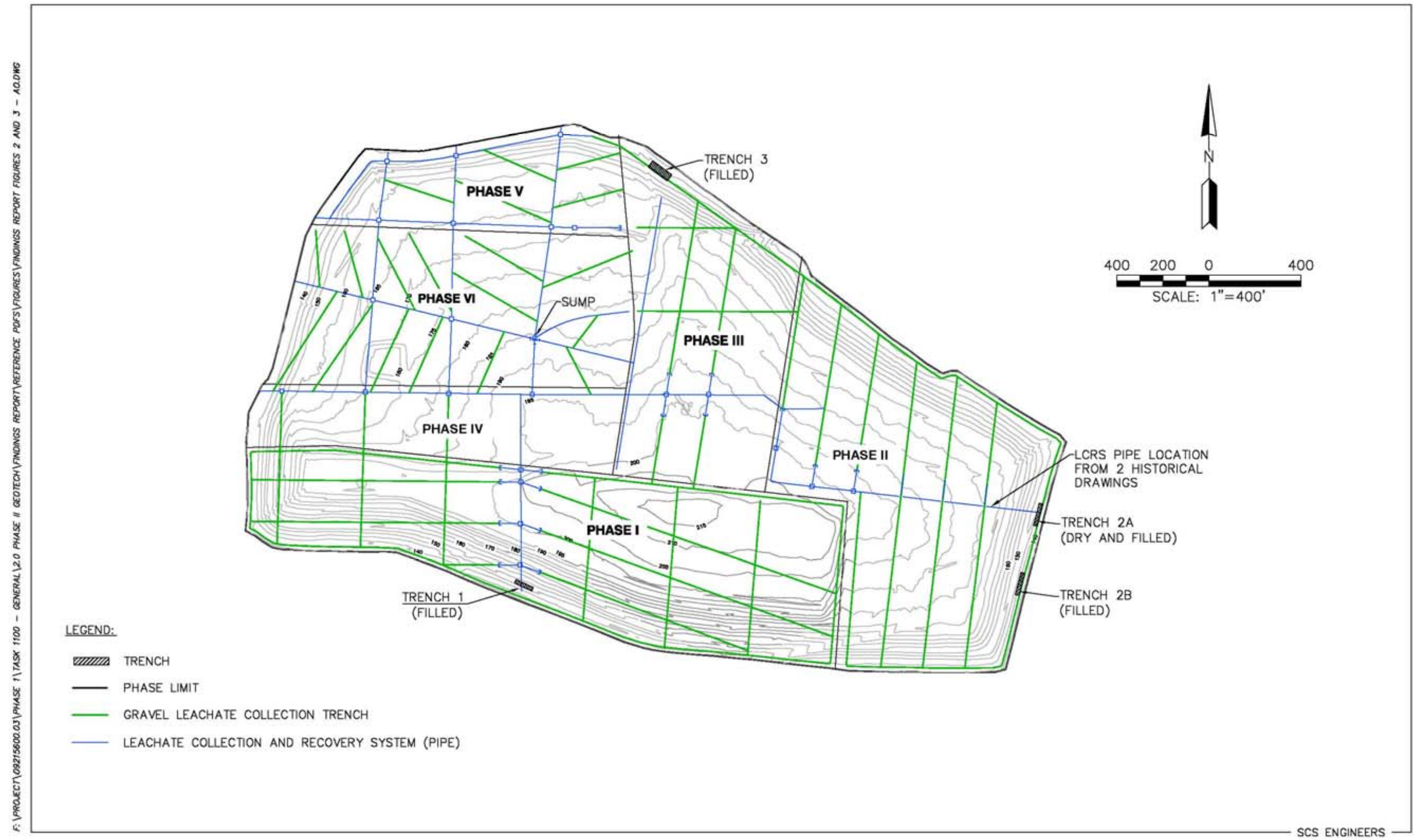

Figure 2-4. Design of the leachate collection system (LCS). The LCS is located above the clay liner in the sand drainage layer. Green lines represent gravel trenches and blue lines represent leachate collection pipes. The LCS slopes down to a collection point, located in Phase VI. Figure was taken from the SCS corrective action plan from June 2017.

2.3 Issues of Concern and Steps Taken

Beginning in February 2016, groundwater impacts were identified at monitoring well TH-67, located to the east of the Phase II landfill cell. It was determined that some of the nearby landfill gas (LFG) extraction wells in the waste mass contained liquid, and it was suspected that the landfill was saturated, causing leachate to seep from the side of the landfill and impact the surficial aquifer. To better understand the cause of these impacts, piezometers were installed to determine if leachate levels had accumulated to the point that leachate would have overtopped the bottom liner system perimeter berm. The locations of these piezometers are indicated in Figure 2-5. High liquid elevations in some of the piezometers have raised concerns about the effectiveness of the LCS and elevated leachate levels above the bottom liner.

To address the apparent leachate levels measured in the piezometers, a cut-off trench was constructed and a supplemental pumping program was initiated as a part of the corrective action plan. Seven pneumatic pumps were installed in four LFG extraction wells and three condensate traps to remove liquid. In addition, two dewatering wells and three temporary pump stations were installed on the eastern edge of the landfill to provide further liquids removal from the LCS. To determine if the LCS in Phase II had connectivity with the main pump station in Phase VI, a dye test was conducted in January 2018. From this, it was found that dye injected into the header pipe in Phase II was quickly able to reach the main pump station in Phase VI, minimizing the possibility of a blockage in the main header pipe.

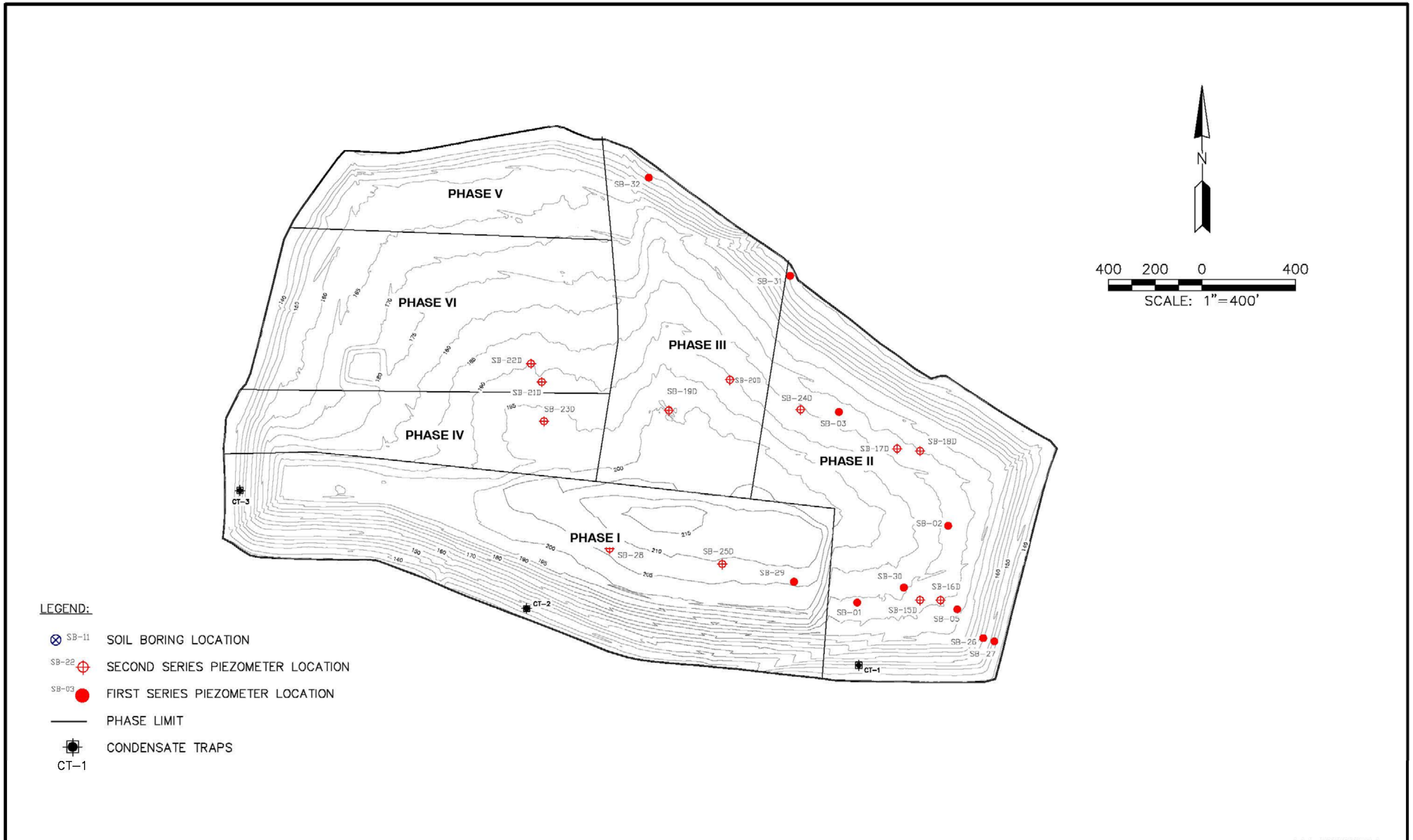

FIGURE 2. PIEZOMETER LOCATION PLAN
SOUTHEAST COUNTY LANDFILL
JUNE 2017

Figure 2-5. Map of the piezometer location plan.

3.0 ANALYSIS OF SITE DATA

3.1 Leachate Removal Rate

Daily leachate removal data for the period January 1, 2005 through December 31, 2017 for the lined landfill areas at the SCLF (Phases I-VI, Sections 7-8, and Section 9) was provided by Hillsborough County. This data was used to calculate leachate removal on a gallon/acre/day (GPAD) basis to allow comparison between these different sized landfill areas. Average monthly and average annual GPAD leachate removal rates are presented in Table 3-1, Figure 3-1 and Figure 3-2.

Table 3-1. Average GPAD leachate removal rates calculated for each year from 2005 to 2017 based on reported daily pumping rates.

	Phases I-VI (gal/acre*day)	Sections 7-8 (gal/acre*day)	Section 9 (gal/acre*day)
2005	299	110	-
2006	238	128	-
2007	206	98	-
2008	273	122	-
2009	275	89	524
2010	274	137	101
2011	274	140	46
2012	322	208	114
2013	380	217	57
2014	397	233	100
2015	374	319	185
2016	549	325	198
2017	595	301	274
Average	343	187	179*

- Indicates the landfill was not constructed at the time

* Excludes years before the landfill was constructed

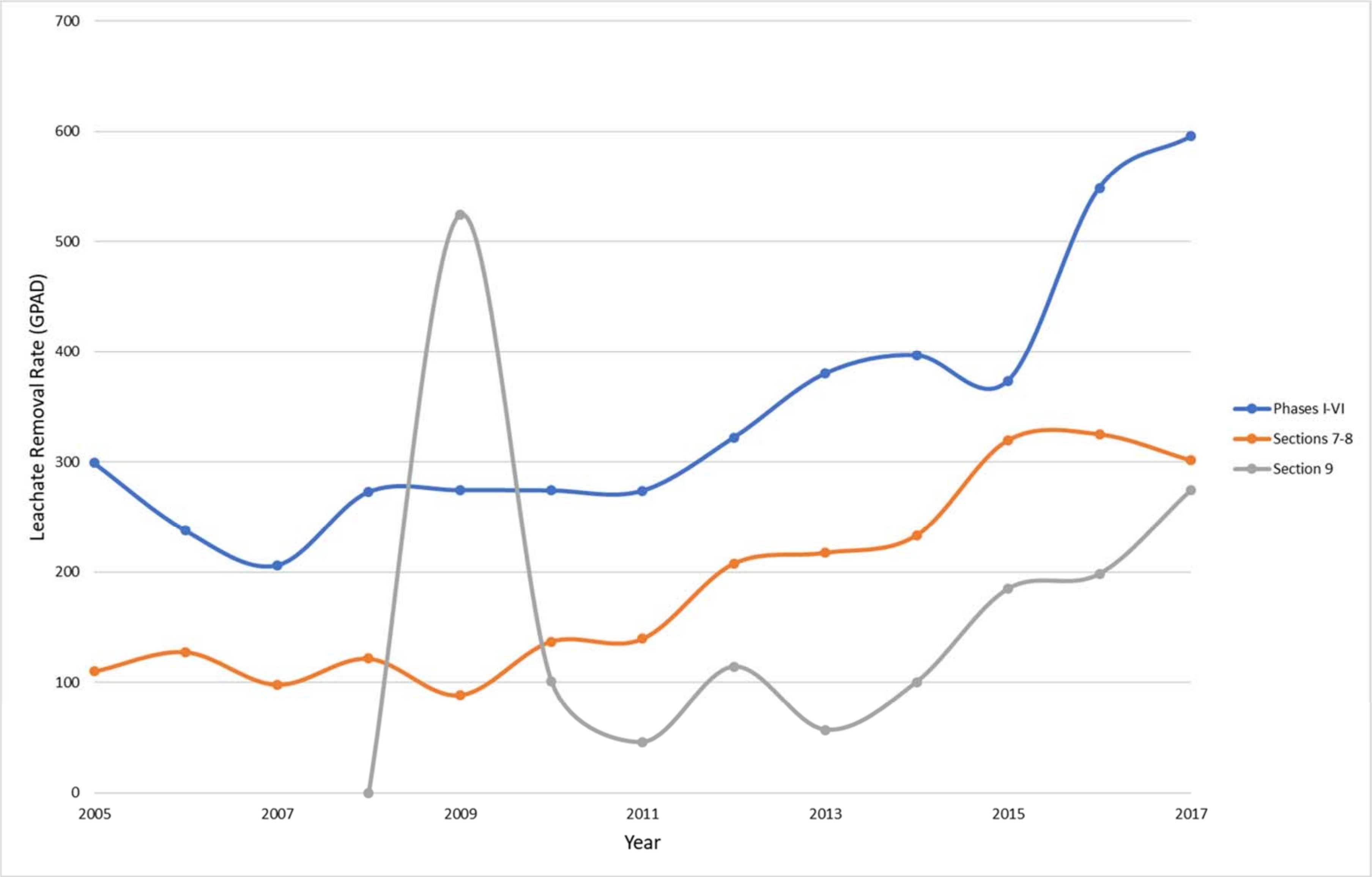

Figure 3-1. Average annual leachate removal rates (GPAD) for all three landfills from 2005 to 2017

From the results obtained, the leachate removal rate for Phases I-VI is observed to be much greater than the leachate removal rates for Sections 7-8 and Section 9 in almost every year (the high removal rate for Section 9 in 2009 was likely due to direct rainfall on the LCS before the newly constructed landfill cell was covered with solid waste). All three landfill sections showed a similar increase in removal rate from 2005 to 2015. Phases I-VI deviated from this trend in 2016 and 2017 when a significant increase in leachate removal was observed. Sections 7-9 did not show a similar increase. The increase in leachate removal in Phases I-VI could have been caused by the supplemental pumping procedure that began soon after the groundwater exceedance in February 2016. Figure 3-2 was constructed show how the impingement rates changed on a monthly basis from 2005 to 2017.

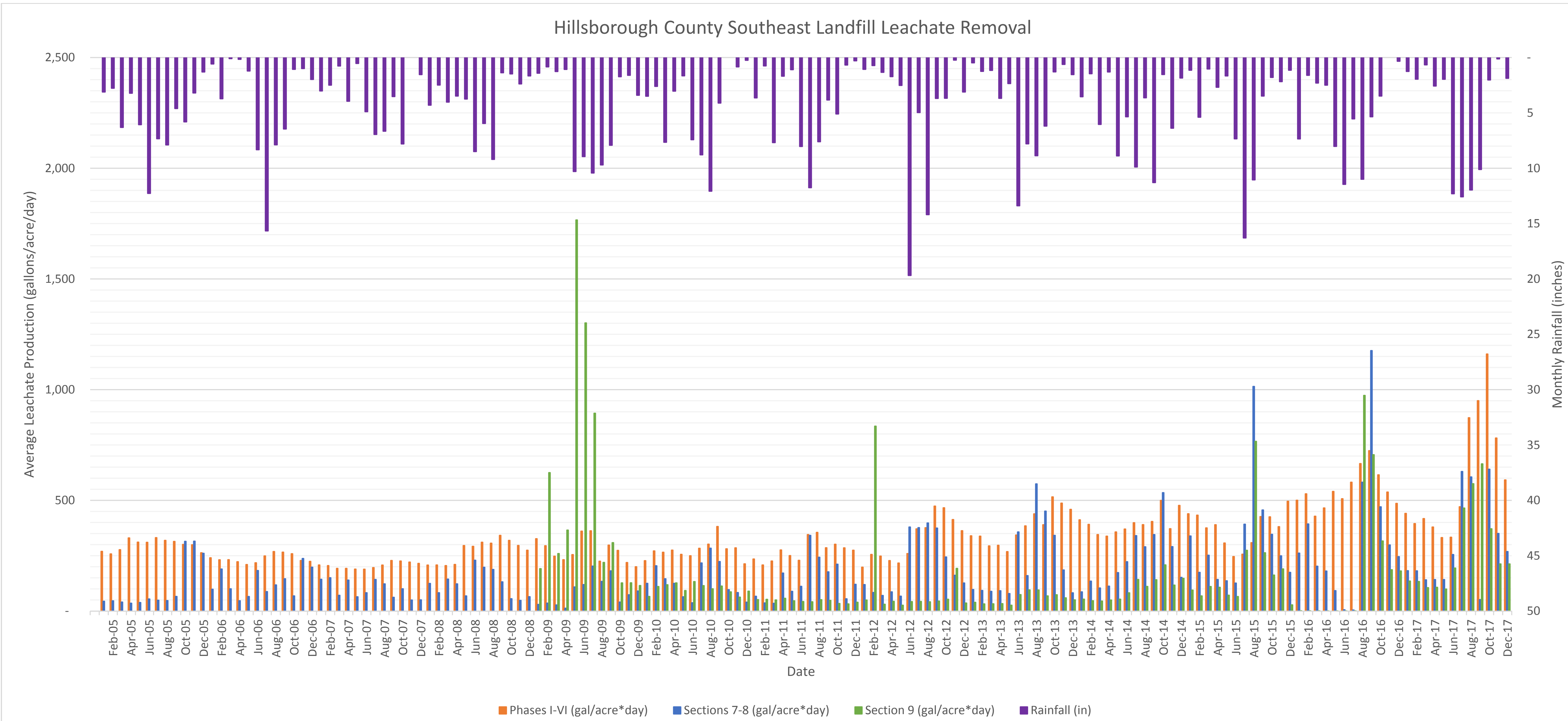

Figure 3-2. Graph of monthly average leachate removal rates from January 2005 to December 2017. Leachate removal rates for Phases I-VI are shown in orange. Monthly rainfall totals are shown in purple.

3.2 Piezometer Data

To estimate the leachate level above the liner, Hillsborough County installed several piezometers throughout the landfill. Two categories of piezometers were used, referred to as Series 1 and Series 2 piezometers. Four Series 1 piezometers were installed during the summer of 2016. One concern with the Series 1 piezometers, depicted in Figure 3-6, was that perched leachate and any accumulated moisture in the waste mass could migrate down the open borehole around the PVC pipe to the sand drainage layer. This additional liquid could cause a localized liquid mound around that piezometer that would not exist without the piezometer, and therefore giving a reading that is not representative of leachate levels that would otherwise be in the LCS. Beginning in 2017, several Series 2 piezometers were installed. The design of these piezometers differs from the Series 1 piezometers in that the open borehole is replaced with grout and a bentonite seal is incorporated at the top of the sand drainage layer. This design was intended to impede the downward migration of leachate that would affect the reading.

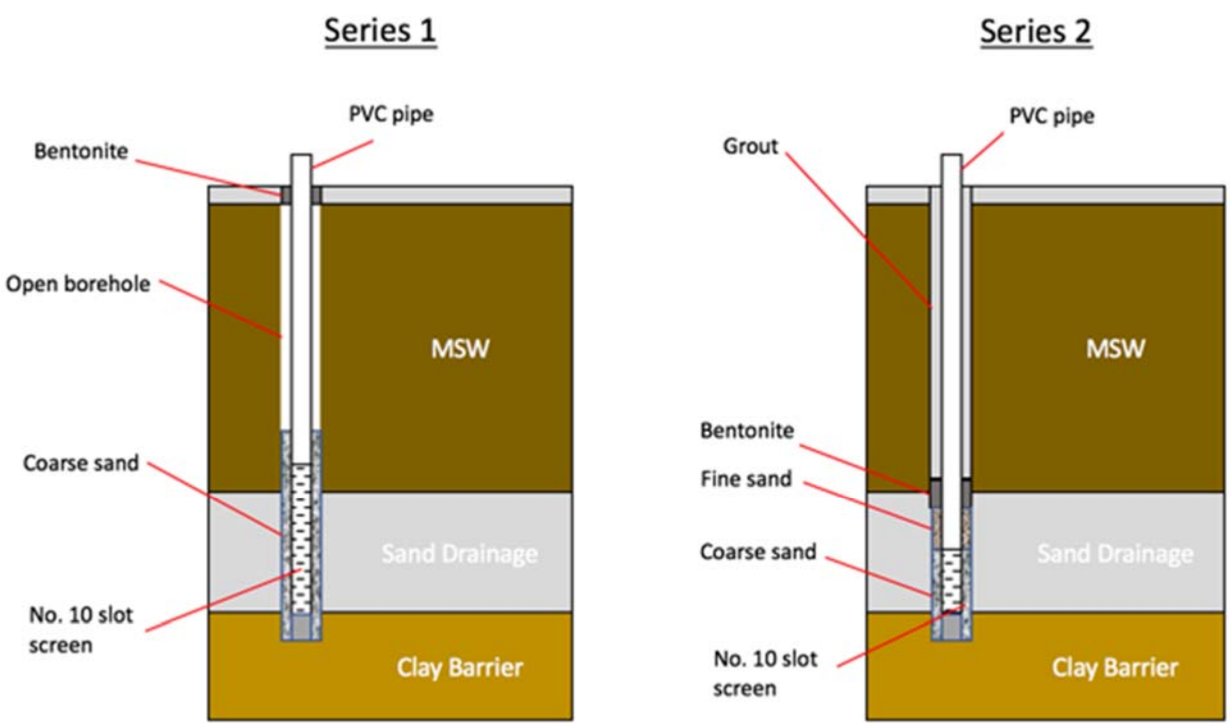

Figure 3-6. Design of the Series 1 and 2 piezometers.

3.2.1 Measurements from 2017

During 2017, weekly liquid level measurements were taken from each piezometer. The Series 1 readings were excluded in this analysis because they were not believed to be as accurate, as discussed in the previous section. Figure 3-7 depicts the location of each Series 2 piezometer and how the liquid level readings changed throughout the course of the year. A liquid level spike in most of the piezometers was observed during September, which was preceded by three months of relatively high rainfall and Hurricane Irma in early September.

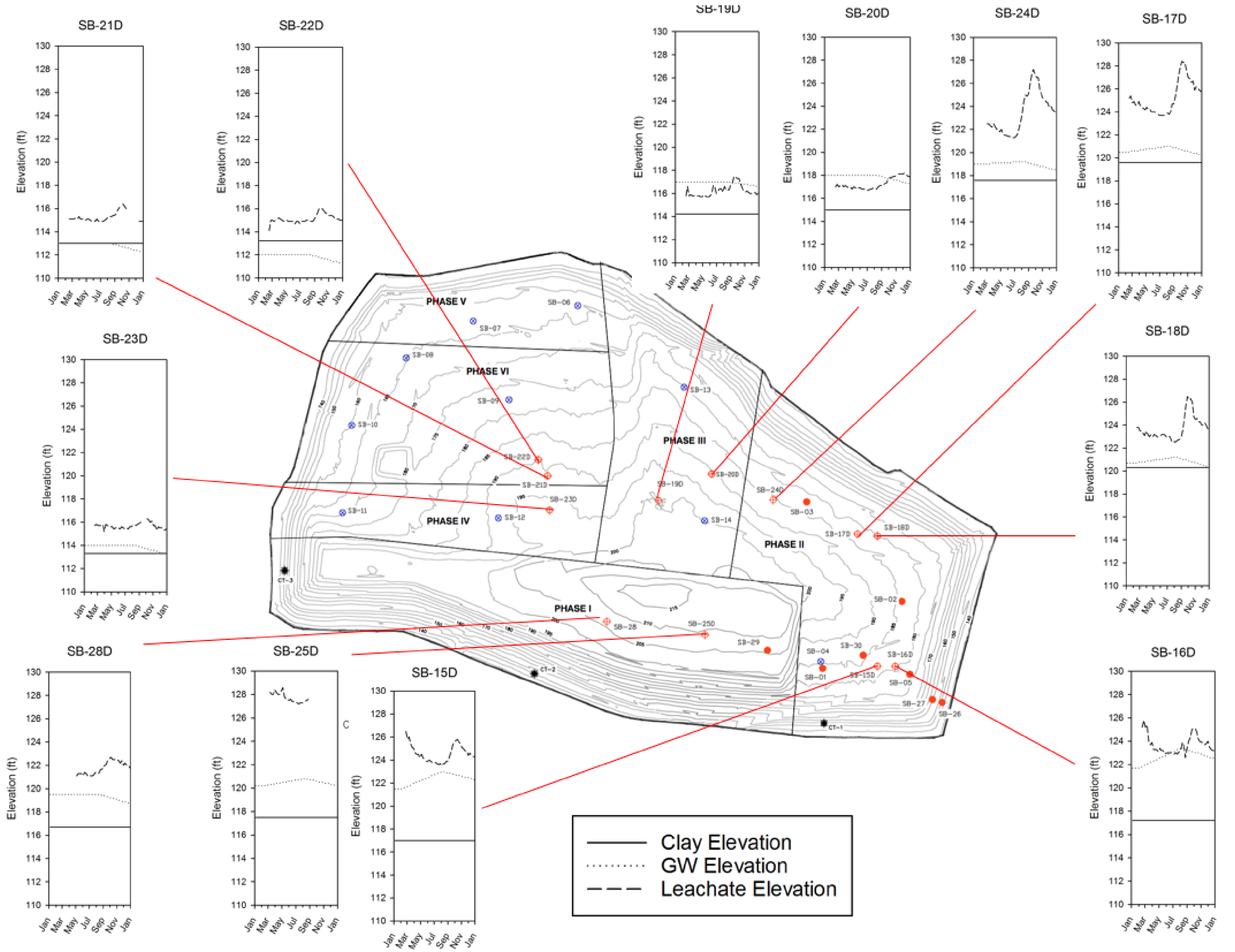

Figure 3-7. Line graphs for all Series 2 piezometers during 2017. Dashed lines indicate the liquid elevation in each piezometer as a function of time. Solid and dotted lines indicate the estimated clay and groundwater elevations at each piezometer, respectively. Groundwater data was only available for February and August.

4.0 PREDICTED LIQUID LEVEL ON THE LINER FROM THE LCS DESIGN

4.1 Methodology

The leachate collection system design can be used to calculate the maximum leachate level that is likely to occur over different regions of the liner. See Figure 2-4 for the LCS design in Phases I-VI. The LCS rests on top of the clay liner, which slopes downward to a leachate collection point in Phase VI - Pump Station B (see Figure 4-1 for a schematic of the LCS superimposed over a clay contour map of Phases I-VI). Leachate that infiltrates the sand drainage layer will move laterally until it reaches a gravel collection trench. From the gravel collection trench it eventually reaches a collection pipe, which conveys it to Pump Station Blocated in Phase VI.

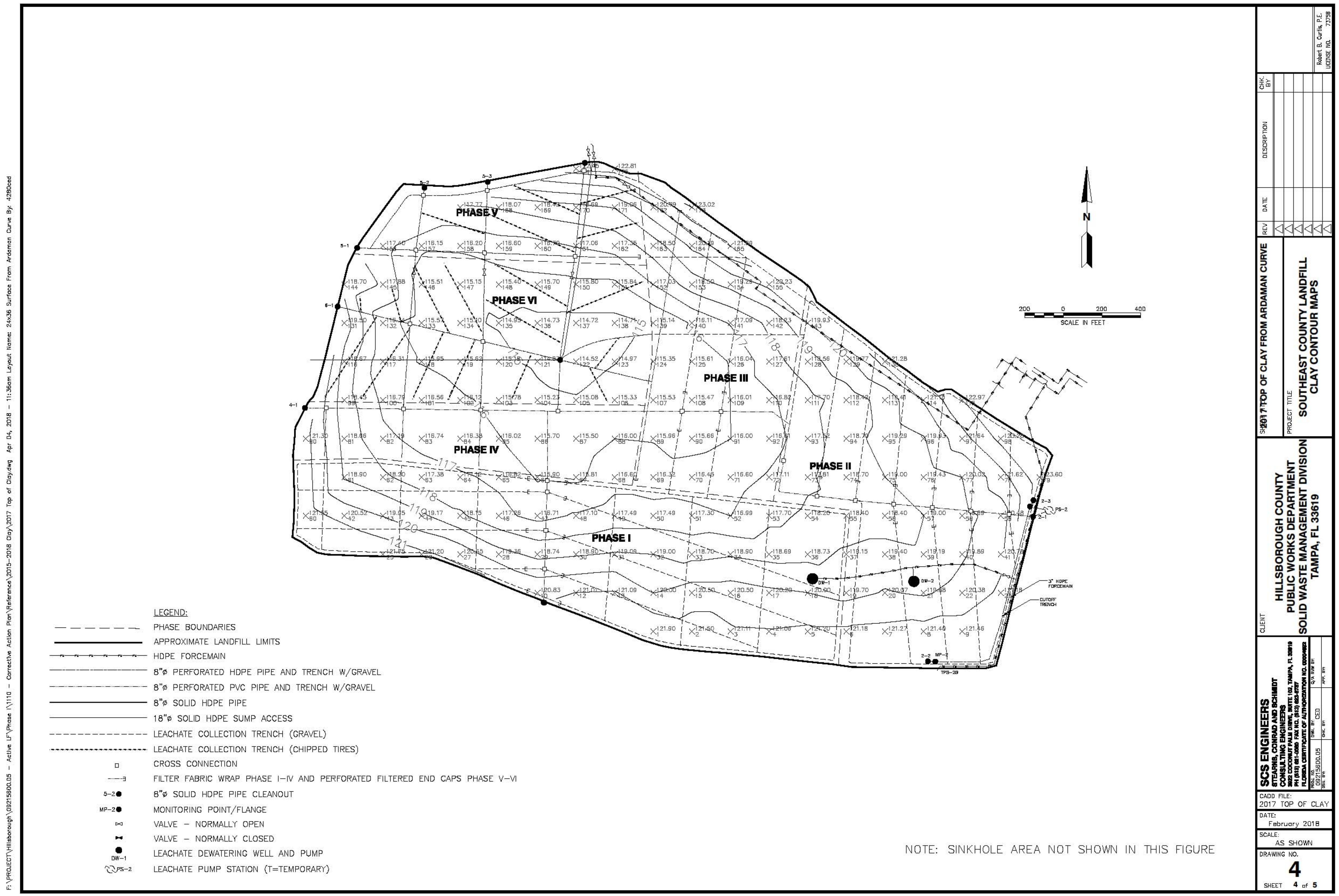

Figure 4-1. Schematic of the LCS superimposed over a clay contour map of Phases 1-VI.

When leachate infiltrates the sand drainage layer, it will typically form a mound in the space between each leachate collection trench. The highest point in this mound is equivalent to the highest liquid level over that section of the liner. Different equations for calculating the maximum liquid level over the liner are applicable for different situations. The two main situations that were applicable to Phases I-VI were a sloped case and a flat case.

The sloped case is shown in Figure 4-2. In this case, the clay liner and LCS are sloped at an angle. The leachate that infiltrates into the sand drainage layer will flow down the sloped surface to the nearest gravel collection trench, from where it will be channeled to the pump station. The Giroud equation is most commonly used for calculating the maximum liquid level over the liner for a sloped case.

$$h_{max} = L * \left(\frac{\sqrt{1 + 4\lambda} - 1}{2} \ x \ \frac{\tan(\alpha)}{\cos(\alpha)} \right) * \ j \qquad \text{(Eq. 4 − 1)}$$

The Giroud equation, shown in Eq. 4-1, is dependent on four parameters: the drainage path length (L), the slope of the sand drainage layer (α), the leachate removal rate (e), and the hydraulic conductivity of the sand (k). Once these four parameters are known, the maximum theoretical liquid level that should develop over that region of the liner can be calculated. The other parameters, λ and j, can be solved with Eq. 4-2 and 4-3 respectively.

$$\lambda = \frac{e}{k * tan^2 \alpha} \qquad \text{(Eq. 4 − 2)}$$

$$j = 1 - 0.12 * exp \left\{ - \left[log \left(\left(\frac{8\lambda}{5} \right)^{\frac{5}{8}} \right) \right]^2 \right\} \qquad \text{(Eq. 4 − 3)}$$

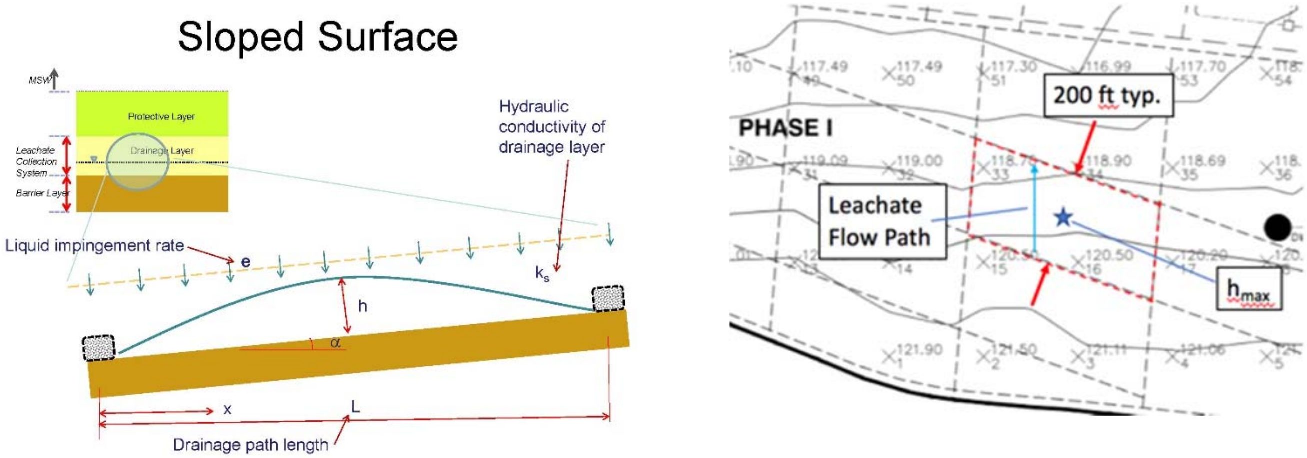

Figure 4-2. Diagram of the sloped drainage surface (left). In this case, leachate will flow from a higher elevation to a gravel trench at a lower elevation (right). A mound of leachate will develop at the point farthest from the nearest gravel collection trenches. This represents the maximum liquid level that should develop over the liner and is indicated by the star in the right-hand figure.

Figure 4-2 was used as an example to show how the Giroud equation can be applied to a sloped surface case. The right-hand figure shows one specific region of the landfill in Phase I. The gravel collection trenches are outlined in red. The highest leachate level would be expected to occur close to where the star is. When leachate infiltrates into the sand drainage layer, the leachate would be expected to flow in the direction indicated (down slope). The flow path, L, is about 225 feet (measured from the gravel trench up slope to the gravel trench down slope). The slope along the flow path was estimated to be about 0.8% based on the clay contour map in Figure 4-2. The leachate removal rate was set at 595 GPAD, based on the results obtained from Table 3-1 for 2017. The hydraulic conductivity of the sand drainage layer, k, was estimated at 0.0058 cm/s based on test results provided by AREHNA Engineering for samples collected from the sand drainage layer. After determining these parameters and using them in Eqs. 4-1 to 4-3, the maximum liquid level that should develop over this region of the clay liner was estimated to be 1.45 feet.

In some instances, a flat surface case is more appropriate than a sloped surface case for estimating the liquid level over the liner. An example of this is shown in Figure 4-3 below. Eq. 4-4 is used for the flat drainage case.

$$h_{max} = \left[\frac{e * L^2}{4k}\right]^{\frac{1}{2}} \qquad \text{(Eq. 4 − 4)}$$

Eq. 4-4 is only dependent on three parameters: the drainage path length (L), the leachate removal rate (e), and the hydraulic conductivity of the sand (k). Once these three parameters are known, the maximum theoretical liquid level that should develop over that region of the liner can be calculated.

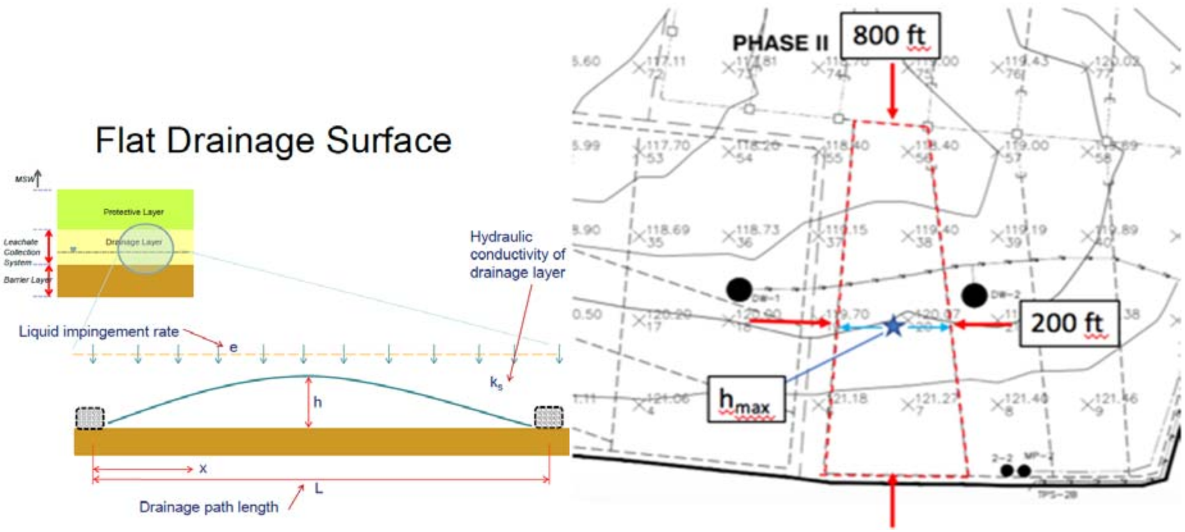

Figure 4-3. Diagram of the flat drainage surface (left). In this case, leachate will flow to the nearest gravel collection trench from either of two directions (right). A mound of leachate will develop at the point farthest from the nearest gravel collection trenches. This represents the maximum liquid level that should develop over the liner and is indicated by the star in the right-hand figure.

Figure 4-3 was used as an example to show how the Eq. 4-4 can be applied to a flat surface case. The right-hand figure shows one specific region of the landfill in Phase II. The gravel collection trenches are outlined in red. The highest leachate level would be expected to occur close to where the star is. When leachate infiltrates into the sand drainage layer, the leachate would be expected to flow in the directions indicated (toward the nearest gravel trenches). In this case, it would not flow down slope because the leachate is more likely to take the shortest path possible to the gravel collection trench, which happens to be nearly flat. The average flow path, L, is about 200 feet (measured as the distance between gravel trenches). The leachate removal rate was set at 595 GPAD, based on the results obtained from Table 3-1 for 2017. The hydraulic conductivity, k, was estimated at 0.0058 cm/s based on test results for samples collected from the sand drainage layer. After determining these parameters and using them in Eq. 4-4, the maximum liquid level that should develop over this region of the clay liner is estimated to be 1.05 feet.

4.2 Theoretical Maximum Liquid Level near Each Piezometer

The methodology discussed in Section 4.1 was used to calculate the maximum liquid level that should occur nearest to each piezometer. If the piezometers are accurate, then the readings should not be higher than the expected maximum liquid level in the region of the landfill they are located. Figure 4-4 shows the average liquid level measured from each piezometer throughout the course of 2017. Most of the piezometers read a much higher liquid level over the liner than would be expected based on the design of the LCS and leachate removal rate. These higher-than-expected readings may be caused by reasons discussed in Section 6 and modeled in Section 7.

Table 4-1. Maximum Theoretical Liquid Level Calculation Input & Output

Piezometer	Equation	Slope (%)	L (feet)	h_{max} (feet)
SB-15D	Flat		194	1.02
SB-16D	Flat		184	0.97
SB-17D	Giroud	0.56	210	1.54
SB-18D	Giroud	0.54	237	1.76
SB-19D	Flat		218	1.15
SB-20D	Giroud	0.50	377	2.70
SB-21D	Flat		204	1.05
SB-23D	Flat		507	2.67
SB-24D	Giroud	0.50	216	1.64
SB-25D	Giroud	0.80	225	1.45
SB-28D	Giroud	0.50	204	1.55

e = 595 GPAD

k = 0.0058 cm/sec

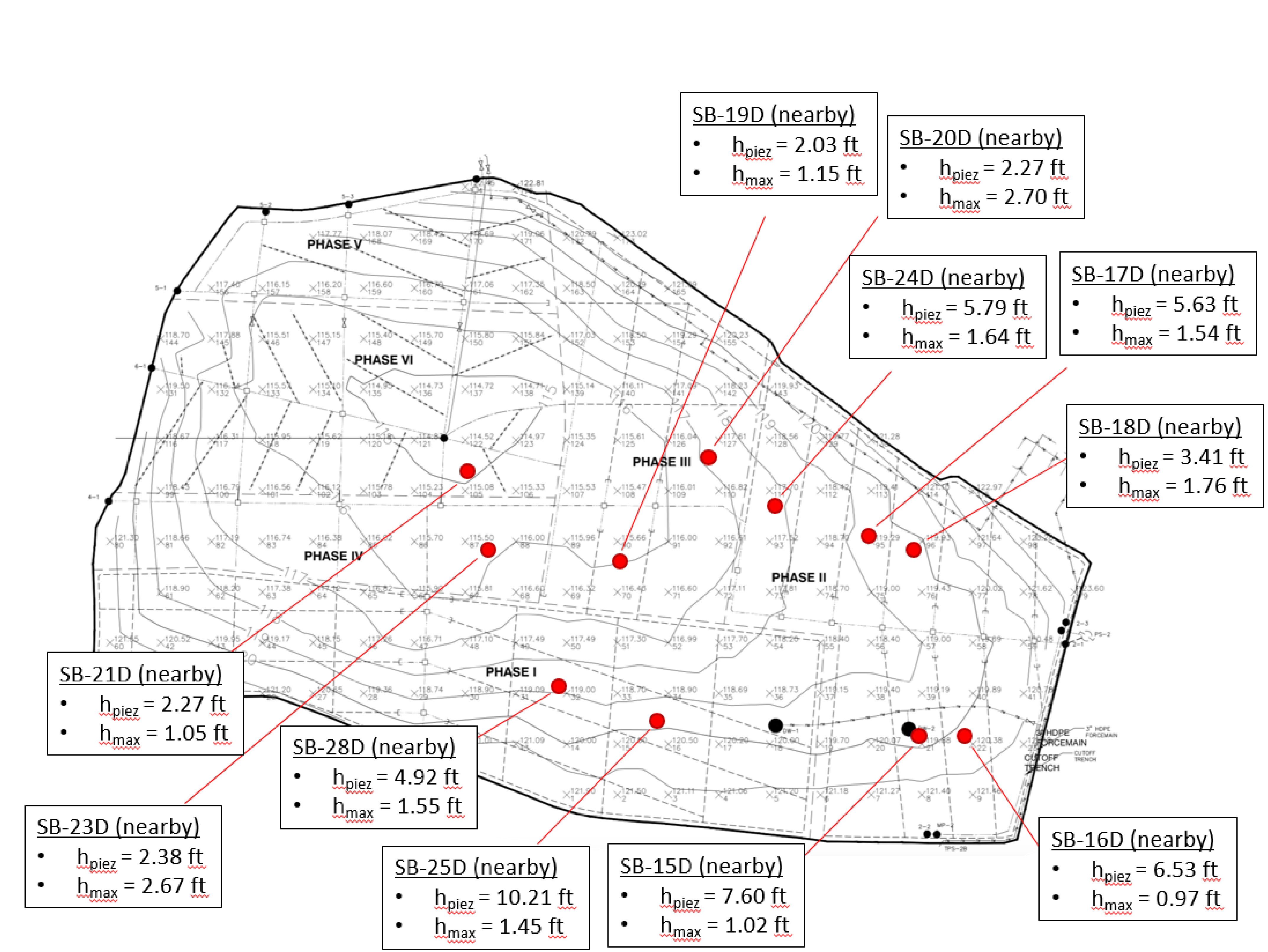

Figure 4-4. Map indicating the average leachate level measured in each Series 2 piezometer during 2017 and the maximum liquid level that would be expected near each piezometer.

5.0 FIELD EXCAVATION AT SCLF

From April 23-26, 2018, a field excavation was conducted at SCLF near piezometer SB-32 in Phase III. The purpose of the excavation was to locate the LCS header pipe so that a cleanout pipe could be installed. This excavation was also used as an opportunity to observe soil moisture contents and actual leachate levels in the LCS sand drainage layer to compare with a nearby piezometer. The trench was excavated about 5-10 feet to the south of the piezometer (Figures 5-1 and 5-2); construction progressed from east to west and the trench extended through the waste mass and underlying sand drainage layer to the top of the clay layer. During excavation, the piezometer indicated there 0.4 feet of leachate above the liner, but the surrounding sand that was excavated was not saturated with moisture as the piezometer predicted. Personnel on site observed the excavation (which had been excavated to the top of the clay layer) to initially be dry, but then noticed liquid flowing from waste layers higher up in the sidewall into portions of the bottom of the trench (see Figure 5-3, 5-4, and field observations made by Pelz Engineering Services). A surveying level was used to compare the levels recorded from the piezometer to the elevations in the adjacent trench (see Figures 5-5, 5-6 and 5-7). Using the top of the piezometer casing, previously determined as EL 146.9 feet by a registered land surveyor, as a reference point, the bottom of the excavation trench was measured to be EL 122.23 feet. At the same time, the leachate level in the piezometer was measured with a water level tape and determined to be at EL 122.62 feet (0.4 feet above the bottom of the trench).

As the excavation progressed, the trench appeared to be dry all the way down to the bottom of the drainage sand. Samples of the drainage sand were collected, stored in a sealed bag and transported to the laboratory to determine the moisture content.

The laboratory results are displayed in Table 5-1. Saturated water content (porosity) was determined by taking a known volume of the completely dried sample and adding a known volume of water to it over a funnel with wetted filter paper. The volume of water retained in the sand was used to calculate the porosity. The field capacity (moisture content where water will no longer drain) was estimated by allowing the covered sample to drain freely for 1.5 days and recording the volume of water that was still retained in the sand. The volumetric moisture content of the original sample was determined by taking a known mass and volume of sand and drying it for 24 hours. The weight after drying was recorded, and the difference between the two measurements was used to calculate the volume of water that left the sample.

The degree of saturation (volume of water divided by the volume of voids) of the sand sample taken from the bottom of the LCS sand layer (just above the clay liner) at the time of excavation was 0.82, which indicates that it was unsaturated. Unsaturated sand does not exert positive liquid pressure (head). In fact, capillary forces cause unsaturated sand to produce a negative pressure.

Table 5-1. Laboratory test results of drainage sand samples collected from the excavation.

Parameter	% of Total Volume	Degree of Saturation
Saturated Water Content	31.0%	1.0
Field Capacity	24.1%	0.78
Sample Moisture Content	25.5%	0.82

One key observation that was made following the excavation of the section of the trench closest to the piezometer was that perched water higher up in the waste mass began to seep through the side of the waste and pond in the trench (see Figure 5-1This observation provides further evidence that leachate may be building up around the piezometer for the reasons described in Section 6. Another observation made during the excavation process was that the buried waste exhibits a high degree of heterogeneity (see Figures 5-3 and 5-4). A wide range of materials, such as plastics, metals, bulky items, and soil, were found in the MSW layer. As can be seen from these trench excavation photographs, the walls of the trench are very rough and uneven. Drilling a borehole through this MSW would likewise produce a similar pattern. Completely sealing the piezometer with bentonite would therefore be very difficult because of the many empty spaces that can develop along the sides of the borehole.

Figure 5-1. Trench dug near piezometer SB-32 on April 26, 2018. The piezometer is shown in the top left hand corner of the picture. The sand drainage layer was initially dry when it was excavated. A significant buildup of leachate occurred when the section of the trench nearest to the piezometer was dug up. This leachate originated from the middle layers of the MSW, not the sand drainage layer. About 0.4 feet of leachate developed in that area of the trench.

Figure 5-2. Picture of piezometer SB-32.

Figure 5-3. Looking down the trench in the section closest to the piezometer. The sidewall of the trench shows the 4-foot sand layer at the bottom with MSW on top of it. Note the heterogeneity in the MSW layer. When this section of the landfill was excavated, the sand was originally reported to be dry. However, water soon began to seep from the side wall, where the black agricultural plastic is located (the water did not originate in the sand layer). The water ponded at the bottom of the trench, as can be seen in the figure above.

Figure 5-4. Photo illustrating the heterogeneity of the MSW layer.

Figure 5-5. Surveying equipment used to determine elevations above the ground surface.

Figure 5-6. Determining the height of the piezometer above the ground surface with a surveying level.

Figure 5-7. Measuring the depth to the top of the clay liner.

6.0 EXAMINATION OF THE OBSERVED PIEZOMETER READINGS

6.1 Possible Explanations

The results presented in Section 3.2 indicate there are potentially significant leachate levels above the liner. There are two explanations that may be able to provide an interpretation of these results. One possibility is that the piezometers provide an accurate representation of the actual level above the liner. However, based on the design of the leachate collection system and the calculations that were presented in Section 4, this may not be a realistic estimation. The levels measured in the piezometers exceed the calculated design calculations for the actual system and this was not seen in the excavations. Another explanation for the observed piezometer readings is that they are not representative of the area wide liquid levels that would exist in the absence of the piezometer. One hypothesis for why this might be true is presented in Section 6.2. This second hypothesis is more reasonable and was confirmed since the liquid levels measured in the piezometers prior to excavation, in all three separate locations in Phase II and III, exceeded the calculated design level (Refer to Section 4.2) and would have indicated a standing liquid level at the location of the excavation; however, based upon actual field observations of the conditions of the sand and waste layers within the excavations, these "measured" levels were not encountered as a static, free standing liquid level. The sands were only moist and liquids were observed flowing horizontally in the waste layer. The liquids entered the trench from the above waste layers and possibly into, or influencing, the piezometers measurements.

6.2 Sources of Inaccuracy

It is hypothesized that the piezometer data presented in Section 3.2 will lead to an overestimation of the leachate level above the liner. The cause of these higher-than-expected leachate levels would originate from the piezometer itself. Under normal conditions, the hydraulic conductivity of waste within a landfill exhibits anisotropy, leading to 10 to 100 times greater permeability in the horizontal directions than in the vertical direction (Singh et al., 2014).

This is the result of the compaction process employed at most landfills, which creates layers of low vertical hydraulic conductivity. This anisotropy can be disturbed if a borehole is drilled through these layers, which forms a zone where leachate can percolate downward to the sand drainage layer. A similar situation can occur when a piezometer is installed; the anisotropy is disturbed immediately around the newly installed piezometer, forming a region of greater isotropy. This isotropic region around the piezometer acts as a drain for the surrounding waste. Because the surrounding waste has higher horizontal hydraulic conductivity, leachate can seep horizontally towards the piezometer, where it will then flow downward in the isotropic region around the piezometer casing. This would create a drawdown effect in the upper regions of the landfill under steady-state conditions, resulting in the mounding of leachate in the sand drainage layer immediately around the piezometer. This mounding effect would influence piezometer readings that are used in determining the level above the liner; in this case, the liquid levels in the piezometer would be higher at the piezometer than what would otherwise be in the LCS if the piezometer did not exist. The piezometer would therefore not be representative of water levels in the region around the piezometer.

Although a grout and bentonite seal was installed between the borehole wall and piezometer casing in the Series 2 piezometers, the seal would not be able to effectively prevent water from seeping into the borehole. This is because compacted waste exhibits a high degree of heterogeneity (see Figures 5-3 and 5-4). Hundreds of different types of materials can be present in a given sample of MSW, with each material having different sizes, shapes, and properties. Drilling through a layer of MSW would therefore be expected to result in pockets of empty space and regions of isotropy around the outer edges of the borehole. As can be seen from Figures 5-3 and 5-4, effectively establishing a complete seal around this material would be extremely difficult. See Section 5 for further discussion.

Figures 6-1, 6-2, and 6-3 visually describe the phenomenon discussed above. In an ideal case where the installation of a piezometer does not disturb the surrounding anisotropy of the waste, the readings from the piezometers should be accurate. Section 7 will discuss the results from modeling different scenarios of these phenomena in SEEP/W.

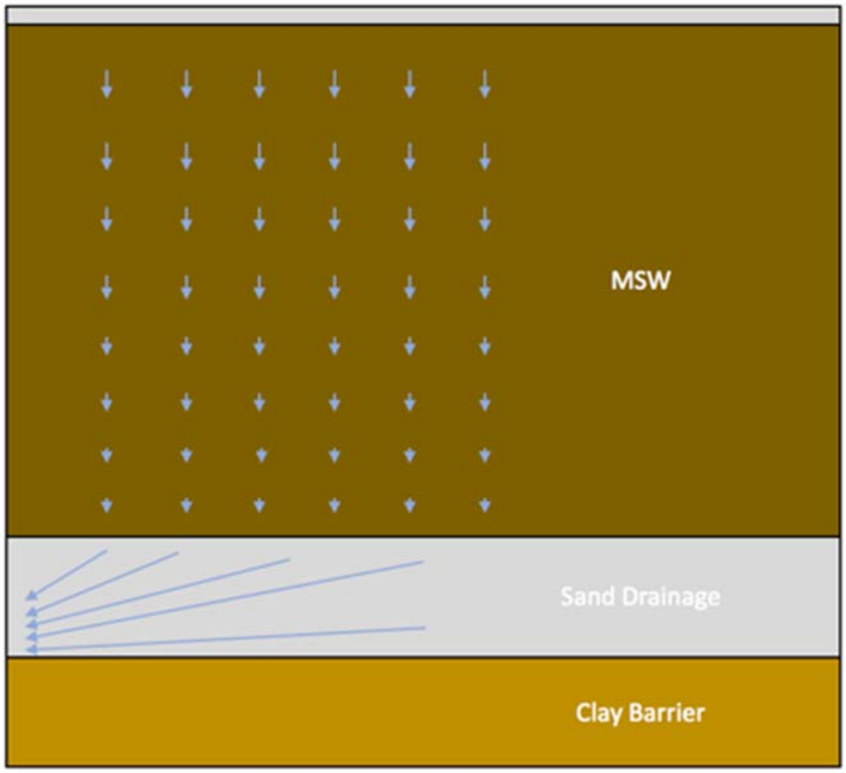

Figure 6-1. Flow vectors depicting leachate movement within a landfill before a piezometer is installed. Although there is greater hydraulic conductivity in the horizontal direction than in the vertical direction (anisotropy), the average movement of the leachate is downward since there is nowhere for leachate to travel horizontally. The vertical hydraulic conductivity of the MSW decreases with depth because of greater compaction.

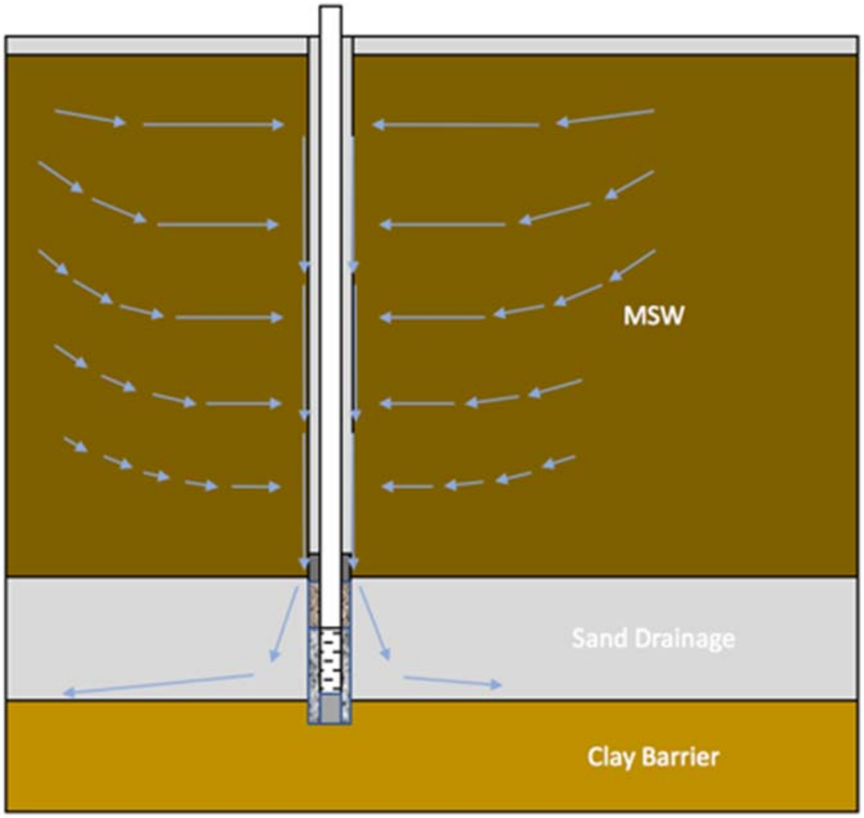

Figure 6-2. Flow vectors depicting leachate movement within the landfill after a piezometer is installed. The installation of the piezometer disturbs the anisotropy of the surrounding waste, creating a thin layer around the casing that has a high vertical hydraulic conductivity. Leachate in the surrounding area of the MSW will flow horizontally in all radial directions toward the piezometer casing, which provides a pathway of least resistance to the sand drainage layer. This leads to a buildup of leachate immediately around the piezometer.

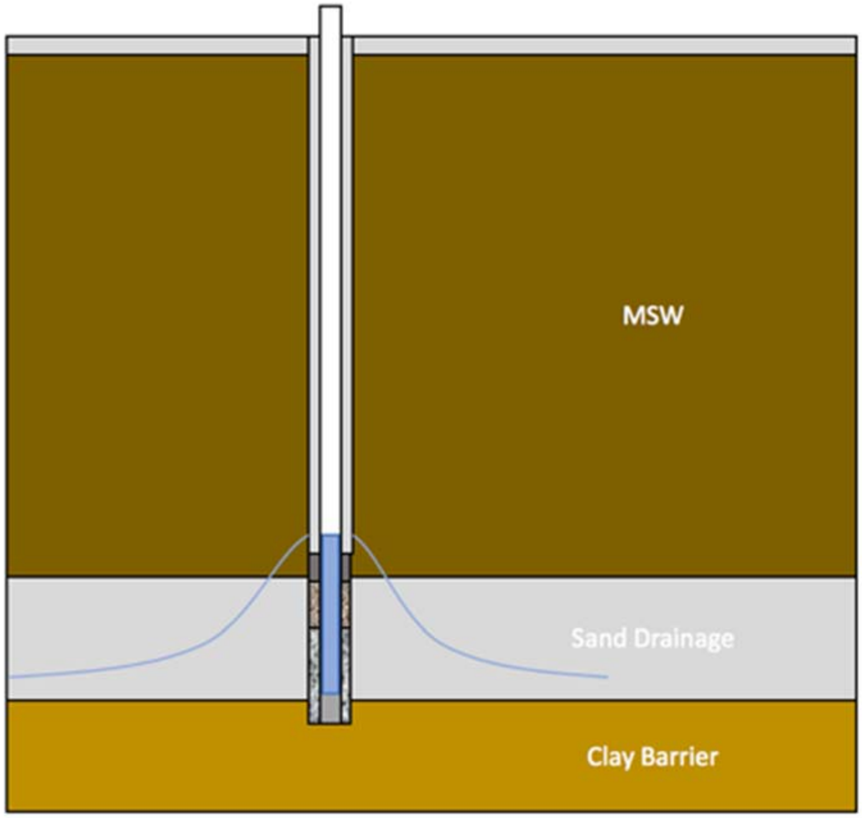

Figure 6-3. Depiction of the average leachate level above the liner. A mounding effect is observed in the sand drainage layer immediately around the piezometer due to influx of leachate from above (as described in Figure 4-2, leading to a greater liquid elevation in the piezometer than would be expected.

7.0 MODELING OF THE LEACHATE LEVEL ABOVE THE LINER WITH SEEP/W

The landfill leachate flow concepts described in Section 6 can be best-illustrated using computer simulations of subsurface flow within a landfill. A computer model was constructed to demonstrate that, even in unsaturated conditions and because of anisotropy of the waste mass, leachate moves horizontally to eventually fill boreholes drilled into a landfill (landfill operators who install landfill gas extraction wells are familiar with this phenomenon). The computer model also simulates movement of the leachate downward in the borehole and the groundwater mounding that occurs where the leachate accumulates at the bottom of the borehole (in the LCS). This section includes both steady-state and transient computer simulations of boreholes installed in unsaturated landfills and landfills that have perched liquid zones.

7.1 Description of SEEP/W

SEEP/W is a finite element software product for modeling groundwater flow in porous media. The software can model simple saturated steady-state problems or sophisticated saturated / unsaturated transient analyses with atmospheric coupling at the ground surface. The SEEP/W model is constructed to solve two-dimensional flow situations with multiple soil layers (see Figure 7-1). Flow directions of groundwater can also be analyzed. Under steady state conditions, the difference between input flux and output flux is zero at all times. For finite element calculation, the SEEP/W model is divided into nodes. The software calculates the water level elevation at each node.

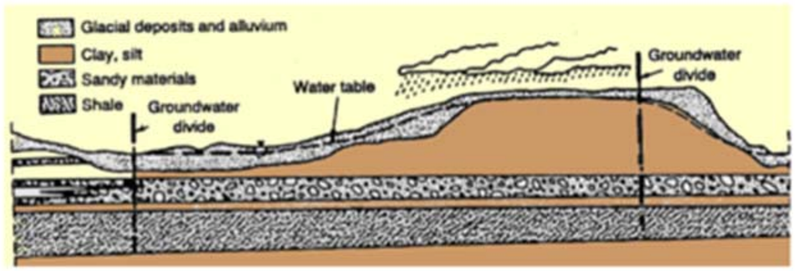

Figure 2-16 Example of a stratigraphic cross section (from National Research Report 1990)

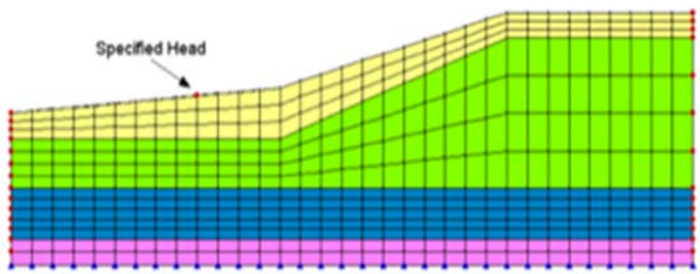

Figure 7-1. Example of finite element mesh generation with different soil layers (adopted from SEEP/W manual).

Richards equation (Eq. 7-1) is the governing equation used in this model.

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = \frac{\partial \theta}{\partial t} \qquad (\text{Eq. } 7-1)$$

where, H is the total head, K_x and K_y is the hydraulic conductivity in the x and y directions, respectively, Q is the applied boundary flux, θ is the volumetric water content, and t is time. This equation states that the difference between the flow (flux) entering and leaving an elemental volume at a point in time is equal to the change in storage of the soil systems. More fundamentally, it states that the sum of the rates of change of flows in the x- and y-directions plus the external applied flux is equal to the rate of change of the volumetric water content with respect to time.

Under steady-state conditions, the flux entering and leaving an elemental volume is the same at all times. The right side of the equation consequently vanishes and the equation reduces to:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right) + Q = 0 \qquad \text{(Eq. 5} - 2)$$

The solution of governing equation depends on the model geometry as well as the initial and boundary conditions, which will be discussed in the following section.

7.2 Types of Runs Performed in SEEP/W

In this study, a series of transient to steady-state simulations were conducted with two different scenarios; 1) without and 2) with a perched water table in the waste layer, to investigate the effect of the installation of the piezometer and how this influences the observed readings. The simulation results are presented using a degree of saturation profile. Degree of saturation is the volume of water in a segment of material divided by the total volume of that material. This profile shows the simulated degree of saturation of the waste and soil layers in the simulated landfill. Soil or waste with a degree of saturation less than 1.0 is considered unsaturated. Soils or waste with a degree of saturation equal to one is considered saturated. The figures in this report use colors to show various degrees of saturation between 0 and >0.9. A blue line is shown to delineate between unsaturated (degree of saturation < 1.0) and saturated (degree of saturation = 1.0) areas of the model. This line is known as the phreatic surface, or liquid level.

7.2.1 Geometry of modeled landfill segment

Figure 7-2 represents a schematic model of an axisymmetric landfill segment that contains a well on the left-hand side along the y-axis (geometry as in Figure 7-3). Note that five different MSW layers are considered where the hydraulic conductivity and anisotropy decrease and increase respectively in vertical direction due to compaction. Detailed dimensions including hydraulic conductivities are listed in Table 7-1.

7.2.2 Description of boundary conditions

As previously mentioned, assigning a proper boundary condition plays an important role in solving the governing equation. In SEEP/W unless otherwise specified, all boundaries that contact with no adjacent cell (outer boundaries) has “no flow” boundary. Therefore, in this study, all flow within the MSW layers occurs in either the vertical direction or horizontal direction toward the piezometer (left end); the sand layer has a drainage boundary at the right side (i.e., leachate collection system). An impingement rate of 6.6×10^{-9} $m^3/sec/m^2$ (610 GPAD) at the top layer was assumed based on the results from Table 3-1. Later, a perched water table scenario was considered by adding a highly impermeable layer at the bottom of layer 4.

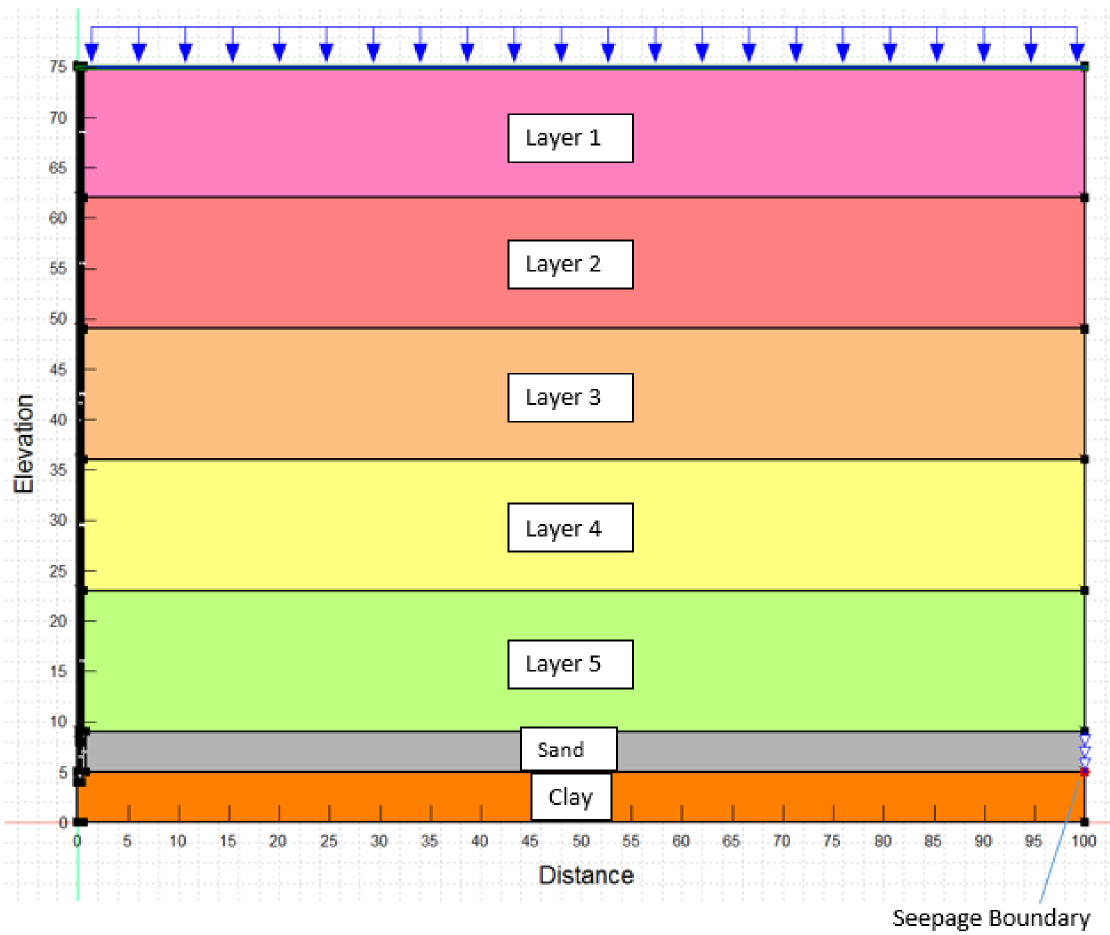

Figure 7-2. Schematic model of the landfill segment around the piezometer. The radial distance (x-axis) is 100 feet and the total height from the bottom of the clay to the top of the landfill is 75 feet.

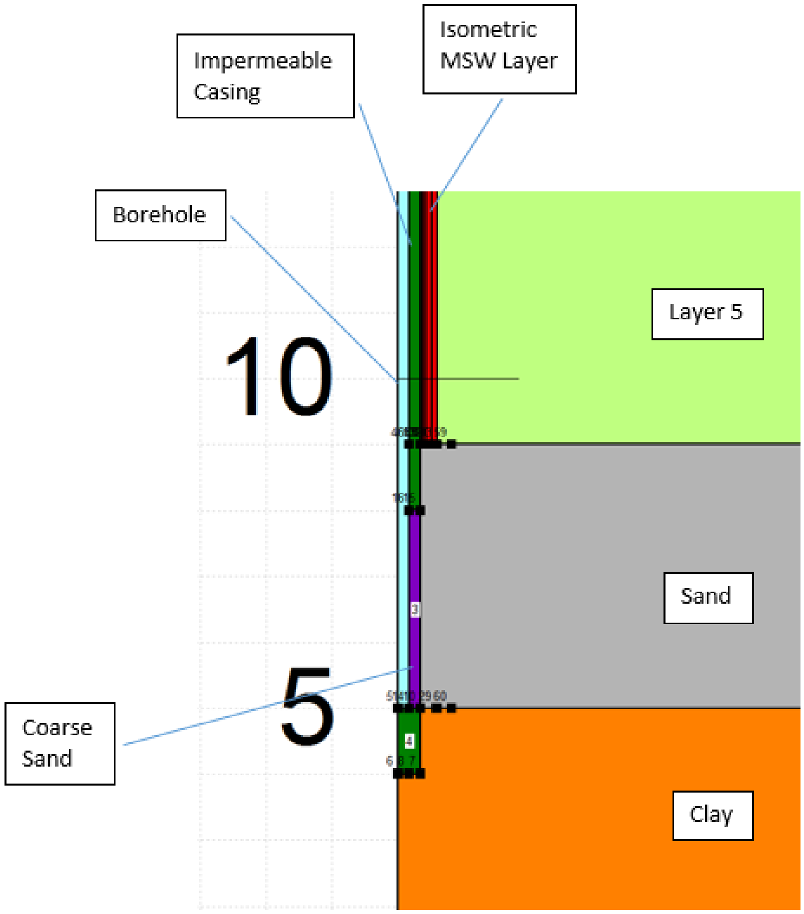

Figure 7-3. Schematic model of landfill segment. The piezometer is shown on the left-hand side.

Table 7-1. Dimensions and hydraulic properties at each layer.

		Ky/Kx	Ky (cm/s)	Kx_{sat} (cm/s)	Residual WC	Sat. WC	Height (ft)
MSW	Layer 1 (top)	0.08	1×10^{-4}	1.25×10^{-3}	0.1	0.5	13
	Layer 2	0.04	5×10^{-5}	1.25×10^{-3}	0.1	0.5	13
	Layer 3	0.02	1×10^{-5}	5×10^{-4}	0.1	0.5	13
	Layer 4	0.01	5×10^{-6}	5×10^{-4}	0.1	0.5	13
	Layer 5 (bottom)	0.005	1×10^{-6}	2×10^{-4}	0.1	0.5	14
	Isometric Layer	1	10	10	0.1	0.5	N/A
Sand (LCS)		1	1.5×10^{-3}	1.5×10^{-3}	0.1	0.45	4
Clay liner		1	1.8×10^{-8}	1.8×10^{-8}	0.1	0.5	5
Impervious Material (grout and bentonite)		1	1×10^{-20}	1×10^{-20}	0	0.5	N/A

7.3 Results

The following simulation results show how the saturation profile and leachate level on liner changes from transient to steady-state with and without a perched water table in the MSW layer.

7.3.1 Simulation result without the perched water table

A steady-state simulation was first conducted without the piezometer to provide an initial condition for the following transient analysis. In this simulation water moves vertically thorough the landfill waste layers until it reaches a highly permeable LCS sand layer. A degree of saturation profile is shown in Figure 7-4. Degree of saturation gradually increases with depth in this profile (from 0.3 to 0.4 near the surface to >0.9 at the bottom of the waste layers) due to the gradually decreasing hydraulic conductivities of the waste layers with depth. Degree of saturation abruptly drops to 0.3 to 0.4 in the sand layer. This is caused by the higher hydraulic conductivity of the sand layer compared to the lower hydraulic conductivity in the overlying waste layer; the sand layer has greater capacity to transmit liquid than the waste layer has to provide liquid. This liquid then accumulates to a maximum depth of about 0.5 feet on the low hydraulic conductivity clay layer at the bottom of the sand layer. In this simulation, water will flow from left to right toward the seepage boundary, so the maximum depth of 0.5 feet is on the left side.

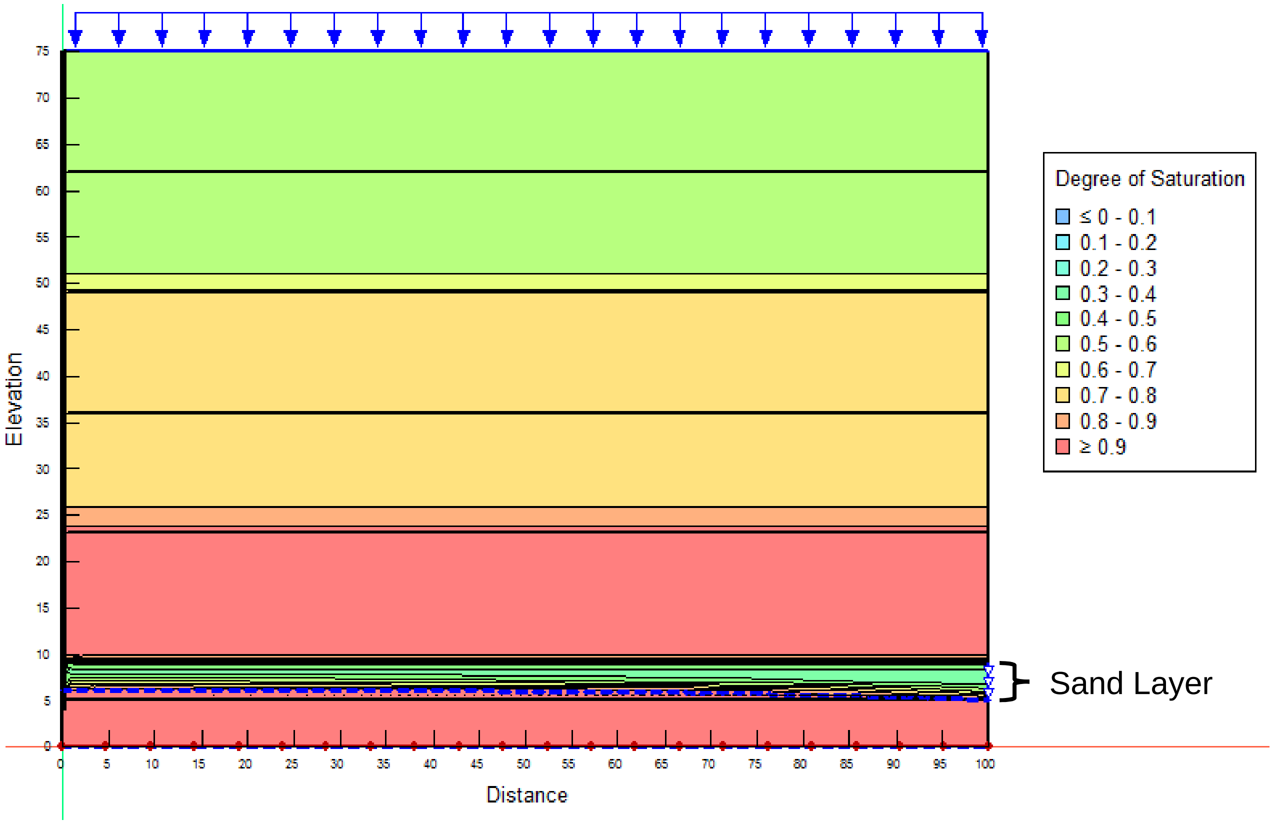

Figure 7-4. Degree of saturation profile before installation of the piezometer (without the perched water table).

Figure 7-5 represents the simulated saturation profile one day after installing the piezometer. The piezometer is installed by drilling a hole through all of the waste layers, removing the low permeability waste material and replacing it with a higher permeability material that represents a poorly sealed borehole annulus. Liquid then begins to move laterally from the waste layers to the piezometer. This causes the degree of saturation in the waste layers around the well to decrease. The liquid then enters the borehole and flows downward to the sand layer, where it accumulates around the piezometer.

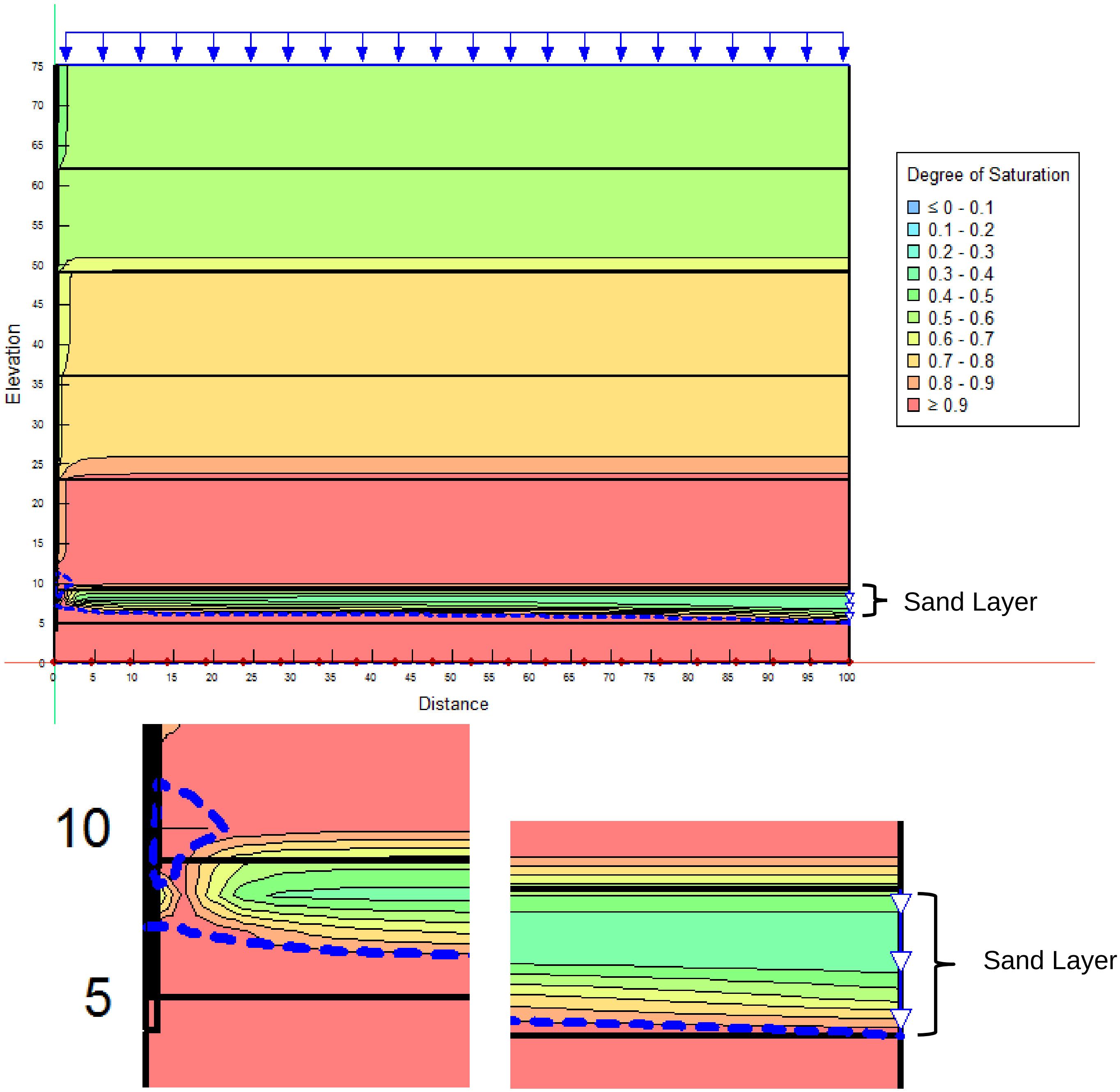

Figure 7-5. Degree of saturation profile and leachate level on the liner at the both ends of sand one day after installation of the piezometer (without the perched water table).

This trend continues until it reaches steady state (after about five years). Figure 7-6 represents the saturation profile five years after installing the piezometer; the leachate level on the clay liner was about 2.3 feet near the piezometer.

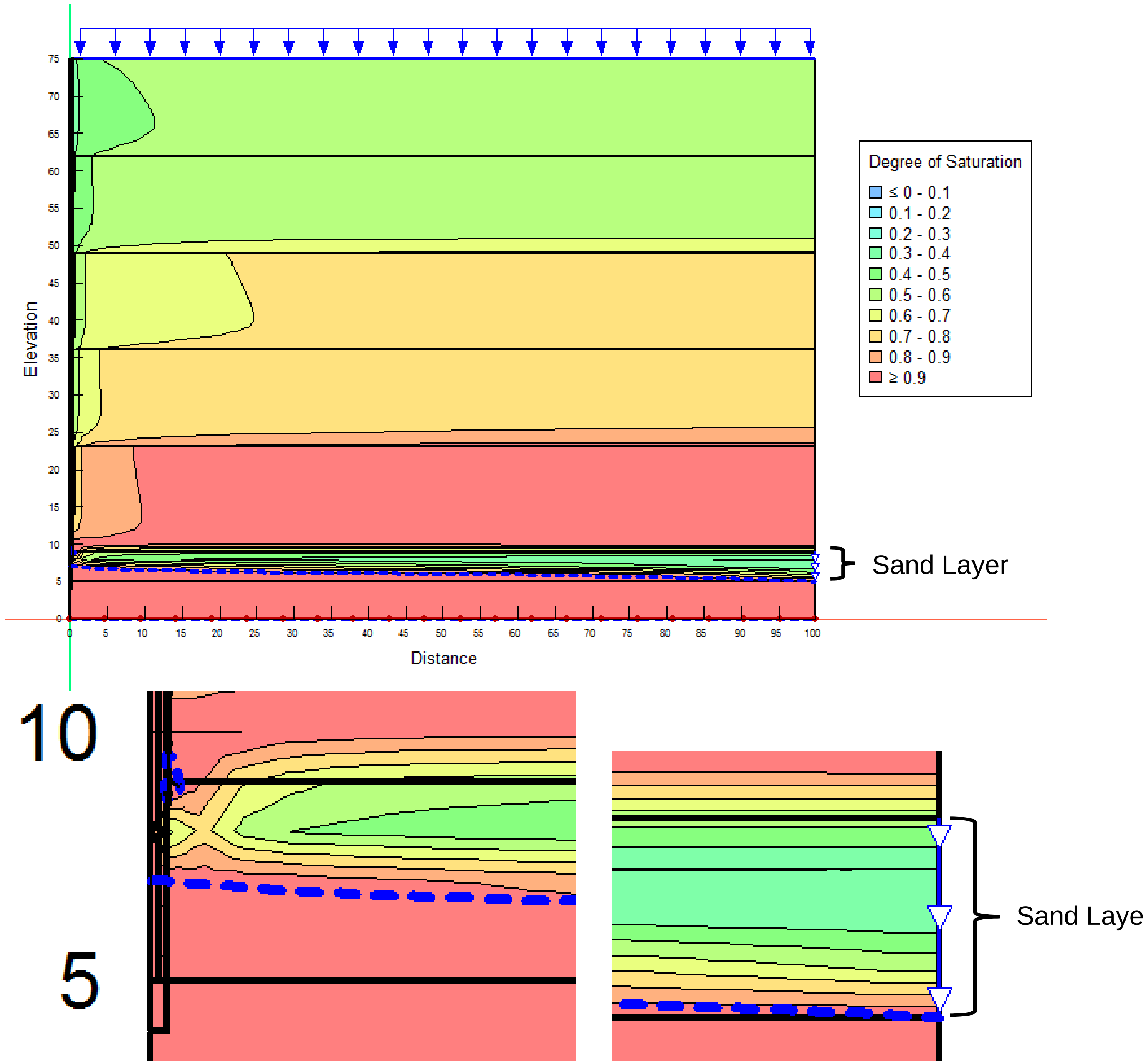

Figure 7-6. Degree of saturation profile and the leachate level on the liner at the both ends of sand layer five years after installation of the piezometer (without the perched water table).

7.3.2 Simulation result with perched water table

A similar series of simulations were conducted by creating a perched water table at the bottom of layer 4 to model the possibility of perched conditions within the waste mass. Figure 7-7 shows the steady-state saturation profile before installation of the piezometer. Note that there are two different phreatic water surfaces (blue dotted lines) in the middle of waste layer as well as in the sand layer. The steady-state level on the liner was almost zero, which indicates that the drainage system operates properly under the moderate impingement rate (610 GPAD).

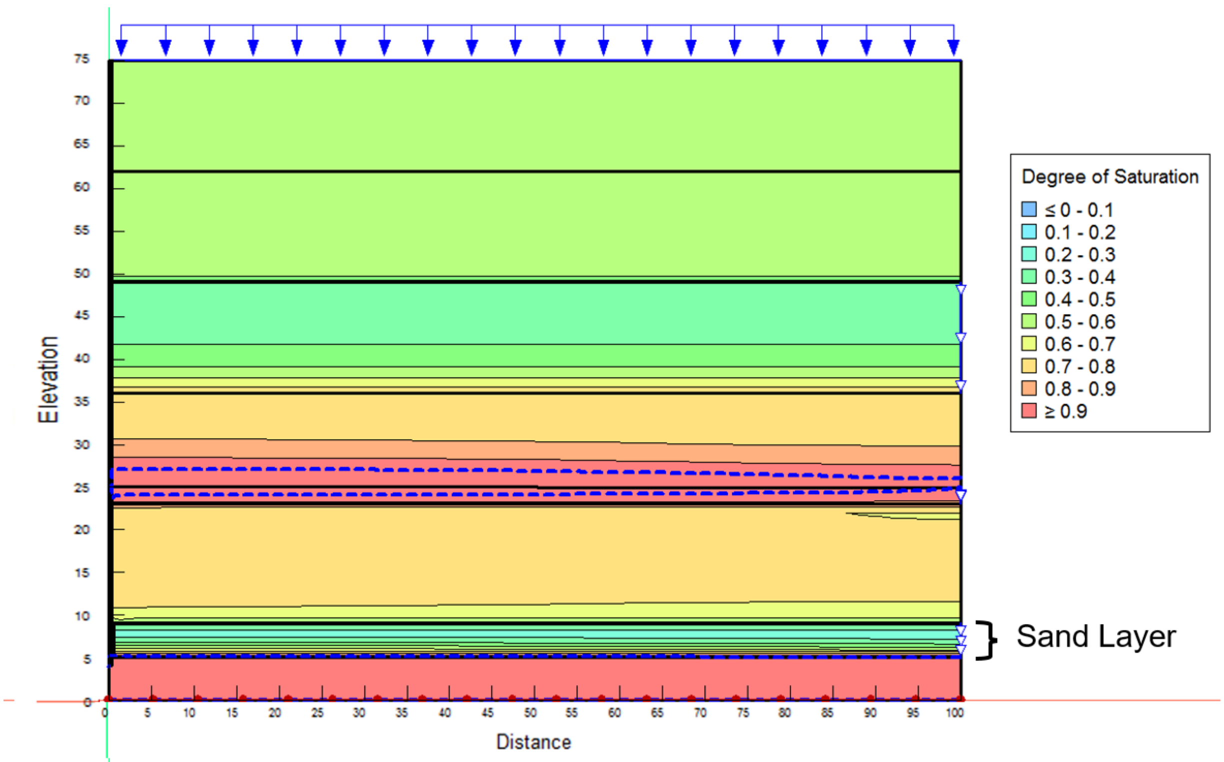

Figure 7-7. Degree of saturation five years after the installation of the piezometer (with the perched water table).

Figure 7-8 represents the saturation profile one day after the installation of the piezometer. Similar to the previous case, water near the piezometer starts to move in the MSW toward the piezometer and the degree of saturation in the waste layers around the well decreased. In this case, free water in the perched layer also began to flow to the piezometer. This increased quantity of liquid then enters the borehole and flows downward to the sand layer, resulting in an abrupt increase in the liquid levels in the sand layer.

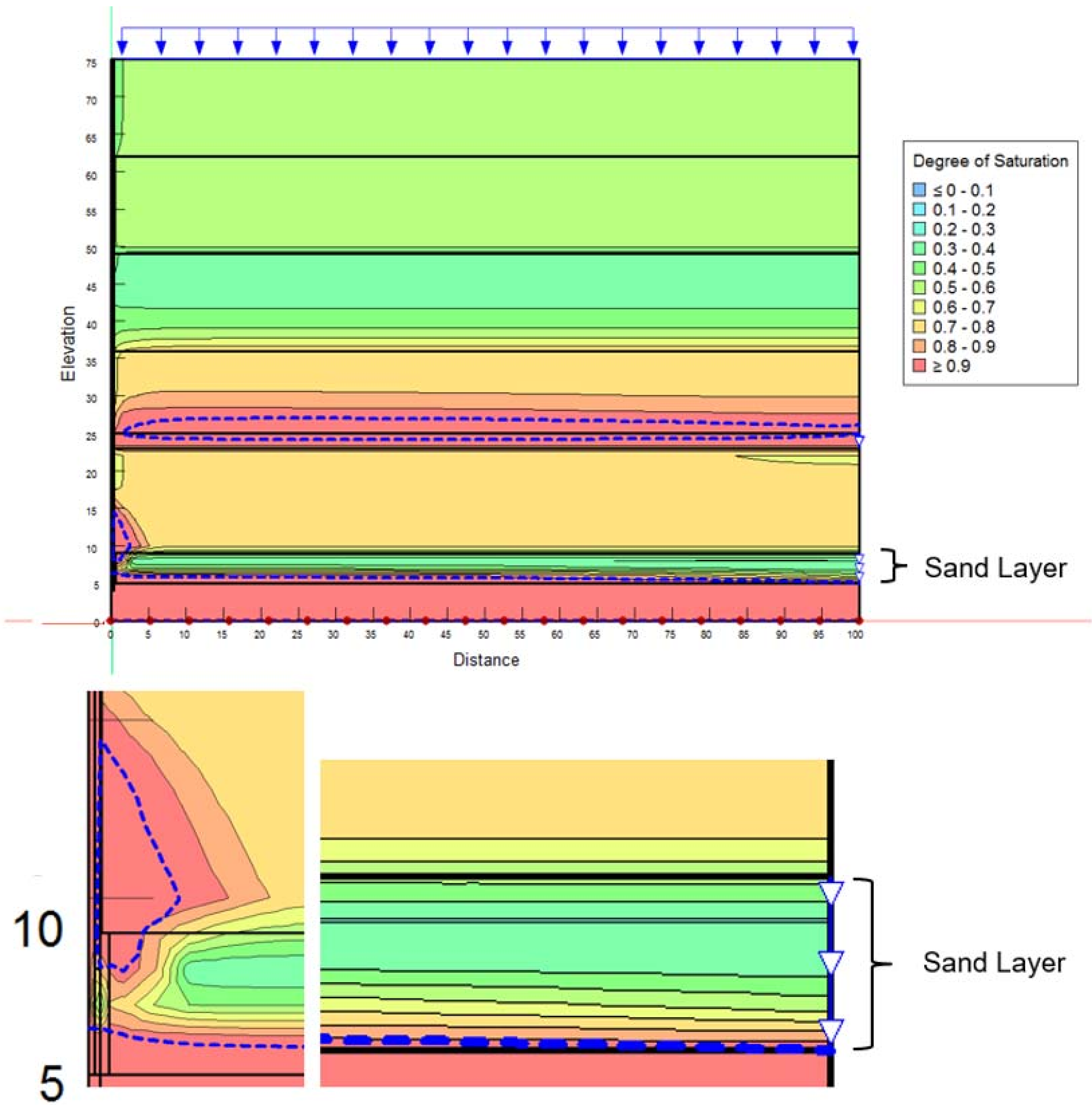

Figure 7-8. Degree of saturation and the leachate level on the liner at the both ends of sand layer five days after the installation of the piezometer (with perched water table).

Figure 7-9 represents the saturation profile at steady-state conditions 6.5 years after the installation of the piezometer. Note that the water elevation inside the piezometer increased up into the MSW layer (approximately 7.9 feet above the bottom of the sand layer), and the subsequent build-up of liquid was observed in the LCS around the piezometer, which gradually decreased towards the drainage boundary at the end of the sand layer.

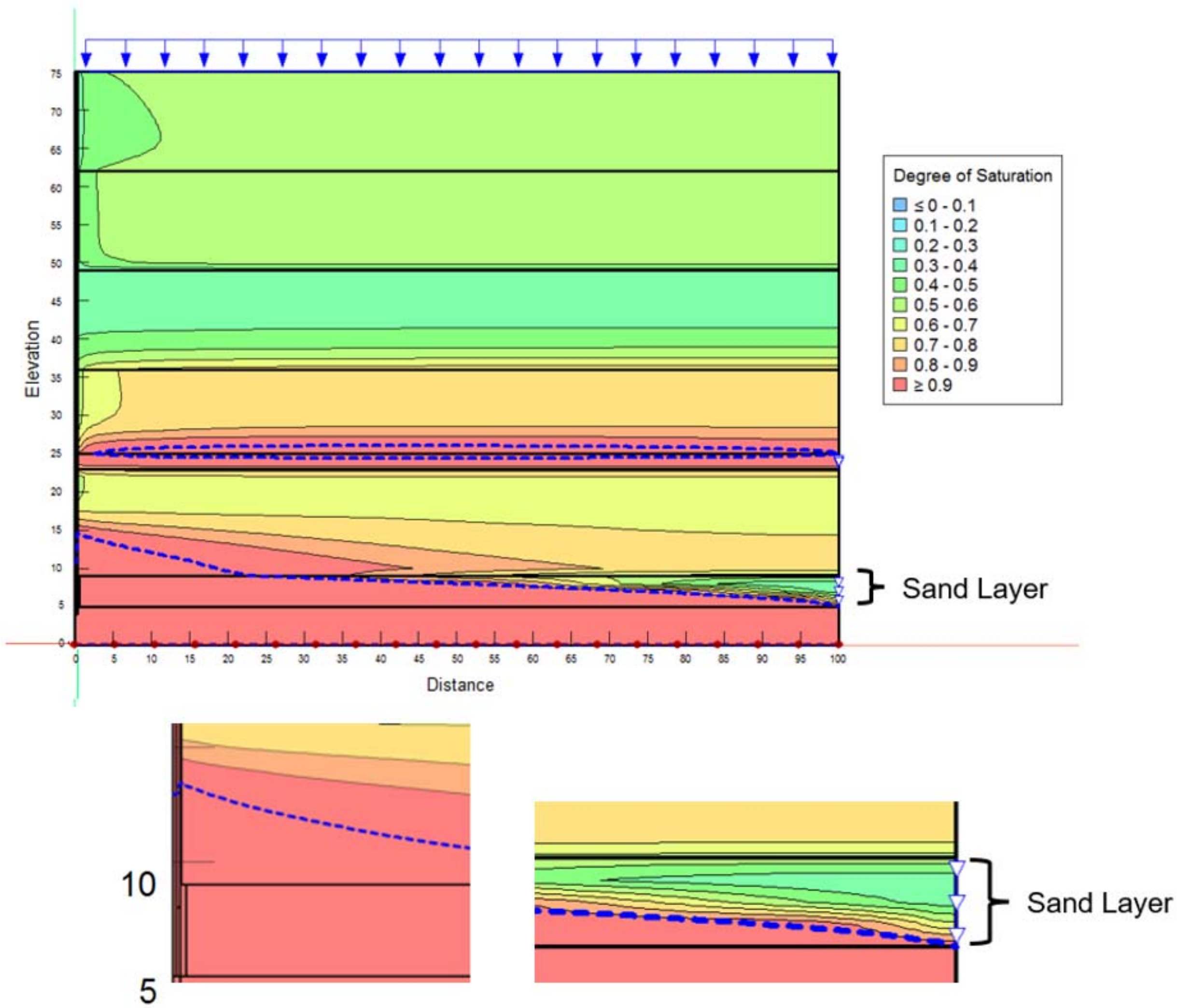

Figure 7-9. Degree of saturation and the leachate level on the liner at the both ends of sand layer 7 years after the installation of the piezometer (with perched water table).

7.4 SEEP/W Summary

Based on the SEEP/W simulation results, the installation of a piezometer, like the Series 2 piezometers at the SCLF, can draw moisture and free liquids from the waste layers around the piezometer (the anisotropic properties of the surrounding waste directs the moisture horizontally) to the piezometer borehole. This liquid can then flow down the borehole and accumulate in the sand layer at the bottom of the landfill, resulting in a build-up of leachate above the clay liner around the piezometer. This localized mounding of leachate around the piezometer can persist indefinitely.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Several methods were used in this investigation to determine if the readings from the piezometers in the Phase I –VI cells of the SCLF provide an accurate representation of the actual liquid level over the clay liner. The major findings from this report support the case that they do not.

Based on a review of 13-years of leachate pumping data, the per-acre leachate removal rate in the Phase I-VI cells has been significantly higher than the other, more modern landfill cells that have operated on this site for many years. The leachate removal rate also fluctuates seasonally in a pattern similar to these other landfills. This indicates that the LCS sand layer, gravel trenches and leachate collection laterals are successfully transmitting leachate that is percolating from the waste layers in response to seasonal precipitation variation, and that the pumps are keeping up with the quantities of leachate that are being delivered to them. This is an indication that the LCS is functioning properly. One interesting observation is that the Phase I-VI cell leachate removal rate has dramatically increased in the past two years compared to the Section 7, 8 and 9 cells, which could be a result of piezometer installation and/or with the addition of the supplemental pumping.

Using the most recent leachate removal rate and the original LCS design plans, it was calculated that the leachate levels in the sand drainage layer should be much lower than most of the piezometer readings indicate. A field investigation was also conducted to measure the presence of moisture in the sand drainage layer to compare with the readings in a nearby piezometer. The drainage sand in the trench was observed (and later confirmed through laboratory testing of soil samples) to be unsaturated down to clay liner. However, the adjacent piezometer reading indicated there were several inches of leachate over the liner, which contradicts conditions documented in the trench excavation. During the excavation, perched leachate was observed to seep from the sides of the trench nearest to the piezometer, which supports the idea that the piezometer has an effect on the flow of moisture in the area. This would explain why there was liquid present in the piezometer while the surrounding drainage sand was unsaturated. An additional observation made was that the waste along the sides of the trench were ragged and exhibited a high degree of heterogeneity. These characteristics make it very difficult to attain a complete seal around the piezometer. As a result, moisture would be able to easily migrate to the sides of the piezometer casing.

It was hypothesized that the installation of a piezometer disturbs the surrounding anisotropy, and results in a thin region around the outer piezometer casing that exhibits much greater vertical hydraulic conductivity than the surrounding waste. This provides a pathway of least resistance for leachate to flow vertically downward. The leachate that flows down the piezometer casing can accumulate in the immediate area around the piezometer in the sand drainage layer, leading to high water level readings inside the piezometers relative to the rest of the sand drainage layer. To demonstrate the plausibility of this hypothesis, this phenomenon was simulated using the computer model SEEP/W. The results support the hypothesis that the piezometers have an effect of the flow of moisture within the landfill. A mounding effect around the piezometer was also observed, which was particularly pronounced when perched leachate conditions were present.

A key conclusion of this study is that the act of installing a piezometer through a waste mass disrupts the anisotropy of the waste mass and creates a preferential flow path (the piezometer borehole) to the underlying LCS. The leachate that flows from the waste layers to the LCS sand layer at the bottom of the landfill can then accumulate in and around the piezometer (mounding), influencing the leachate levels in the piezometer. Piezometers installed through a waste mass are therefore not an accurate or reliable means to determine liquid levels in a landfill LCS, and that the installation of the piezometers can result in an increased leachate impingement on the LCS since the piezometer acts as a drain for the surrounding waste. We recommend against installing any more piezometers in the landfill.

REFERENCES

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