U.S. Army Corps
of Engineers
Philadelphia District

RESERVOIR HYDRAULICS AND BERM STABILITY INVESTIGATION

BoRit Asbestos Superfund Site, Ambler, PA

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Reservoir Hydraulics and Berm Stability Investigation

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1. INTRODUCTION

The Philadelphia District of the US Army Corps of Engineers (CENAP) was tasked with analyzing the hydraulics of the reservoir and the stability of the reservoir's perimeter berm at the BoRit Asbestos Superfund Site in Ambler, PA (see Figure 1.1 for location). The site was used originally for disposal of asbestos waste from the Keasby & Mattison Company, which manufactured a number of products using asbestos starting in the late 1800s. Succeeding corporations operating on the same property continued to produce asbestos-containing goods. The site consists of three parcels: the Asbestos Pile parcel, the Park parcel, and the Reservoir parcel. This report describes activities and data analysis of the reservoir located in the Reservoir parcel.

The reservoir is approximately 11 acres in area (area measured at the inner top-of-bank) and is held in place by a berm on the south and west sides. Two streams run adjacent to the reservoir: Wissahickon Creek and Rose Valley Creek. A third nearby creek, Tannery Run, runs approximately 100 yards to the southeast of the reservoir. See Figure 3.1 for the site overview map. Based on the recently completed subsurface investigations and bank stabilizations along the Wissahickon and Rose Valley Creeks, the berm seems to have been constructed, at least partially, of asbestos waste material. Asbestos has also been detected in reservoir sediment samples as reported in the 2010 Phase 1 Data Evaluation Report completed for the site by CDM for the United States Environmental Protection Agency (USEPA). Excess seepage through the southwest corner of the berm was noted during construction on Tannery Run in March 2011 when water from that creek was being pumped into the reservoir. The excess seepage caused minor surface sloughing on the exterior berm in one area along the Wissahickon Creek in the southwest corner of the reservoir. The pumping practice was discontinued, the slough was repaired, and the area has been stable ever since. The seepage continues in this area, but at a slower rate as compared to when the reservoir was being pumped into. Concern has been noted about the stability of the berm and the possibility of mobilization of contaminants through either seepage emanating from the berm or from a catastrophic failure of the berm. Further, the hydraulics of the reservoir are not clearly understood. In order to clarify these issues, the following investigations were performed:

- Geotechnical Investigation
- Water level investigation
- Berm slope stability and seepage analysis.

The purpose of the geotechnical investigation was to collect subsurface information for use in the berm slope stability and seepage analysis. The purpose of the water level investigation was to study the response of water levels to storm events and to determine if there was any interaction between the reservoir and the shallow groundwater. The purpose of the berm slope stability and seepage analysis was to evaluate the reservoir's stability in its existing condition.

2. Geotechnical Investigation

2.1 Geophysical Investigation

Quantum Geophysics was contracted through Gannett Fleming to perform a geophysical investigation to help determine the soil consistency of the reservoir berm and locate any subsurface anomalies such as pipes, culverts, or buried debris. The investigation utilized a multi-channel analysis of surface waves (MASW) survey, a self-potential (SP) survey, an EM61 metal detector survey, and ground penetrating radar (GPR). All geophysical surveys and analyses were completed before borings were drilled to help determine the best location for the borings.

The MASW survey uses seismic surface waves to determine shear wave velocities. The wave velocities are related to the stiffness and density of the material they are traveling through. The MASW analysis allows a relative depiction of the subsurface that can differentiate between bedrock, dense compacted soils, and loose fill material such as asbestos containing material (ACM) and debris. This information can be used to determine the general composition of the berm.

The SP survey is used to identify groundwater movement that could be an indicator of a seepage path. The system works by measuring voltage drop between two electrodes placed in the ground. The change in voltage is indicative of water movement. A 10 foot by 10 foot pattern grid was used on the southwest berm between the reservoir and the Wissahickon Creek to search for water movement.

The EM61 and GPR are both tools that use electromagnetic energy to identify both metallic and non-metallic objects below the surface. These methods were used in four specific locations to verify if pipes were running into or out of the reservoir (See Figure 2.1). Any pipes found could be a conduit for groundwater traveling into the reservoir.

The MASW survey showed low shear wave velocities in the southwestern corner of the reservoir at the area where there has been seepage in the past (See Figure 2.2). The low velocities are indicative of soils mixed with ACM representing a loose condition, which could be a concern for slope stability. The MASW also showed a cut into the bedrock beneath the gravel road on the eastern side of the reservoir (See Figure 2.3). This square notch in the bedrock is consistent with historical accounts that suggest the site was previously used as a quarry. The geophysical investigation did not identify any previously unknown pipes leading into or out of the reservoir.

2.2 Test Borings

The data from the geophysical analysis and topography was used to determine the most critical areas where test borings should be performed. Three borings labeled BOB-1, BOB-2, and BOB-3 were completed by Hetager drilling, who was also contracted through Gannett Fleming (See Figure 2.3 for boring locations). The borings were completed using the continuous, standard penetration test (SPT) boring method (a.k.a., split-spoon sampling), which was performed concurrent with hollow-stem augering. Borings were advanced until auger refusal on bedrock was reached. Borings ranged from 20 to 28 feet in depth. Offset holes were also drilled immediately adjacent to the original boring locations to provide undisturbed samples for laboratory testing.

In general, it was found that each boring contained 14 to 16 feet of fill material. The fill material is generally very loose to medium dense silty sand. BOB-1 had only minor amounts of ACM while BOB-2 had 12 feet of ACM and BOB-3 contained 5 feet of ACM. While drilling BOB-2 at a depth of 8-18 feet below the top of berm, there was little sample recovery and few soil cuttings exited the hole. This indicates that the material is very soft in this area and/or contains large amounts of debris or ACM, which is consistent with the results of the geophysical survey. There was 7 to 14 feet of alluvial (natural) clay, sand and gravel, and decomposed rock under the fill and overlaying the bedrock.

Laboratory tests on samples from the three boreholes were conducted by GeoStructures Inc. of King of Prussia, PA. Tests run were chosen based on the type of soil and included sieve analyses, Atterberg limit determinations, water content, organic content, triaxial consolidated-undrained, and unconfined compression. The results of the laboratory tests are located in Appendix B: Geotechnical Report.

2.3 Summary of Geotechnical Investigation

The geophysical survey and test borings concluded that the reservoir berm is composed of highly variable fill with varying amounts of ACM. There were pockets of material near the Southwest corner that were particularly soft and likely contain large amounts of ACM or poor soils. The reservoir berm foundation is composed of soft alluvial clays and medium to dense sand and gravel deposits. Refer to Appendix B for the complete Geotechnical Report prepared by Gannett Fleming.

3. Water Level Investigation

3.1 Data Collection

Figure 3.1 shows the location of the reservoir in Ambler, PA and the nearby monitoring wells and staff gauges which were measured during the hydraulic investigation. At the start of the investigation, a total of 4 transducers were utilized to make frequent water level measurements. In the beginning of March 2013, these transducers were placed in monitoring wells: MW-01A, MW-02, MW-03 and MW-05. After approximately two and a half weeks, the transducer from MW-05 was removed and placed in the reservoir horizontally in a protective conduit near staff gauge SG-03. This was done so that the reservoir surface water level could be recorded and compared to water levels in the groundwater wells. The transducers were initially set up to record water level readings at hourly intervals, but the recording interval was reduced to 15 minutes on March 29 to increase the data resolution. This automated data was stored in a data-logger built into each transducer. The data from the data-logger was periodically downloaded during the investigation. Hand measurements of water levels were also periodically performed at all wells and staff gauges to evaluate/calibrate the transducer data. In July, a new background well (MW-7) was installed north of the reservoir, near Maple Avenue. This well was fitted with an additional transducer for the final five weeks of the investigation. This report section discusses the data collected between March 13, 2013 and August 23, 2013.

3.2 Data Evaluation

Groundwater levels in all of the monitoring wells were immediately affected by rainfall. The transducer placed in the reservoir also showed immediate impacts from rainfall. This water level data was compared to hourly rainfall data from the Wings Field Airport, located approximately 2.5 miles southwest of the site. The two locations are marked on Figure 3.2. Hourly rainfall data was obtained from NOAA's National Climatic Data Center (www.ncdc.noaa.gov).

Figures 3.3 through 3.8 show the water level data and the precipitation data at each location with a transducer. The precipitation data is presented as cumulative inches for each storm. The storm was assumed to have ended if the succeeding 24 hours were dry and the precipitation data collection was restarted. Note the sudden impacts from rainfall in each of the wells and in the reservoir. All wells have a 9-day break in data at the end of May and a 3-day break during July when the transducers were removed for a sampling event performed by CDM as part of the Phase III field investigations of the BoRit site. A larger break in data during May and June occurred at MW-03 due to condensation on the transducer. Note that the reservoir water level is 5 to 10 feet higher than the measured groundwater at most of the wells other than MW-06. At MW-06, the typical measured groundwater elevation was similar to the reservoir water level. Figure 3.10 shows all of the transducer data, zeroed out on March 29th to show relative water level changes.

MW-03 (Figure 3.5) clearly shows an interesting phenomenon each weekend. Note that the dark vertical lines on the plots are placed between Friday and Saturday. Nearly every weekend, a significant head rise is noted on Friday or Saturday. The head remains high through the weekend and then drops back to previous trends on Monday or Tuesday. This occurs on weekends when there was no rain. Occasionally weekend rain masks part of the signal. Note the following examples on Figure 3.5:

- Saturday, March 16 – Monday, March 18. Although there was only a trace amount of rain on Saturday, the head rose nearly 0.5 feet and then dropped off. The falling water level was halted by a new rainstorm beginning in the evening of March 18.
- Saturday, March 23 – Tuesday, March 26. The head rose about 0.2 feet on Saturday. It was prevented from dropping back to its previous level until Tuesday by a small rainstorm on Monday.
- Friday, March 29 – Monday, April 1. The head rose over 0.5 feet on a nearly dry weekend and then dropped back to lower levels.
- Saturday, April 6 – Monday, April 8. The head rose nearly 0.5 feet on a dry weekend and then dropped back to lower levels.
- Saturday, April 13. The signature may have been masked by the rainfall.
- Saturday, April 20. The signature may have been masked by the rainfall.
- Saturday, April 27 – Monday, April 29. Water levels began rising ahead of rainfall on the 29th. The transducer battery died before the water levels recovered.
- Saturday, May 4 – Monday, May 6. Water levels rose by approximately 0.3 feet although there was no rain. On Monday, the water levels fell back to the pre-existing trend.
- Saturday, May 11 – Monday, May 13. The rise in water levels was masked by rainfall on Saturday. After the rain, water levels fluctuated until Sunday afternoon, and then they

continued to rise, although the rain had long-since stopped. On Monday, the levels began to drop.

- Saturday, June 15 – Monday, June 17. Water levels rose by approximately 0.25 feet although there was no rain. On Monday they dropped back to the original trend.
- Saturday, July 20 – Monday, July 22. Water levels rose by approximately0.25 feet although there was no rain. On Monday they dropped back to the original level
- Saturday, August 3 – Monday, August 5. Water levels rose by approximately 0.25 feet although there was no rain. On Monday, they dropped back to the original trend.
- Saturday, August 10 – Monday August 12. Water levels rose by approximately 0.25 feet after a trace amount of rainfall on Friday. On Monday, the water levels dropped again just ahead of a large storm on Wednesday.
- Saturday August 17 – Monday, August 19. Water levels were already dropping after a large storm event, but the falling trend was interrupted by a rise in heads of approximately 0.25 feet on Saturday. On Monday the water levels dropped and continued the falling trend.

This same weekly signature can be clearly seen in the MW-07 (Figure 3.7) and, to a lesser degree, in MW-01A (Figure 3.3) and MW-02 (Figure 3.4), where the head changes are smaller and often masked by the noise of the signal. This anomaly is not, however, noted in the reservoir, although MW-03 is adjacent to the shore of the reservoir. The cause of this anomaly is most likely two nearby upgradient industrial wells associated with a business in Ambler. Pumped volumes are high (about 16 million gallons per year together) and generally they are reported to be pumping for around 20 days per month.

The reservoir data is shown on Figure 3.8. Note that the scale on this figure is much smaller than those on previous figures since the reservoir water level changes very slightly during the data period. This data is much noisier (i.e., contains occasional spike anomalies) than the groundwater data, possibly due to water movement caused by wind. The head changes are also much closer to the precision of the transducer, which may make the data seem noisier. The noise was filtered slightly by providing a 6-hour average water level throughout the monitoring period. Notice that, like the groundwater wells, the reservoir head levels are immediately impacted by falling rain. Generally, the rise in water level is close to the depth of rain measured at the weather station. The recovery to pre-storm levels seems to be slower in the reservoir than in the groundwater. Between the storms, reservoir head levels tend to slowly drop. This could be due to seepage from the reservoir (due to higher heads than those measured in the surrounding groundwater) or due to evaporation. It may also be a combination of the two. Recovery slopes seem to be steeper during May, June, July and August than during March and April. Because air temperatures were higher as summer approached, this slope change could be caused by greater evaporation.

On May 31, there was a sudden, large head increase of nearly 0.4 feet in just 90 minutes. The reason for this sudden change is unclear as there was no rain during this period. This increase would equate to a 15,000 gpm inflow of water over the 10 acres of the reservoir's water surface, which is unlikely to have been caused by a release from an undiscovered pipe. It seems to have been a permanent change in the location of the transducer, possibly caused by wildlife disturbing the conduit. It may also be a recovery from an apparent gradual loss of head during the month of May. The error between the mid-May staff gauge measurements and the transducer measurements may indicate a problem with the transducer beginning in early May and continuing until the sudden uptick on May 31.

The reservoir data is also anomalous at times in relation to the rainfall. An obvious example of this is the storm between May 23 and May 25. This is the third largest storm from the measurement period, but the response of the reservoir is small or non-existent. A similar anomaly is noted in comparing the impacts of the August 1 storm to the August 13 storm. Both storms had similar total precipitation values, but the head rise in the reservoir is much greater for the second storm. Some of these anomalies may be due to the distance between the weather station and the reservoir. The August 13 storm was a series of thunderstorms which may not have covered a large area and may not have impacted Ambler to the same degree as Wings Field Airport.

3.3 Water Level Investigation Conclusions

Although the small variability in the reservoir water levels make analysis difficult, it does not appear that there is a direct correlation between groundwater levels and the reservoir levels other than the fact that both are impacted by rainfall. The weekend rise in groundwater heads is not noted in the reservoir despite the fact that the greatest rises are at MW-03, which is only a few feet from the reservoir. Also, groundwater levels recover much more quickly after a rainstorm than the reservoir levels.

With the exception of a few anomalies, all significant water level increases seem to be directly correlated to rainfall. This indicates that the only significant inflow to the reservoir is likely to be rainfall. Note that small outfalls into the reservoir may not be able to contribute sufficient volumes of water to impact water levels significant enough to be separated from the noisy data. There is a general lowering of water levels in the reservoir through the data period that is broken only by rainfall. This water must be going somewhere. Some of it is being lost to evaporation, and this theory is supported by the steeper slopes during water level reduction as the temperatures increased with the changing seasons. There is a known seep through the berm, but it does not seem to allow significant volumes of water to pass. It is possible that some reservoir water is lost to the groundwater, but it happens so slowly that it is not noted in the groundwater wells.

3.4 Recommendations

One additional investigation that may be helpful in further clarifying the hydraulics of the reservoir is to install an evaporation pan. Evaporation data would be used to develop a mass balance relationship for the reservoir and determine how much is lost to seepage vs. evaporation.

4. Berm Slope Stability and Seepage Analysis

4.1 Introduction

The geophysical investigation and test borings were completed to gather data for use in the stability analyses of the reservoir berm in its existing condition. The water level investigation helped determine that a water level of Elevation 186 feet (NAVD 88 datum) should be used in the analysis of the reservoir under normal conditions. A higher pool at Elevation 188 feet was also evaluated to simulate the high head condition that occurred during part of the 2011 Tannery Run stream bank stabilization construction. During the dewatering construction phase of Tannery Run in March 2011, Tannery Run was pumped into the reservoir for about a week, resulting in the pool being raised by about 2 feet above its normal condition. This pool level increase likely caused the minor slope failure that occurred on the exterior berm slope in the southwest corner of the reservoir. The results of the geophysical investigation and laboratory tests were used to build a stability model at three of the most critical berm cross-sections using Geostudio 2012 computer software. The cross-sections selected were in the general location of borings BOB-1, BOB-2, and BOB-3 (See Figure 2.4 for boring locations).

4.2 Stability Analyses

The stability of existing and proposed slopes was analyzed using numerical modeling and limit equilibrium methods. All numerical models were prepared using the Seep/W and Slope/W programs from the Geostudio 2012 (v. 8.0) software package and all limit equilibrium analyses followed the Spencer method of analysis. Topographic survey cross sections from Ludgate Engineering provided existing dike geometry, forming a basis for analysis of existing conditions and proposed berm templates. The results of the geophysical analysis, borings, and lab testing were all used to construct models with the existing geometry at each of the three cross sections. The complete soil parameters used in the model are located in Appendix A.

According to Table 6-1b of the USACE EM 1110-2-1913 Design and Construction of Levees (dated 30 Apr 2000), the minimum required factor-of-safety (FS) for a structure of this type in the long term (steady-state seepage) case is 1.4. For a temporary high water condition, the minimum required FS is 1.3. A lower FS is acceptable during a high water event because it is a temporary loading condition. The first step in the design was to check each of the three sections at the average water level of 186 feet and compare the resulting FS at each section to the minimum required FS of 1.4. The condition with the highest observed water level (during Tannery Run construction) was also checked against the target 1.3.

4.3 Findings

Table 1 shows the results of the Geostudio analyses at each cross-section under both normal and high head conditions. Refer to Figures 4.1-4.6 to see the current berm geometry and critical slip surfaces.

	Current Geometry	
	Factor-of-Safety: Normal Water Level	Factor-of-Safety: High Head Level
BOB-1	3.28	2.70
BOB-2	1.12	0.93
BOB-3	1.46	1.26

Table 1. Factors of Safety with Current Geometry

The results of the analyses show that the cross-sections in the area of BOB-1 and BOB-3 meet the minimum factor of safety required under normal water levels. However, the cross-section in the area of BOB-2 at the Southwestern corner of the berm need improvement to meet the required FS of 1.4. The results at cross section BOB-3 indicate that some improvement may be required to meet the goal of 1.3 during high pool conditions. These findings are consistent with what was observed in the field during the filling of the reservoir in March 2011. The berm in the BOB-2 area is not in immediate danger of a major failure from normal water levels in the reservoir. During the March 2011 reservoir filling, excess seepage occurred in the BOB-2 area, but no issues occurred at BOB-1 and BOB-3. The lower FS in the BOB-2 area is likely due to the fact that it was constructed using a mix of soil and ACM debris in the early 1900s and the berm fill materials may have only been nominally compacted. The results of the geophysical and geotechnical analyses indicate that the berm adjacent to the Wissahickon and approximately 150 feet north along the Rose Valley Creek side from the reservoir's southwest corner require stabilization, with no further action necessary on the remaining berm extents. Further action to stabilize the berm is necessary in the area of BOB-2 and BOB-3 on the Wissahickon Creek berm because of the lower factor of safety.

4.4 Stabilization Options

Several methods of stabilizing the Wissahickon Creek side berm were evaluated, but only three of the stabilization options evaluated were selected for discussion in this report.

Option 1: Typical methods of improving slope stability in a structure of this nature include flattening the exterior slope of the berm and/or adding a stability berm at the exterior toe of the slope. Although these methods would have adequately increased the FS of the berm, they were ruled out as any additional earthwork on the outside of the reservoir berm would encroach into the flood plain of Wissahickon Creek and also impact the existing site access road at the toe of the slope in this area. Encroaching into the flood plain could not only lead to increased flooding, but the placement of additional fill materials would also be more susceptible to erosion in the future.

Option 2: The possibility of driving sheet piles through the top of the berm to a confining layer or bedrock was also explored. The interlocking nature of the sheet piles would reduce seepage through the berm and the steel sheet pile would add strength and rigidity to the berm. This method of stabilization is not recommended due to the anticipated difficulty that a contractor would have while driving sheet piling from the berm top and through the known debris in the berm.

Option 3: This option consists of filling on the interior of the berm slope to increase the berm's cross-sectional width, while also flattening its interior slope to 3H:1V. A top width of 30 feet was added to the existing berm's typical top width of 10 feet (total proposed top width of 40 feet). The 30 feet top width addition was applied to the berm cross-sections near BOB-2 and BOB-3. Analyses were performed for the proposed berm template using both a normal pool at Elevation 186 feet and a temporary high pool at Elevation 188 feet should such a high pool ever occur in the future, which is unlikely. To estimate the new groundwater level across the berm for the proposed condition, a hydraulic conductivity of $1 * 10^{-6} cm/s$ which is typical for clayey soils was assumed in the seepage analysis for the red clay fill material proposed for import to the site. It was found that adding this material stabilized the berm in both the normal pool and the temporary high pool conditions, with the main benefit coming from a lowering the groundwater table across the berm. This proposed filling option would also have the added benefit of capping the ACM on the inside of the reservoir. The reservoir would have to be dewatered in order to place and compact the fill in horizontal lifts. Also, proper quality control would be necessary to ensure the hydraulic conductivity of $1 * 10^{-6} cm/s$ is obtained. The short term, undrained loading condition is not presented in this report because the excess pore water pressures generated do not impact the critical failure surfaces.

If the hydraulic conductivity of the soil used in the above option is higher than $1 * 10^{-6} cm/s$, a geosynthetic clay liner (GCL) should be used in conjunction with the fill to lower seepage through the berm. A GCL typically consists of a thin layer of expansive bentonite clay stitched between two pieces of woven or non-woven geotextile. The material is delivered in rolls that would be rolled out down the prepared embankment slope, with the ends terminating in anchor trenches. The installed GCL would then be covered with a protective fill layer such as rock screenings. Even though a GCL is thin, it has a very low hydraulic conductivity (typically $1 * 10^{-9}\ cm/s$), is resistant to puncture, and is even self healing due to the swelling nature of the clay layer. The exact geometry of this solution would be determined once the hydraulic conductivity of the backfill is known.

No further action is necessary to stabilize the remaining three sides of the berm. As part of remedial actions currently in progress under the Region 3 Emergency Response and Removal Program, the USEPA's planned removal action is to place an additional 10 feet of clean fill on the interior of the reservoir slopes to cap the ACM (10 feet is the horizontal distance of new berm width from the existing inner crest). USEPA's planned removal action is consistent with Berm Stabilization Option 3 discussed herein. When the same numerical modeling and limit equilibrium methods are applied to these berm conditions, the analysis showed that the extra weight of the fill would not have a negative impact on the berm in the area of BOB-1. Table 2 shows the calculated FS with the proposed geometry. Please refer to Figures 4.7-4.12 to view the proposed berm geometry critical slip surfaces.

	Proposed Geometry	
	Factor-of-Safety: Normal with Fill	Factor-of-Safety: High Head with Fill
BOB-1	3.87	3.44
BOB-2	1.63	1.62
BOB-3	1.57	1.47

Table 2. Factors of Safety with Proposed Geometry

For the complete slope stability analysis please refer to Appendix A.

4.5 Recommendations

Stabilization Option 3, the backfilling of the interior of the Wissahickon Creek side berm and part of the Rose Valley Creek side berm with 30 feet of material for a new average width of 40 feet is the recommended solution. It will cap the ACM material on the inside of the reservoir while improving the FS to current guidelines and not impact the exterior of the berm. Although it is not strictly necessary to extend the thirty feet of fill completely to BOB-3, as the section at BOB-3 appears to be stable in its existing condition, it is recommended due to the variable nature of the bank constructed with the asbestos fill. The 30-foot berm width expansion should also wrap around the southwest reservoir corner and continue north along the Rose Valley Creek side berm about 150 feet to cover the zone of weak material found in the MASW survey. If laboratory testing results indicate that the material available for backfill does not meet the minimum required hydraulic conductivity of $1 * 10^{-6} cm/s$, it is recommended that this backfill method be used in conjunction with a GCL to ensure proper reduction of seepage or the berm width be increased accordingly without the use of a GCL.

5. CONCLUSIONS

5.1 GEOTECHNICAL CONCLUSIONS

The geotechnical investigation results indicate that materials originally used for construction of the reservoir berm in the southwestern corner likely contain excessive ACM and are not suitable for long term berm stability. The geophysics did not find any additional pipes that could be filling or draining the reservoir. However, it did find a cut in the bedrock on the eastern edge of the berm that could be a conduit for groundwater flow.

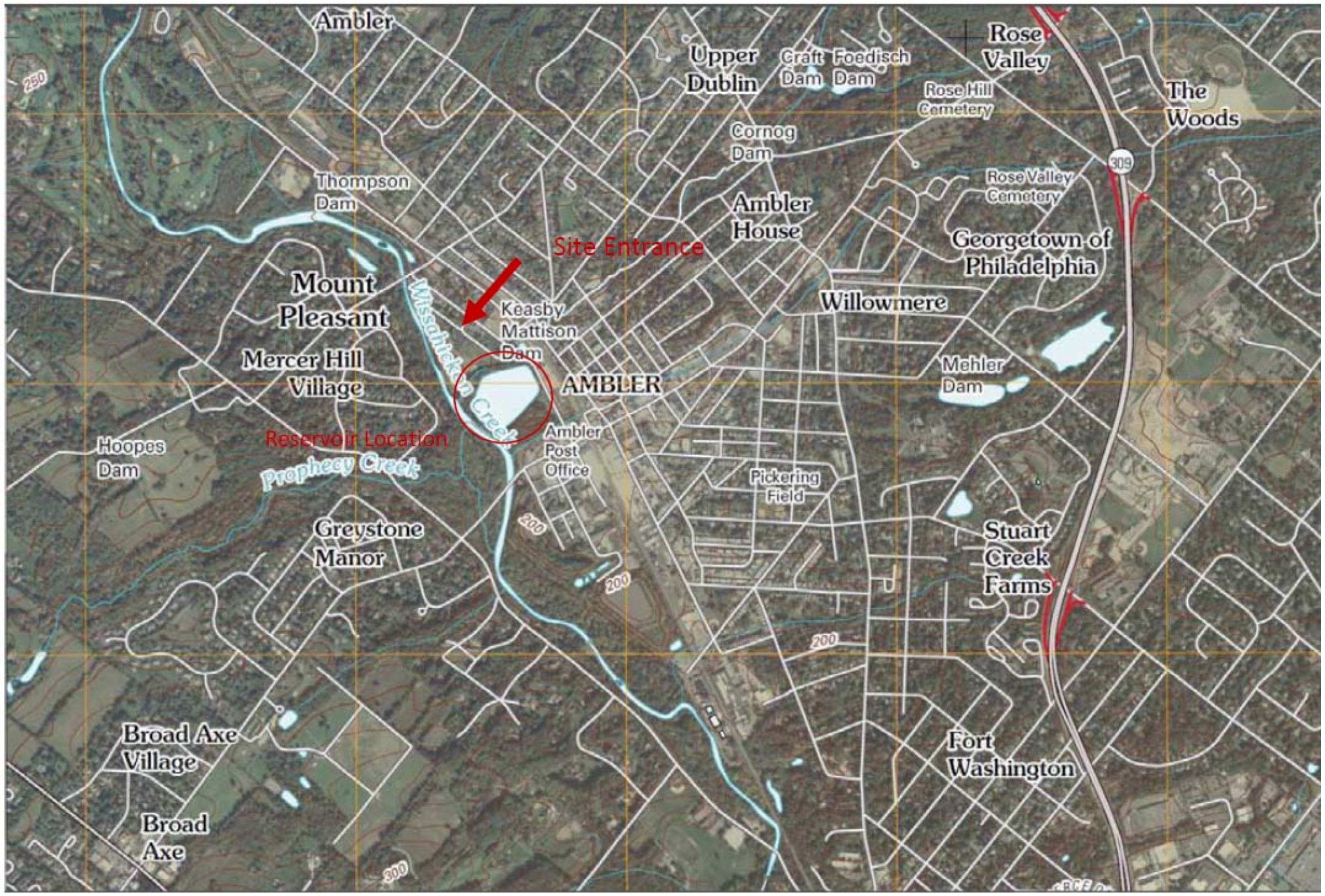
5.2 WATER LEVEL CONCLUSIONS

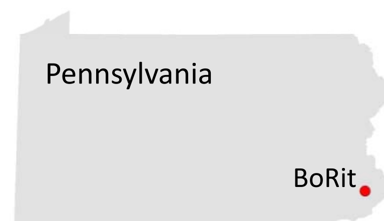
The analysis of water level data did not indicate a direct connection between the reservoir and the shallow groundwater. Anomalies in the groundwater were not noted in the reservoir data. Further, recovery after a rainstorm is much faster in the groundwater than in the reservoir. The reservoir experiences a slow loss of water between rainfall, possibly due to a combination of evaporation and seepage. The slope of the water loss is generally steeper as the spring turns to summer and temperatures rise. Although the data does not indicate direct evidence of seepage, there is a known seep through the berm based on visual evidence.

5.3 BERM SLOPE STABILITY AND SEEPAGE ANALYSIS

The complete analysis of the geophysical, geotechnical, and hydraulic conditions of the reservoir showed that the only area with a slope stability concern is in the Southwest corner in the vicinity of subsurface boring BOB-2. The berm in this area is not in immediate danger of a major failure from normal water levels in the reservoir, but measures that increase its stability should be performed in the near future. The recommended solution of widening the interior slope of the berm by 30 feet will adequately address any slope stability problems. Again, this option is also consistent with remedial measures currently being considered by the USEPA's Region III Emergency Response and Removal Program.

FIGURES





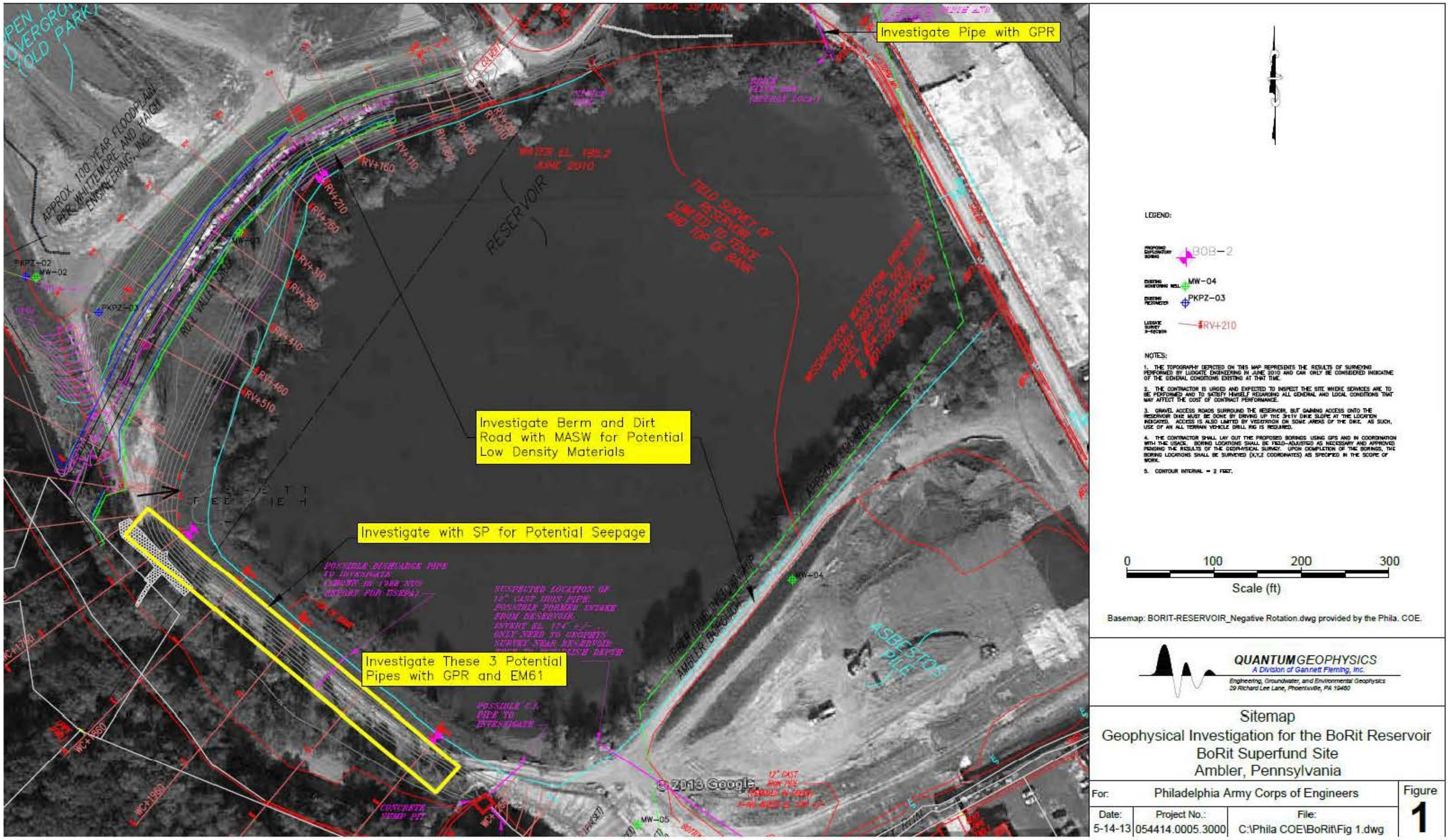
Site Location

BoRit Asbestos Superfund Site

Ambler, PA

Figure 1.1

August 2013



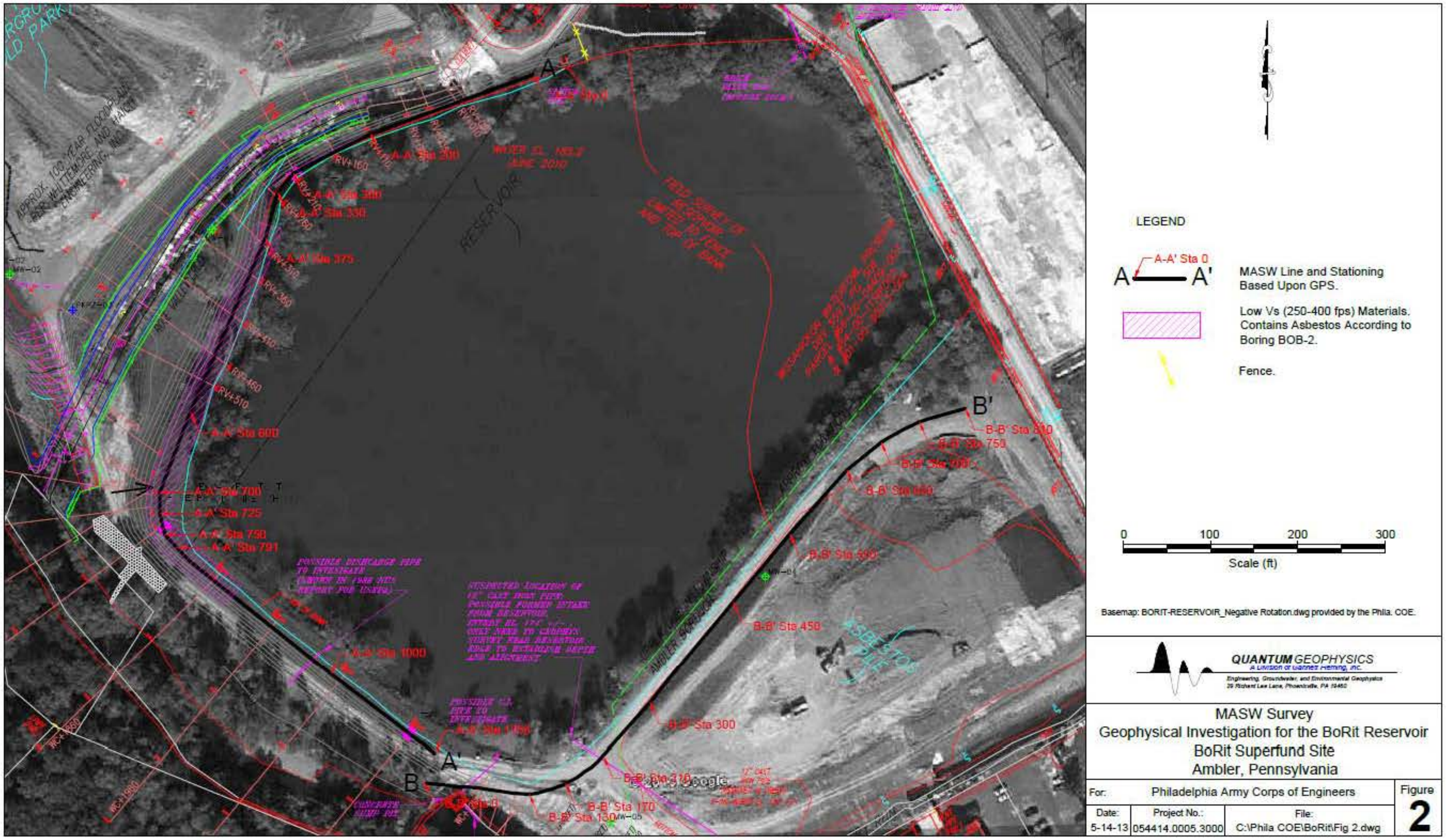
Locations of Geophysical Investigations

BoRit Asbestos Superfund Site

Ambler, PA

Figure 2.1

August 2013



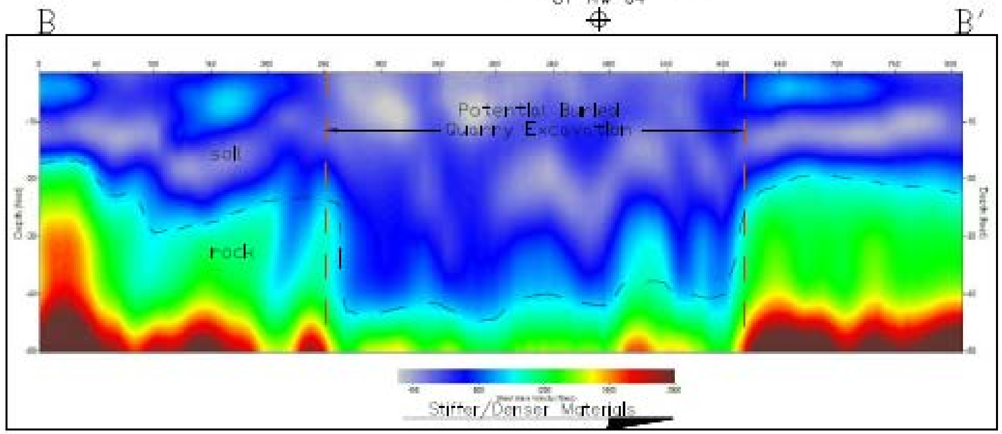
Zone of Weak Material in SW Berm

BoRit Asbestos Superfund Site

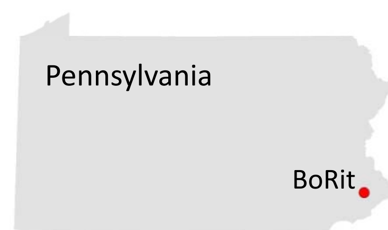
Ambler, PA

Figure 2.2

August 2013



Note: MW-04 reports BACS (bulk asbestos containing waste) debris mixed with soil 2-18 ft bgs. Apparent weathered rock of variable density 18-29 ft bgs.



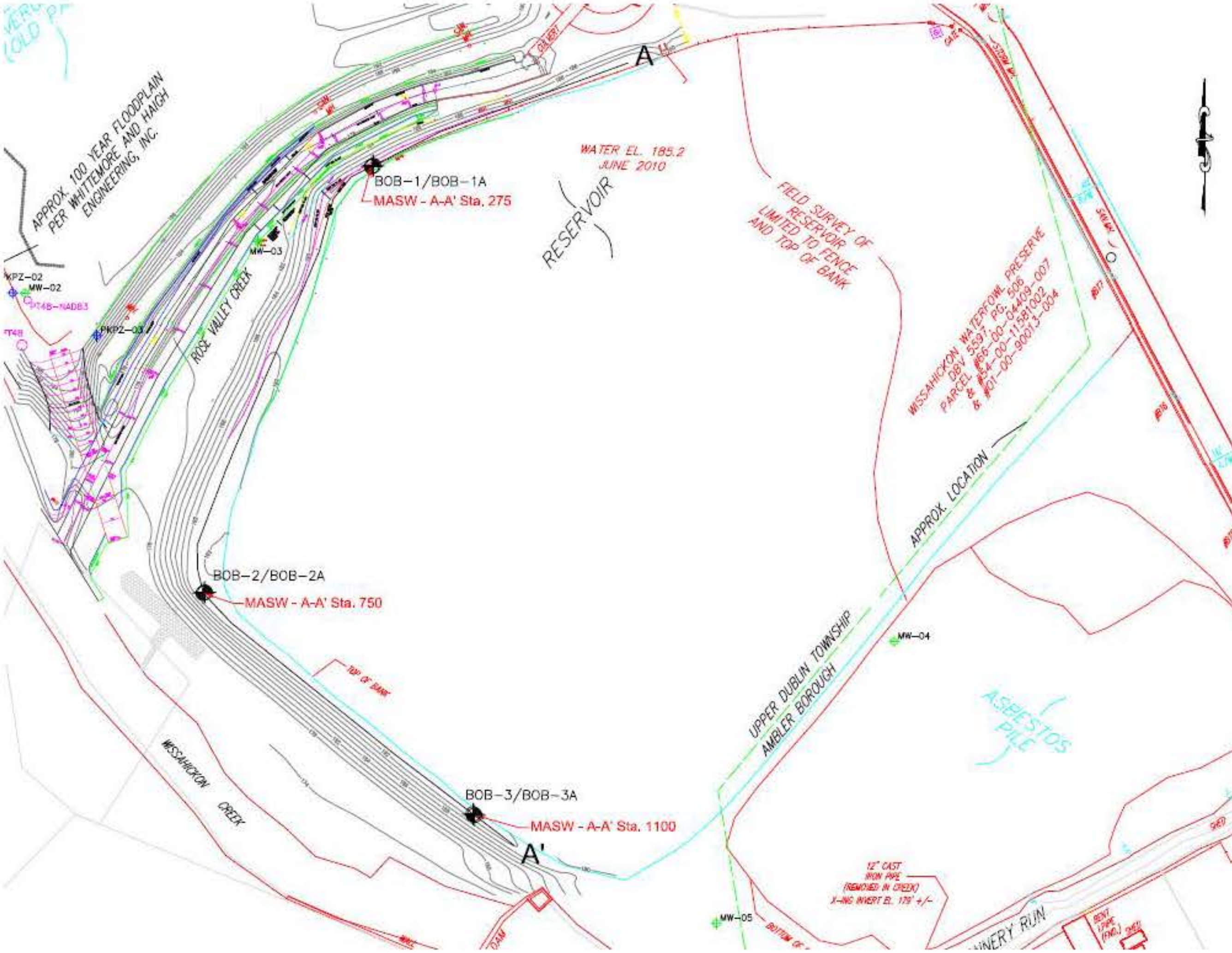
Notch in Bedrock

BoRit Asbestos Superfund Site

Ambler, PA

Figure 2.3

August 2013



LEGEND

GANNETT FLEMING EXPLORATORY TEST BORING/OFFSET BORING — BOB-2/BOB-2A

MASW SURVEY LINE AND STATION REFERENCE — MASW - A-A' Sta 750, A — A'

EXISTING MONITORING WELL — MW-04

EXISTING PIEZOMETER — PKPZ-03

NOTES:

1. THE TOPOGRAPHY DEPICTED ON THIS MAP REPRESENTS THE RESULTS OF SURVEYING PERFORMED BY LUDGATE ENGINEERING IN JUNE 2010 AND CAN ONLY BE CONSIDERED INDICATIVE OF THE GENERAL CONDITIONS EXISTING AT THAT TIME.

2. CONTOUR INTERVAL = 2 FEET.

3. BASEMAP: BORIT-RESERVOIR_NEGATIVE ROTATION PROVIDED BY THE USACE PHILADELPHIA DISTRICT ON MAY 23, 2013.

0 100 200 300

Scale (ft)

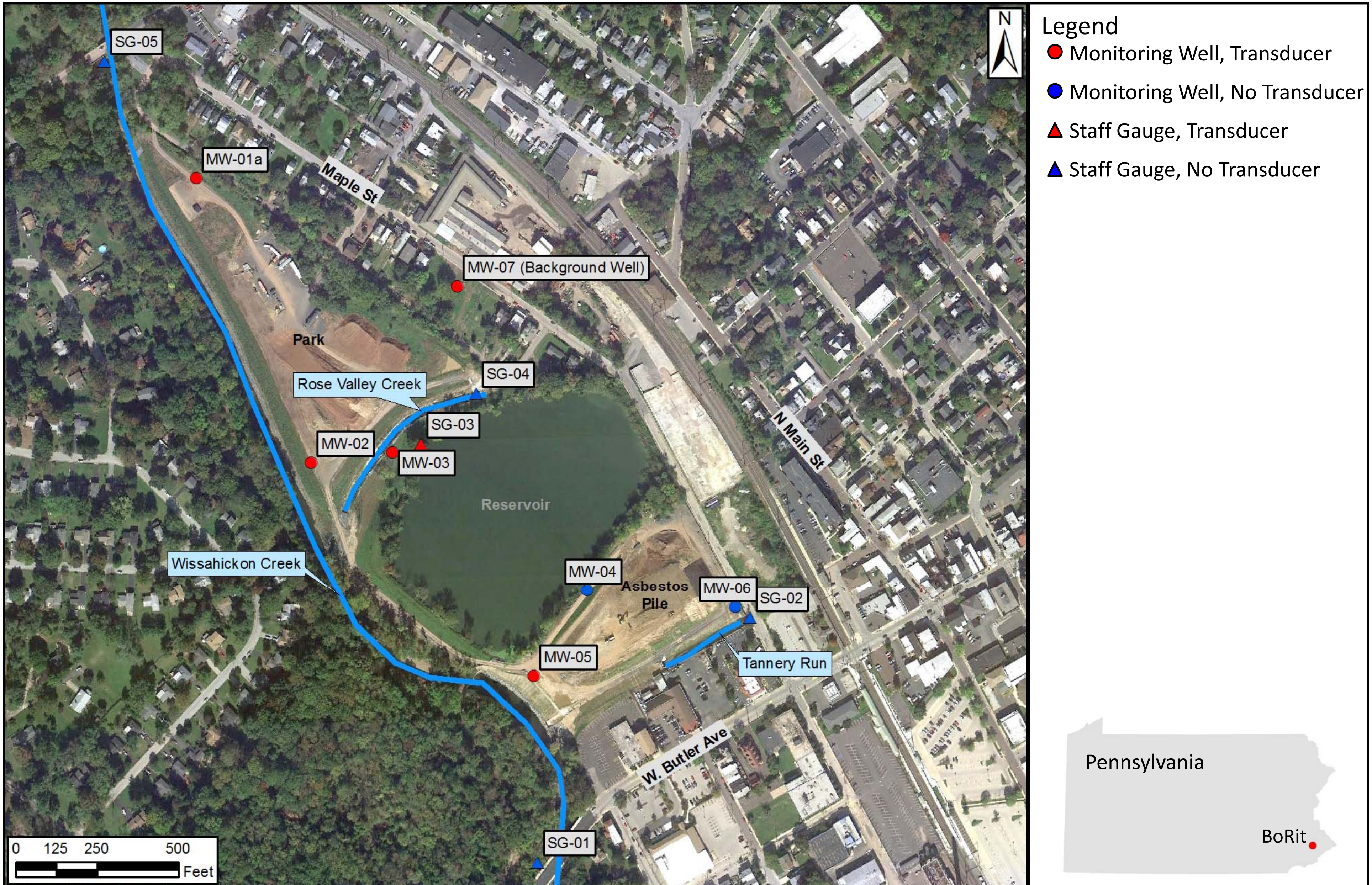
Locations of BOB-1, BOB-2, and BOB-3

BoRit Asbestos Superfund Site

Ambler, PA

Figure 2.4

August 2013



Monitoring Locations

BoRit Asbestos Superfund Site

Ambler, PA

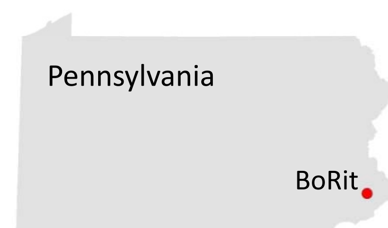
Figure 3.1

August 2013

Legend

BoRit Reservoir

Wings Field Airport Weather Station (64752)



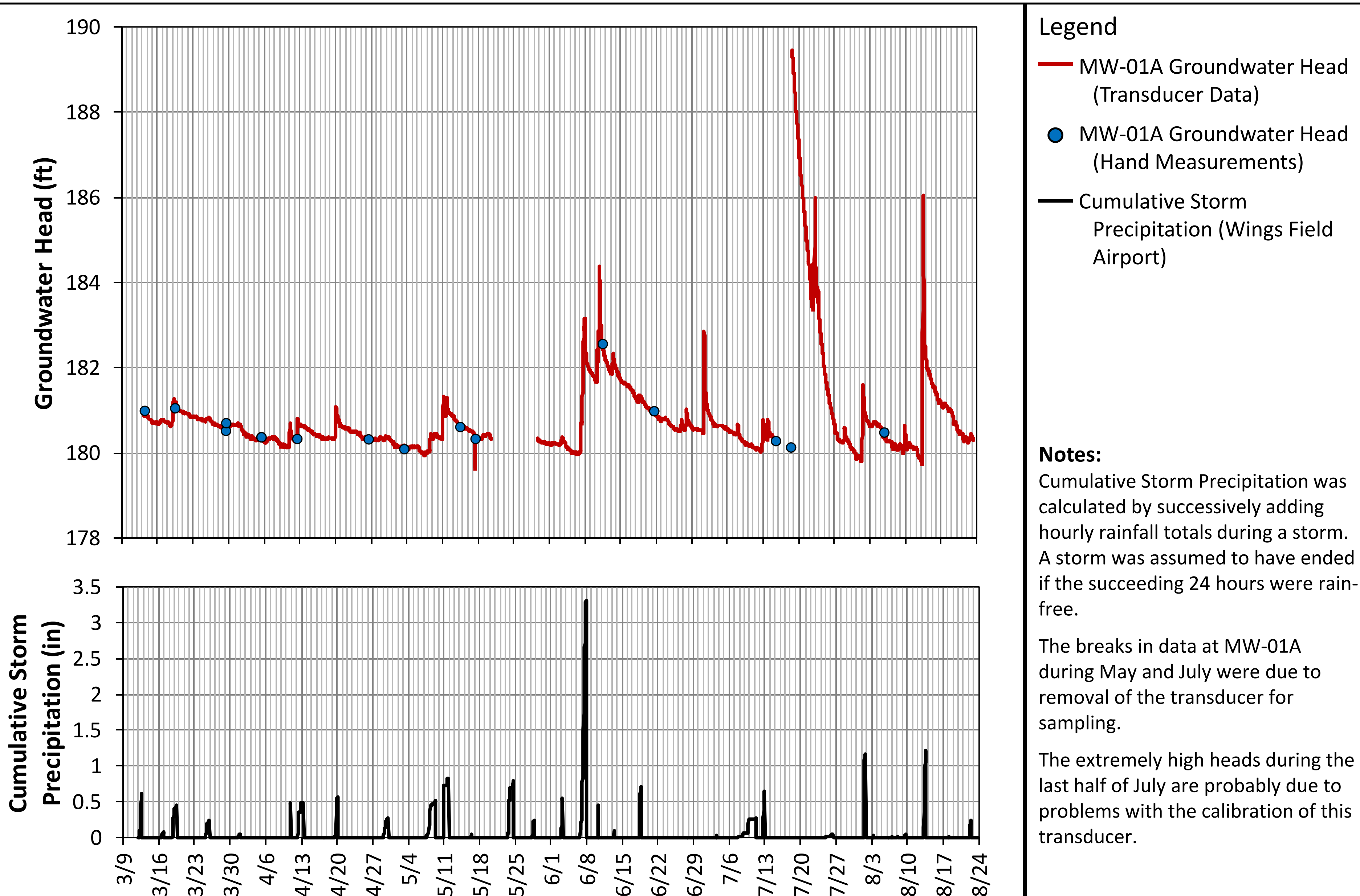
Weather Station Location

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.2

August 2013



Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

The breaks in data at MW-01A during May and July were due to removal of the transducer for sampling.

The extremely high heads during the last half of July are probably due to problems with the calibration of this transducer.

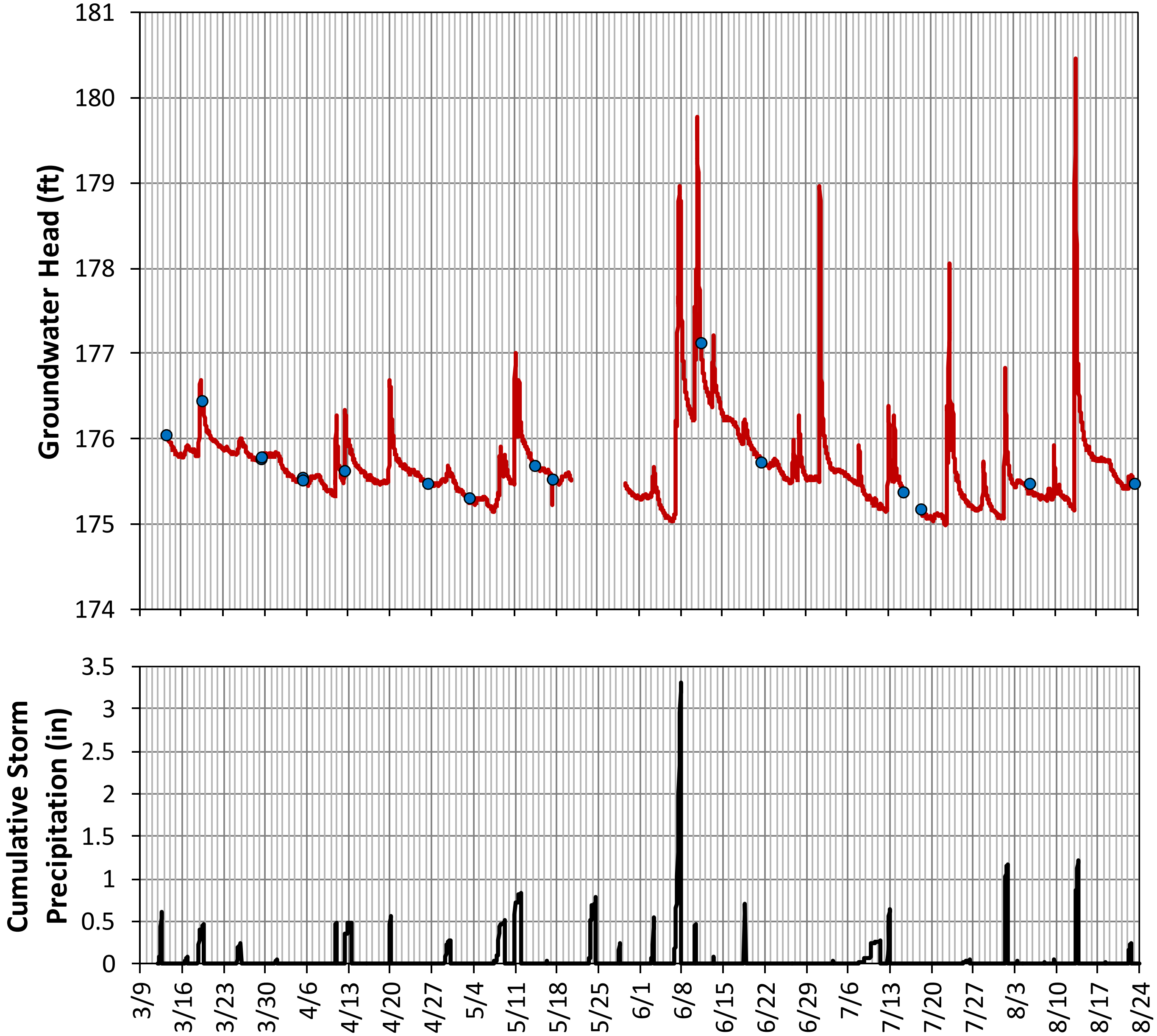
MW-01A Groundwater Head Data

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.3

August 2013



Legend

MW-02 Groundwater Head (Transducer Data)

MW-02 Groundwater Head (Hand Measurements)

Cumulative Storm Precipitation (Wings Field Airport)

Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

The breaks in data at MW-02 during May and July were due to removal of the transducer for sampling.

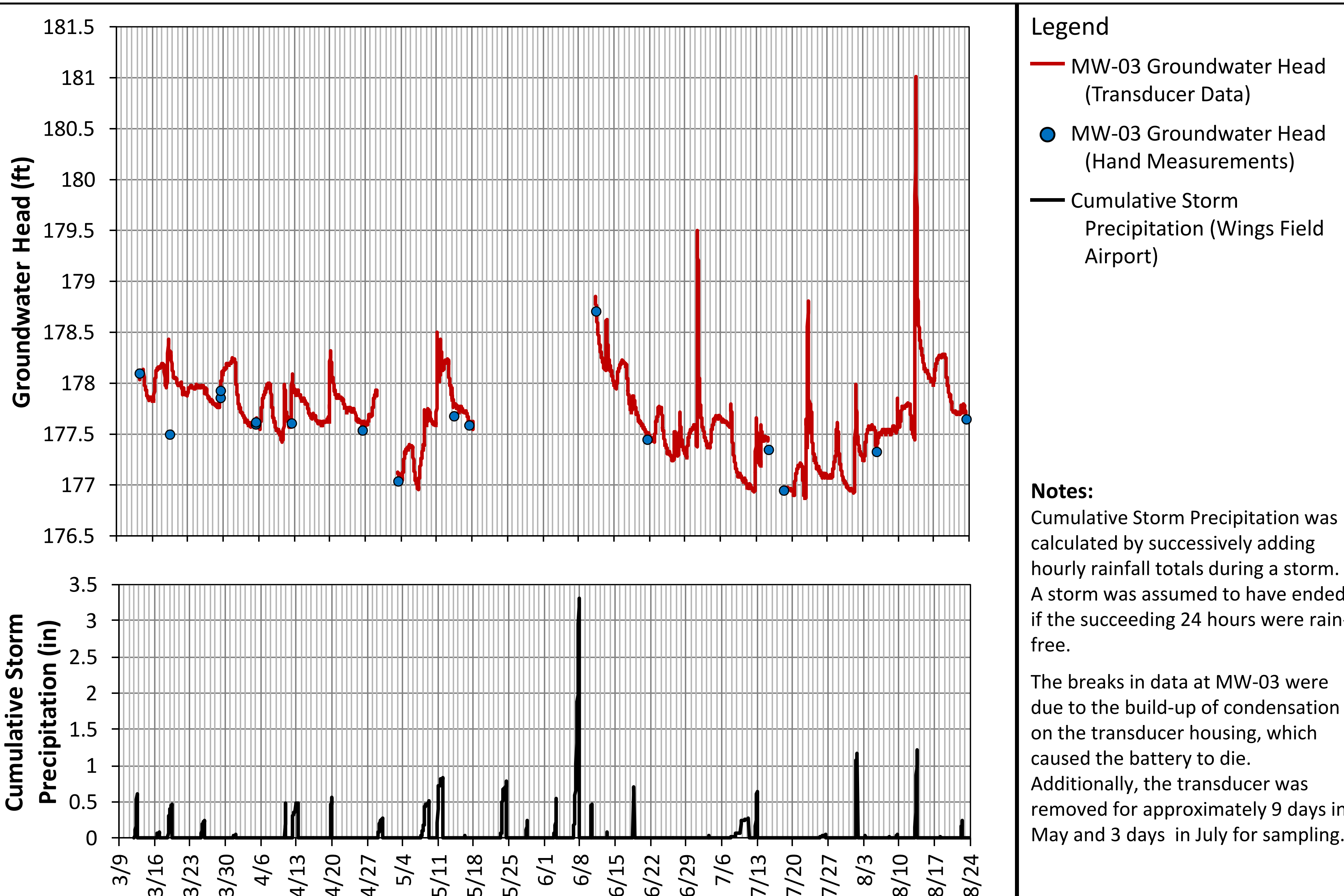
MW-02 Groundwater Head Data

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.4

August 2013



Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

The breaks in data at MW-03 were due to the build-up of condensation on the transducer housing, which caused the battery to die. Additionally, the transducer was removed for approximately 9 days in May and 3 days in July for sampling.

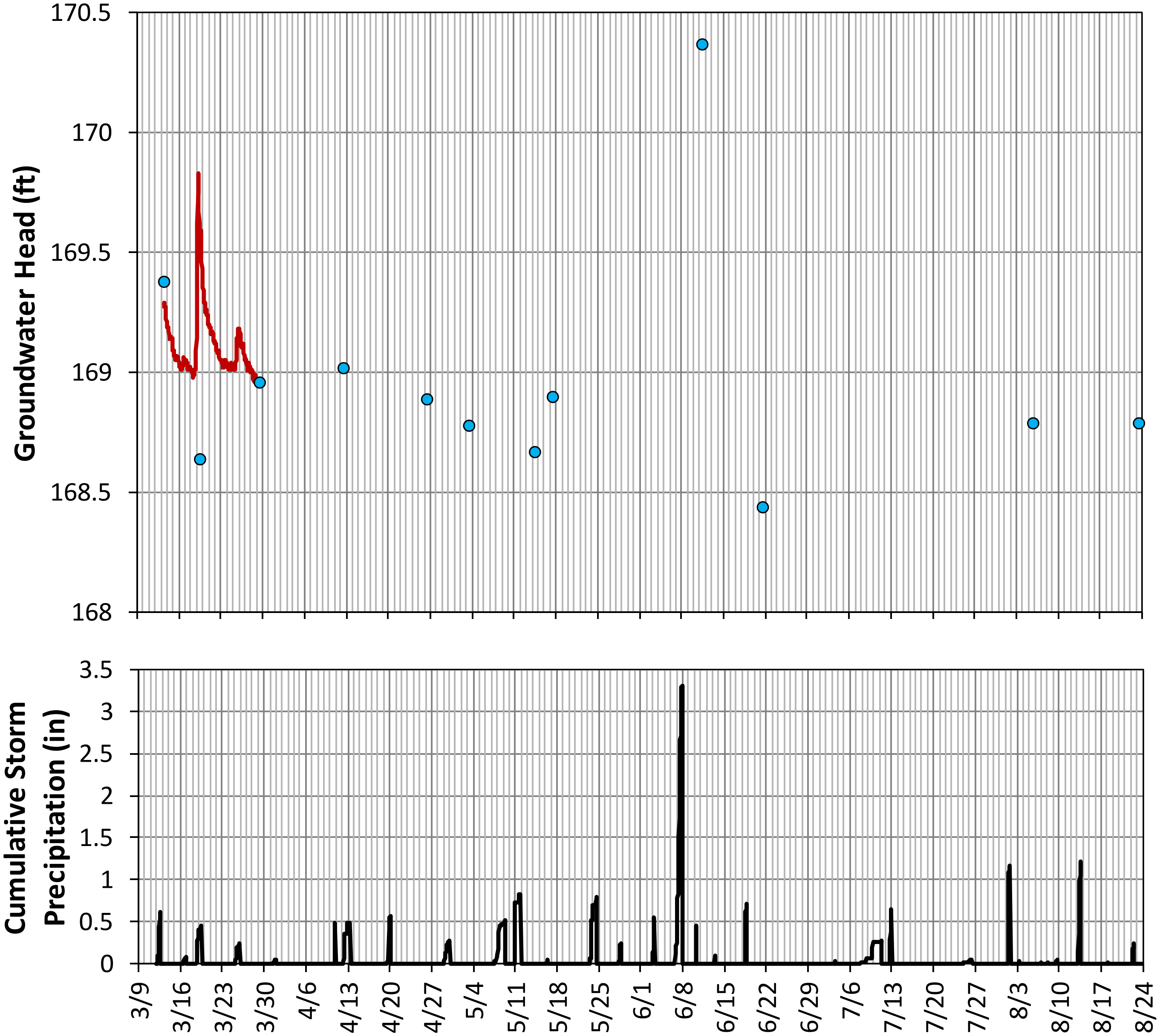
MW-03 Groundwater Head Data

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.5

August 2013



Legend

- MW-05 Groundwater Head (Transducer Data)
- MW-05 Groundwater Head (Hand Measurements)
- Cumulative Storm Precipitation (Wings Field Airport)

Notes:
Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

After the first two and a half weeks, the transducer was removed from this well and placed in the reservoir.

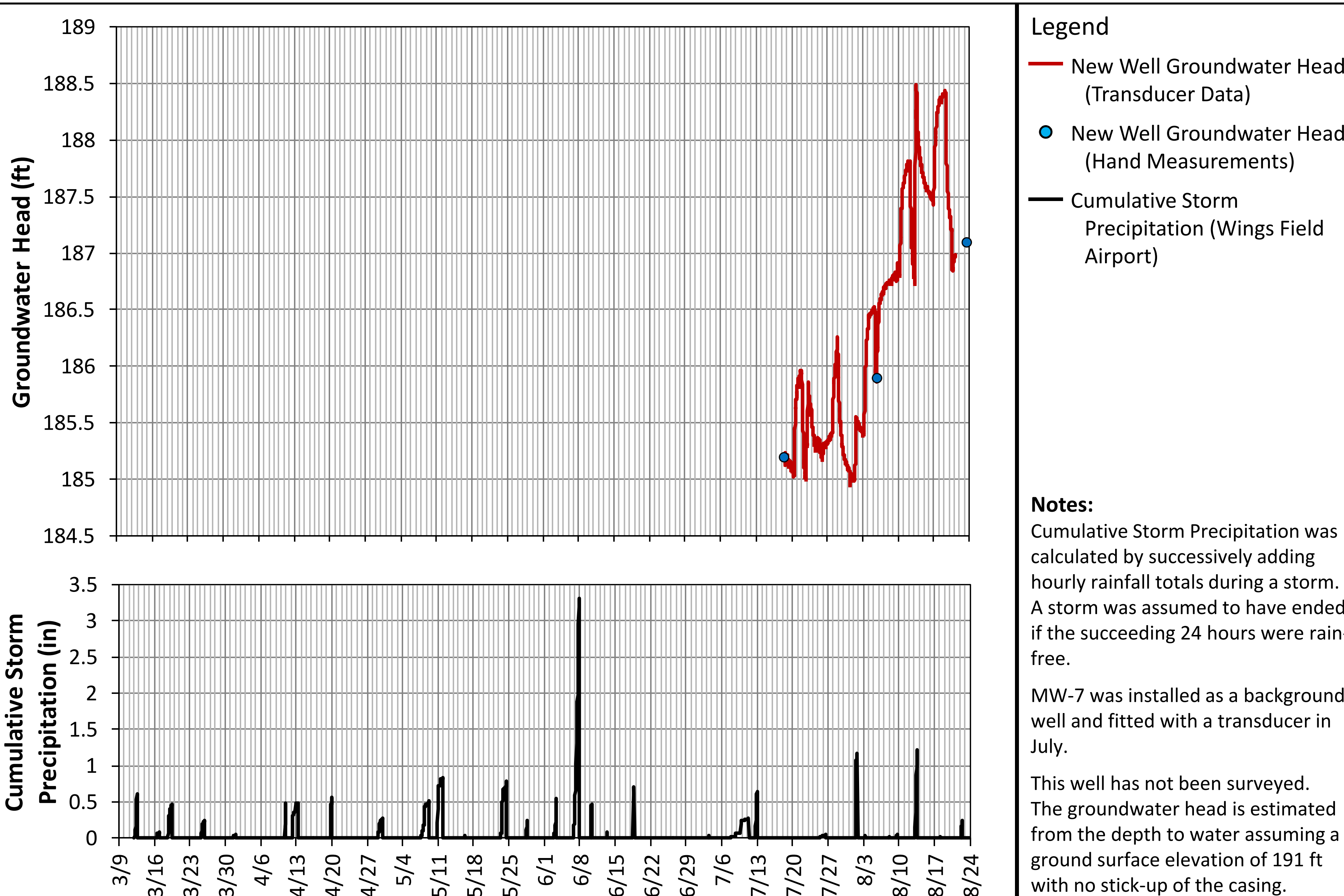
MW-05 Groundwater Head Data

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.6

August 2013



Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

MW-7 was installed as a background well and fitted with a transducer in July.

This well has not been surveyed. The groundwater head is estimated from the depth to water assuming a ground surface elevation of 191 ft with no stick-up of the casing.

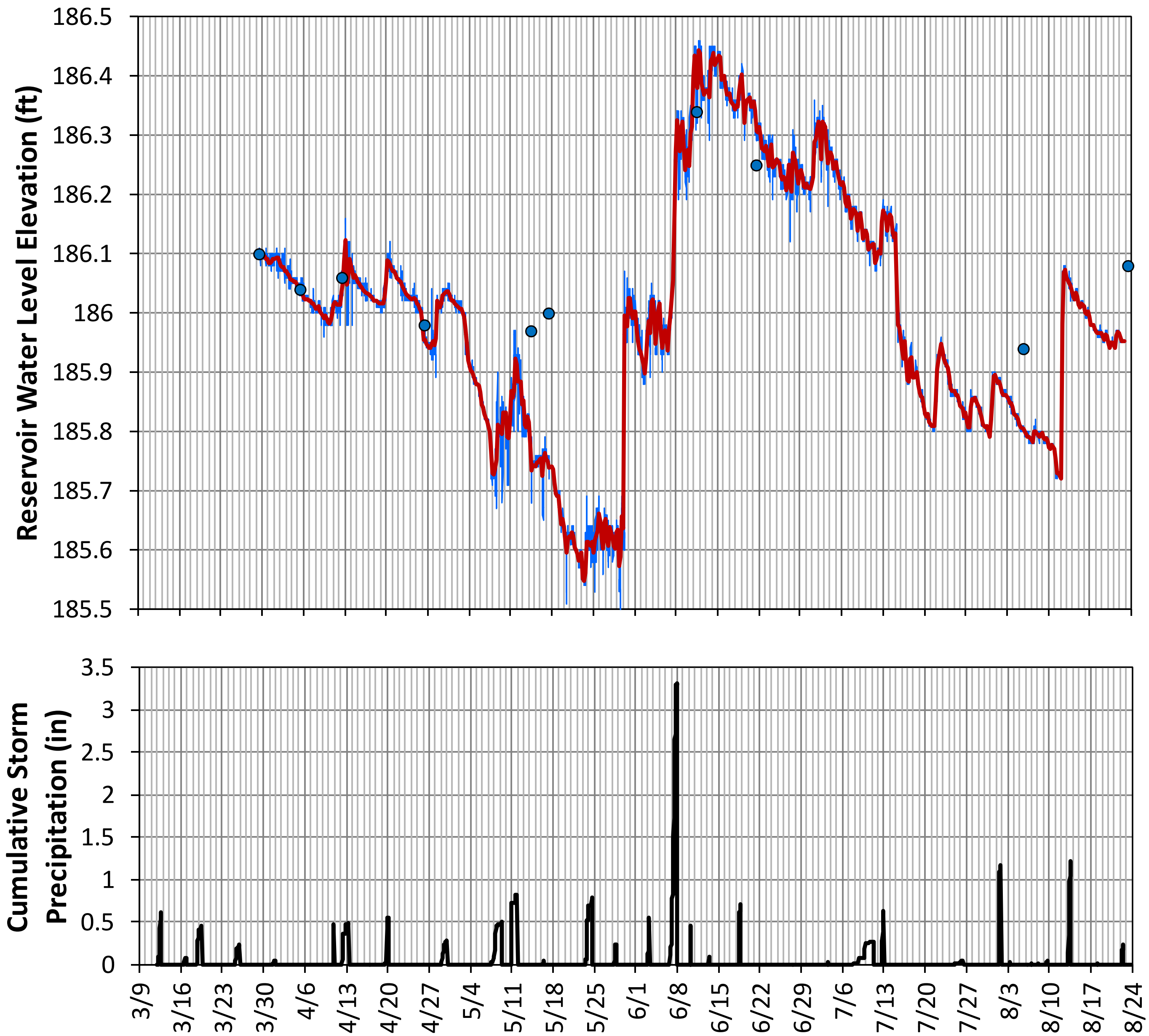
MW-7 (Background Well) Groundwater Head Data

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.7

August 2013



Legend

SG-03 Water Level (Transducer Data)

6-Hour Average Water Level (Transducer Data)

Staff Gauge Measurements

Cumulative Storm Precipitation (Wings Field Airport)

Notes:

This transducer was placed near SG-03, which is on the northwest shore of the reservoir.

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

This transducer was transferred from MW-05 at the end of March.

Because the data for this transducer is so noisy, a 6-hour average was calculated and is also shown in the upper plot.

The May 3 staff gauge measurement was approximately 2 feet higher than the transducer measurement and is not shown on this figure.

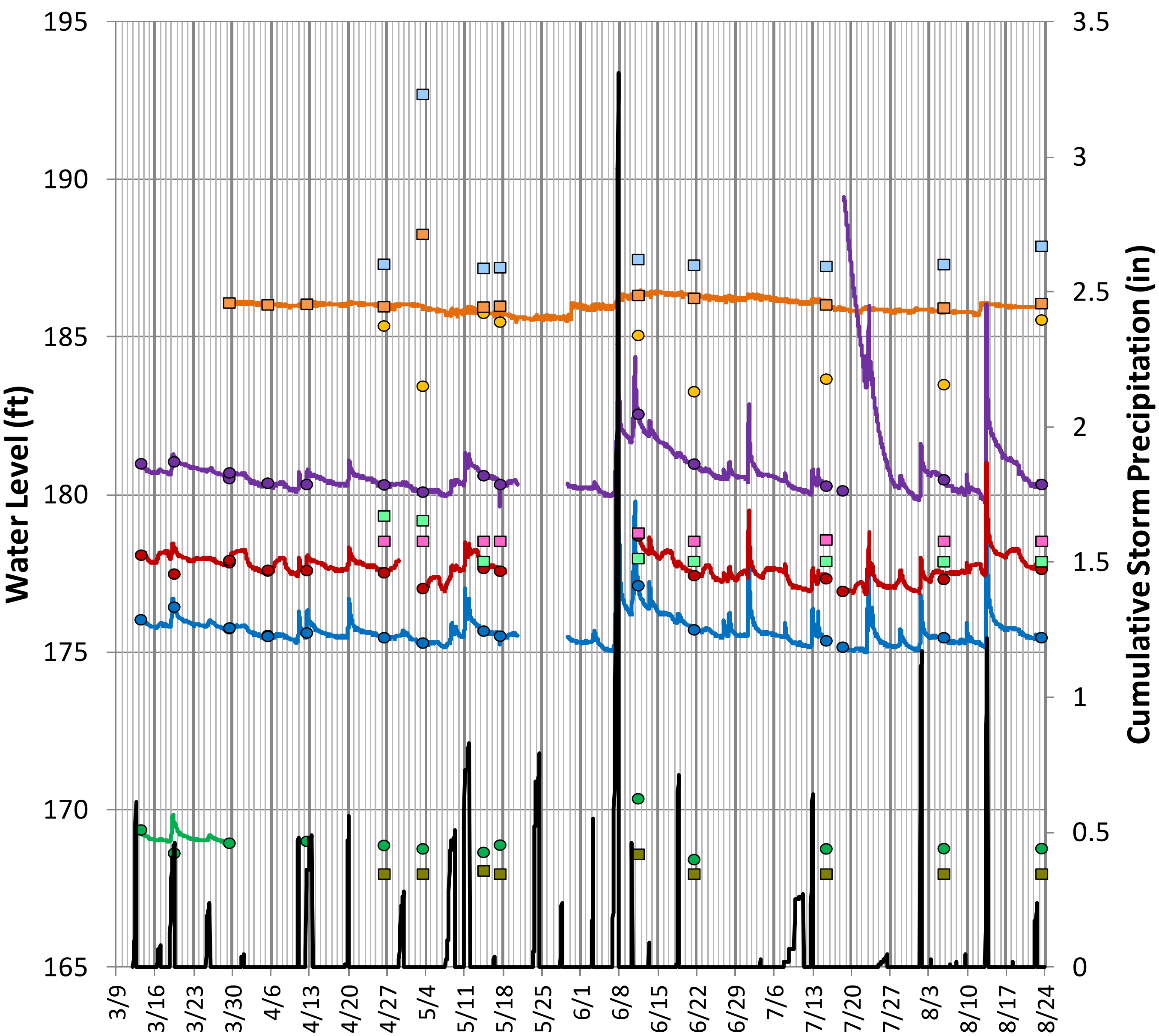
SG-03 Water Level Data (Reservoir)

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.8

August 2013



Legend

- MW-01A Water Level (Transducer Data)
- MW-01A Water Level (Hand Measurements)
- MW-02 Water Level (Transducer Data)
- MW-02 Water Level (Hand Measurements)
- MW-03 Water Level (Transducer Data)
- MW-03 Water Level (Hand Measurements)
- MW-05 Water Level (Transducer Data)
- MW-05 Water Level (Hand Measurements)
- MW-06 Water Level (Hand Measurements)
- SG-01 Water Level (Hand Measurements)
- SG-02 Water Level (Hand Measurements)
- Reservoir Water Level (Transducer Data)
- SG-03 Water Level (Hand Measurements)
- SG-04 Water Level (Hand Measurements)
- SG-05 Water Level (Hand Measurements)
- Cumulative Storm Precipitation (Wings Field Airport)

Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

The data from the new well is not included because there was no survey data to calculate the elevation of the water surface.

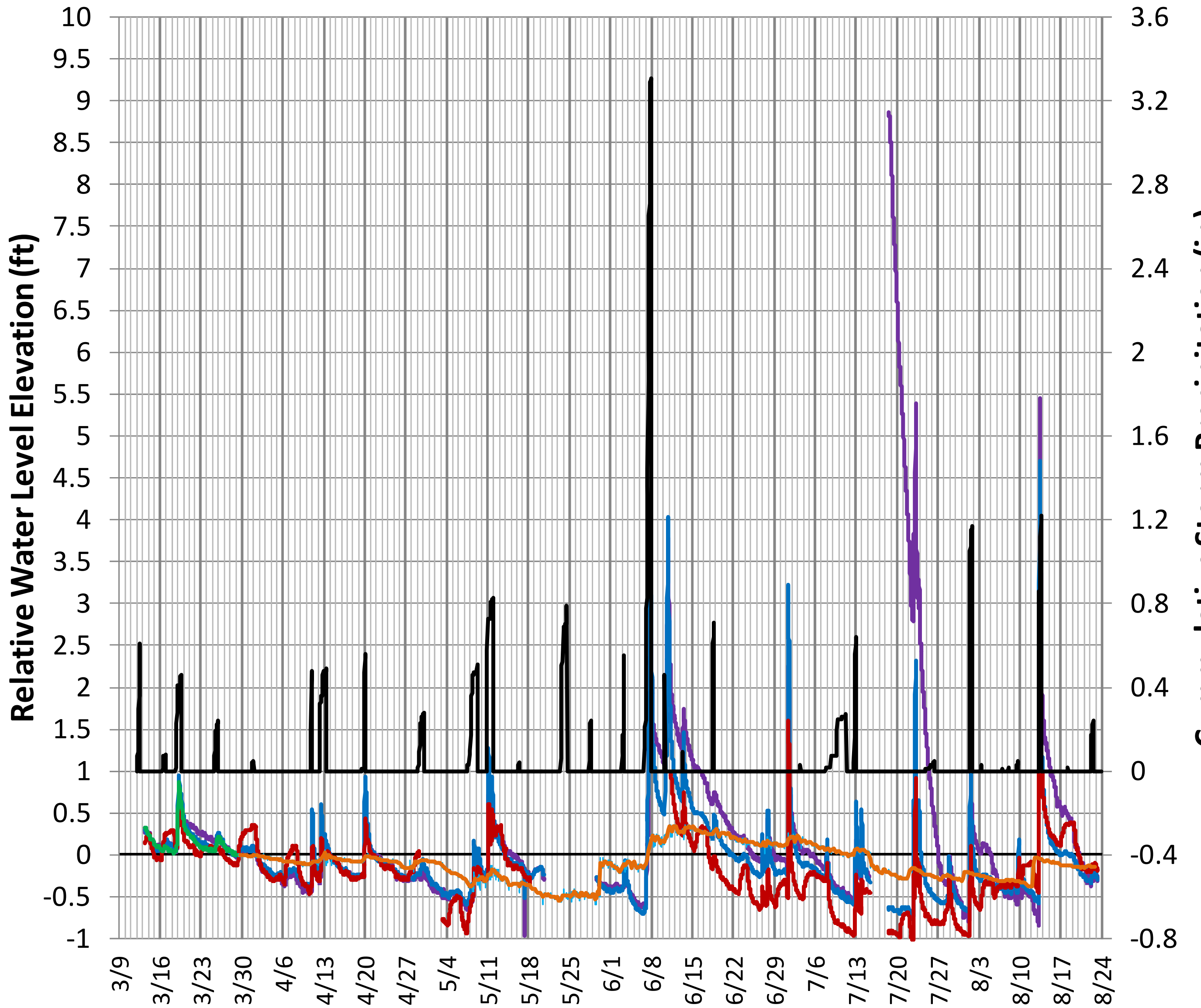
All Measured Water Levels

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.9

August 2013



Legend

- MW-01A Water Level (Transducer Data)
- MW-02 Water Level (Transducer Data)
- MW-03 Water Level (Transducer Data)
- MW-05 Water Level (Transducer Data)
- Reservoir Water Level (Transducer Data)
- Reservoir Water Level (6-hour Average)
- Cumulative Storm Precipitation (Wings Field Airport)

Notes:

Cumulative Storm Precipitation was calculated by successively adding hourly rainfall totals during a storm. A storm was assumed to have ended if the succeeding 24 hours were rain-free.

Relative water levels were calculated by subtracting the 10:00 am measurement on 3/29/2013 from the measurement for the given time.

The head data from the new well is not included because there was no data available on 3/29/2013.

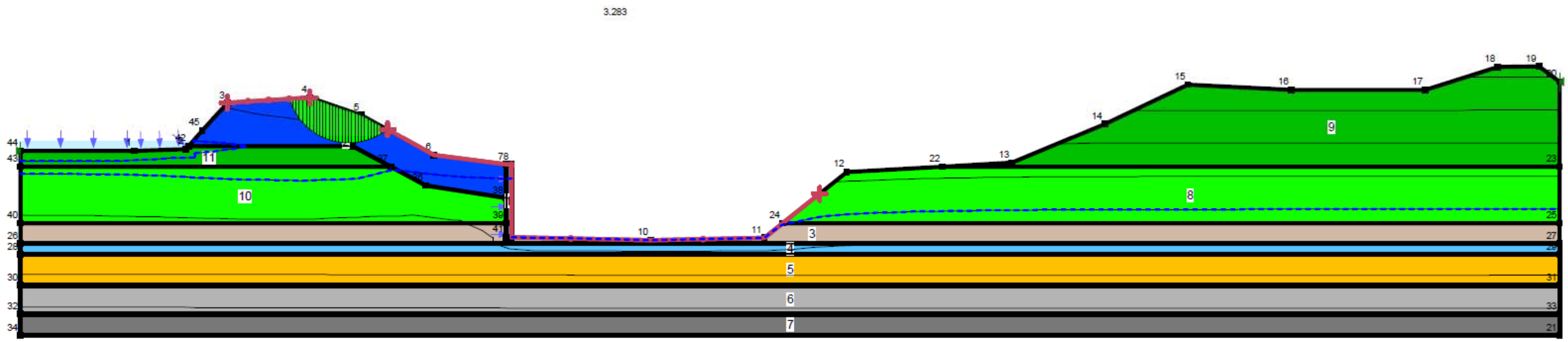
Relative Water Levels

BoRit Asbestos Superfund Site

Ambler, PA

Figure 3.10

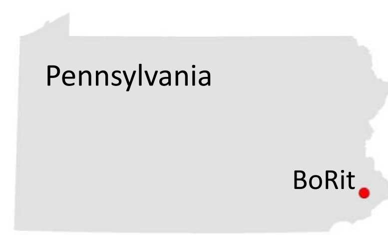
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Bedrock / Retaining wall	N/A	N/A	N/A
Region 2	Clean Silty Sand FILL (Drained)	115	34	0
Region 3	Clayey SAND (Drained)	120	29	0
Region 4	Sandy Lean CLAY (Drained)	124	26	0
Region 5	Poorly Graded SAND (Drained)	120	33	0
Region 6	Silty GRAVEL (Drained)	130	38	0
Region 7	Bedrock / Retaining wall	N/A	N/A	N/A
Region 8	Clayey Sand FILL (Drained)	120	33	0
Region 9	Sandy Lean Clay FILL (Drained)	124	26	0
Region 10	Clayey Sand FILL (Drained)	120	33	0
Region 11	Sandy Lean Clay FILL (Drained)	124	26	0

Legend

FS= 3.28



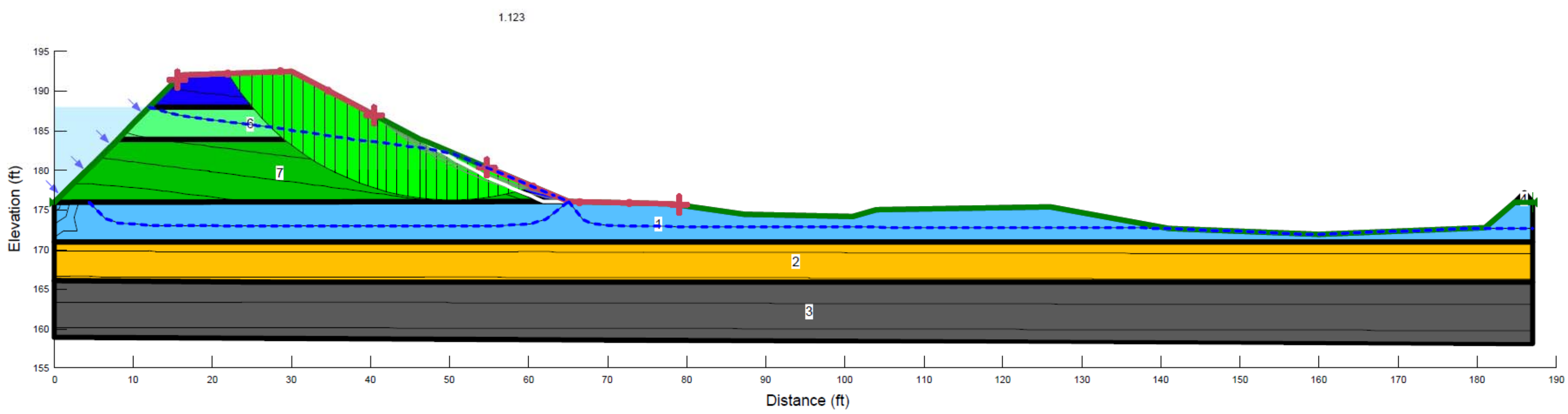
BOB-1 Current Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.1

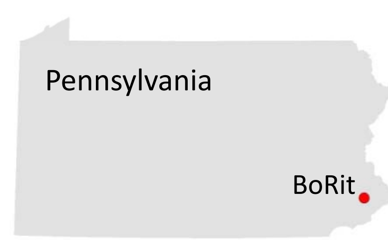
August 2013



Layer	Material	γ (lbs/ft³)	ϕ(°)	Cohesion (lbs/ft²)
Region 1	Sandy SILT (Drained)	115	22	0
Region 2	Poorly Graded SAND (Drained)	120	33	0
Region 3	Bedrock	N/A	N/A	N/A
Region 4	N/A	N/A	N/A	N/A
Region 5	Clean Silty Sand FILL (Drained)	115	34	0
Region 6	Dense Silty SAND (Drained)	125	34	0
Region 7	Loose Silty SAND (Drained)	115	29	0

Legend

FS= 1.12



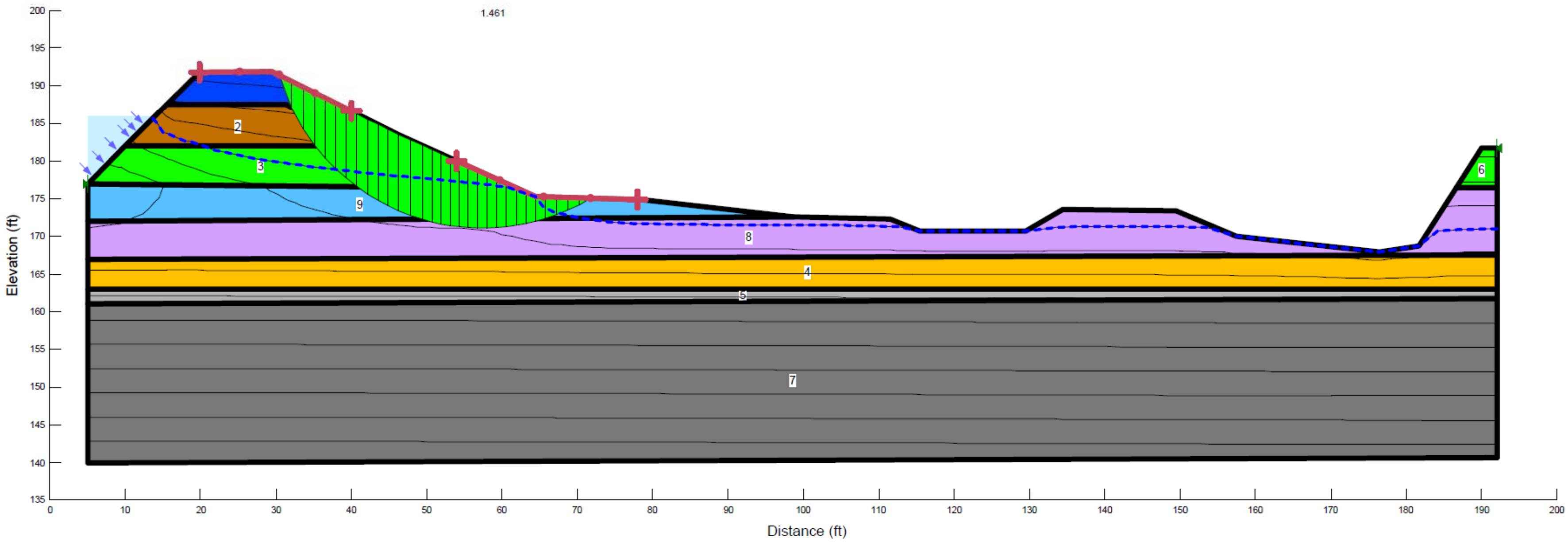
BOB-2 Current Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.2

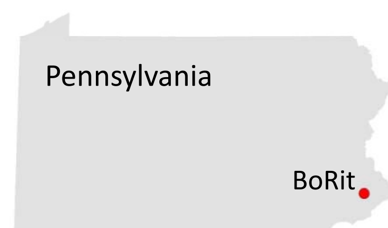
August 2013



Layer	Material	γ (lbs/ft³)	ϕ(°)	Cohesion (lbs/ft²)
Region 1	Clean Silty Sand FILL (Drained)	115	34	0
Region 2	Silty Sand FILL (Drained)	120	33	0
Region 3	Silty CLAY with Sand (Fill-Drained)	120	33	N/A
Region 4	Clayey SAND (Drained)	125	36	N/A
Region 5	Silty GRAVEL (Drained)	130	38	0
Region 6	Silty CLAY with Sand (Fill-Drained)	120	33	0
Region 7	Bedrock	N/A	N/A	N/A
Region 8	SILT with Sand (Drained) (0)	120	22	0
Region 9	SILT with Sand (Drained)	120	32	0

Legend

FS= 1.46



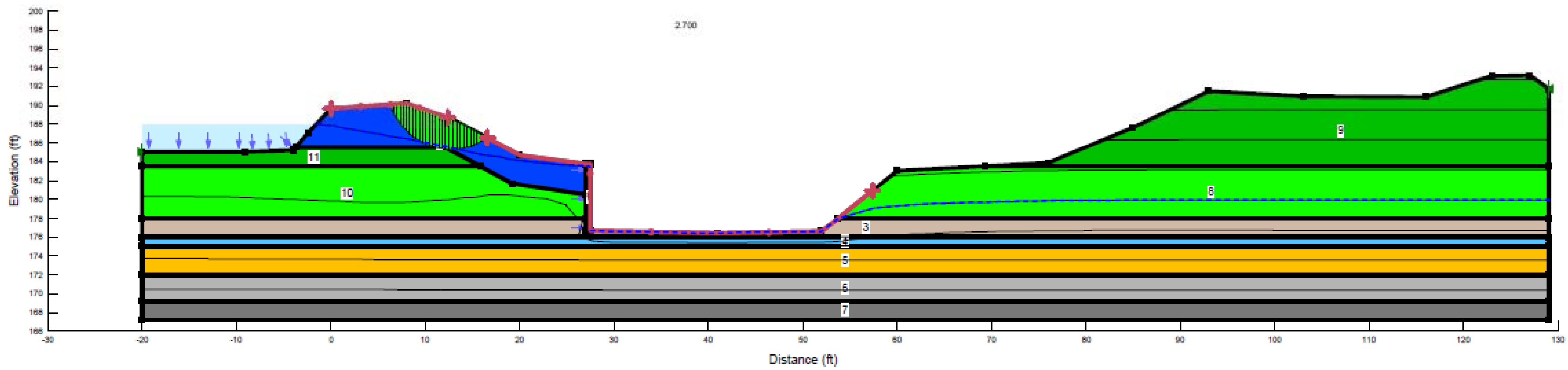
BOB-3 Current Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.3

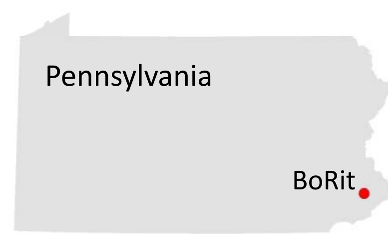
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Bedrock / Retaining wall	N/A	N/A	N/A
Region 2	Clean Silty Sand FILL (Drained)	115	34	0
Region 3	Clayey SAND (Drained)	120	29	0
Region 4	Sandy Lean CLAY (Drained)	124	26	0
Region 5	Poorly Graded SAND (Drained)	120	33	0
Region 6	Silty GRAVEL (Drained)	130	38	0
Region 7	Bedrock / Retaining wall	N/A	N/A	N/A
Region 8	Clayey Sand FILL (Drained)	120	33	0
Region 9	Sandy Lean Clay FILL (Drained)	124	26	0
Region 10	Clayey Sand FILL (Drained)	120	33	0
Region 11	Sandy Lean Clay FILL (Drained)	124	26	0

Legend

FS= 2.70



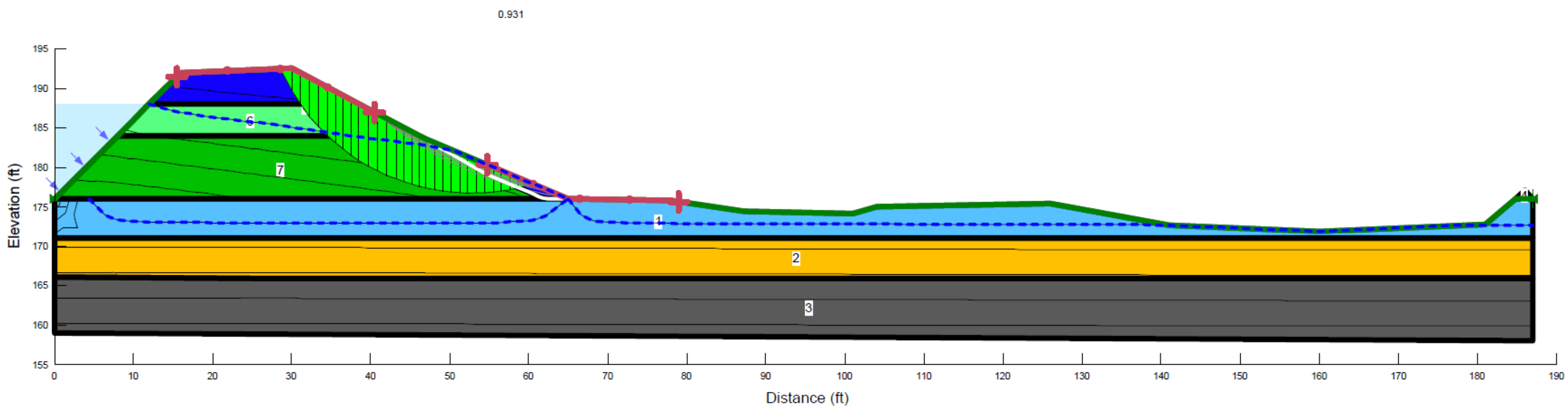
BOB-1 Current Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.4

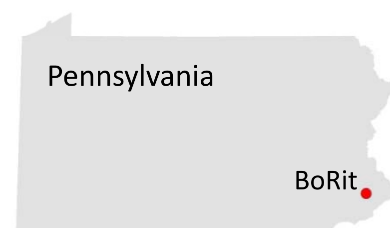
August 2013



Layer	Material	γ (lbs/ft³)	ϕ(°)	Cohesion (lbs/ft²)
Region 1	Sandy SILT (Drained)	115	22	0
Region 2	Poorly Graded SAND (Drained)	120	33	0
Region 3	Bedrock	N/A	N/A	N/A
Region 4	N/A	N/A	N/A	N/A
Region 5	Clean Silty Sand FILL (Drained)	115	34	0
Region 6	Dense Silty SAND (Drained)	125	34	0
Region 7	Loose Silty SAND (Drained)	115	29	0

Legend

FS= 0.93



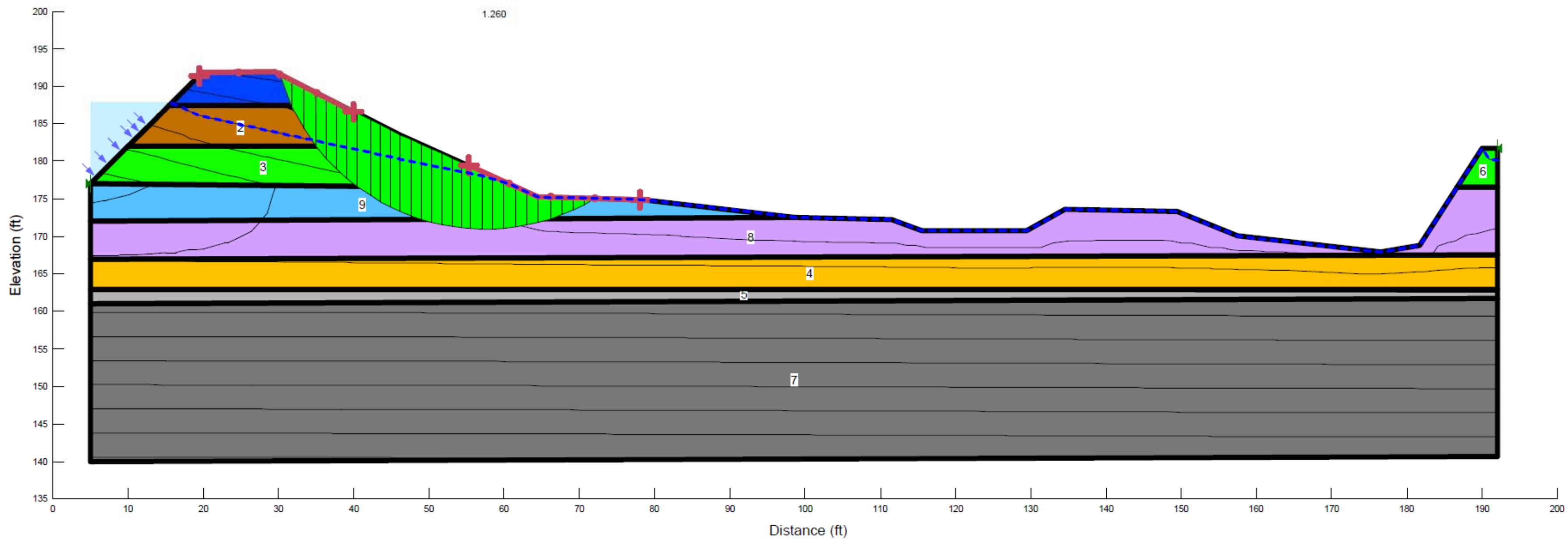
BOB-2 Current Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.5

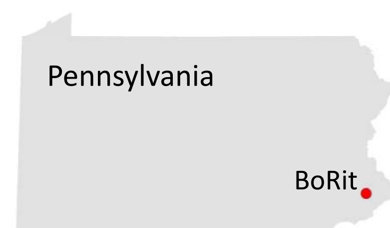
August 2013



Layer	Material	γ (lbs/ft³)	ϕ(°)	Cohesion (lbs/ft²)
Region 1	Clean Silty Sand FILL (Drained)	115	34	0
Region 2	Silty Sand FILL (Drained)	120	33	0
Region 3	Silty CLAY with Sand (Fill-Drained)	120	33	N/A
Region 4	Clayey SAND (Drained)	125	36	N/A
Region 5	Silty GRAVEL (Drained)	130	38	0
Region 6	Silty CLAY with Sand (Fill-Drained)	120	33	0
Region 7	Bedrock	N/A	N/A	N/A
Region 8	SILT with Sand (Drained) (0)	120	22	0
Region 9	SILT with Sand (Drained)	120	32	0

Legend

FS= 1.26



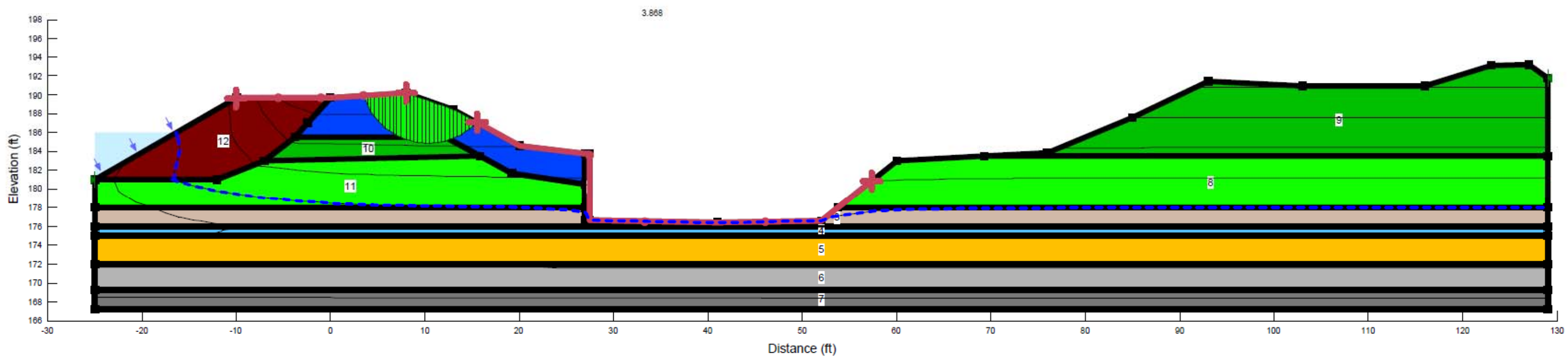
BOB-3 Current Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.6

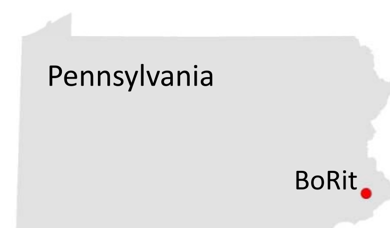
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Bedrock / Retaining wall	N/A	N/A	N/A
Region 2	Clean Silty Sand FILL (Drained)	115	34	0
Region 3	Clayey SAND (Drained)	120	29	0
Region 4	Sandy Lean CLAY (Drained)	124	26	0
Region 5	Poorly Graded SAND (Drained)	120	33	0
Region 6	Silty GRAVEL (Drained)	130	38	0
Region 7	Bedrock / Retaining wall	N/A	N/A	N/A
Region 8	Clayey Sand FILL (Drained)	120	33	0
Region 9	Sandy Lean Clay FILL (Drained)	124	26	0
Region 10	Sandy Lean Clay FILL (Drained)	124	26	0
Region 11	Clayey Sand FILL (Drained)	120	33	0
Region 12	BACKFILL	110	30	0

Legend

FS= 3.87



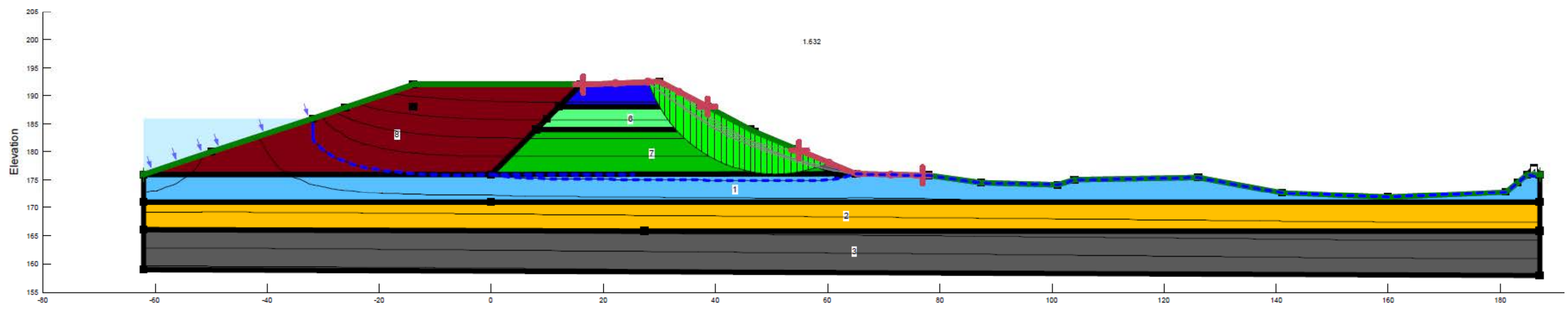
BOB-1 Proposed Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.7

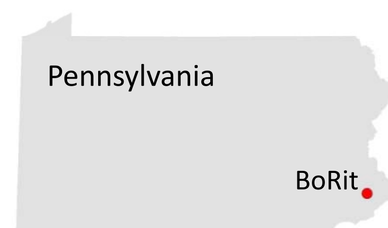
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Sandy SILT (Drained)	115	22	0
Region 2	Poorly Graded SAND (Drained)	120	33	0
Region 3	Bedrock	N/A	N/A	N/A
Region 4	N/A	N/A	N/A	N/A
Region 5	Clean Silty Sand FILL (Drained)	115	34	0
Region 6	Dense Silty SAND (Drained)	125	34	0
Region 7	Loose Silty SAND (Drained)	115	29	0
Region 12	BACKFILL	110	30	0

Legend

FS= 1.63



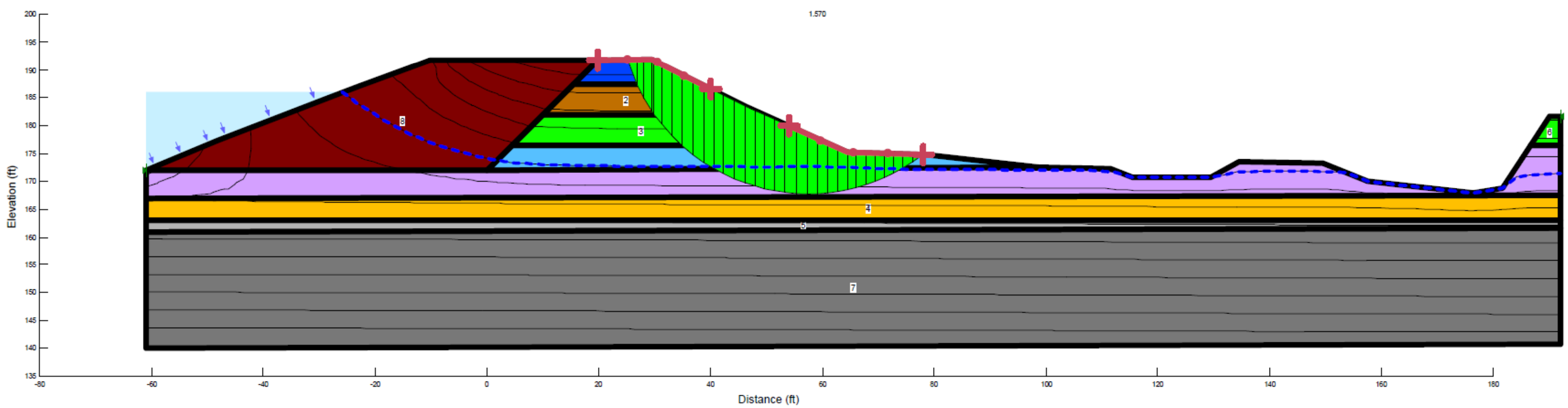
BOB-2 Proposed Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.8

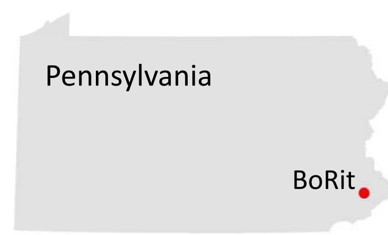
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Clean Silty Sand FILL (Drained)	115	34	0
Region 2	Silty Sand FILL (Drained)	120	33	0
Region 3	Silty CLAY with Sand (Fill-Drained)	120	33	N/A
Region 4	Clayey SAND (Drained)	125	36	N/A
Region 5	Silty GRAVEL (Drained)	130	38	0
Region 6	Silty CLAY with Sand (Fill-Drained)	120	33	0
Region 7	Bedrock	N/A	N/A	N/A
Region 8	Red Clay BACKFILL	110	30	0
Region 9	SILT with Sand (Drained) (0)	120	22	0
Region 10	SILT with Sand (Drained)	120	32	0

Legend

FS=1.57



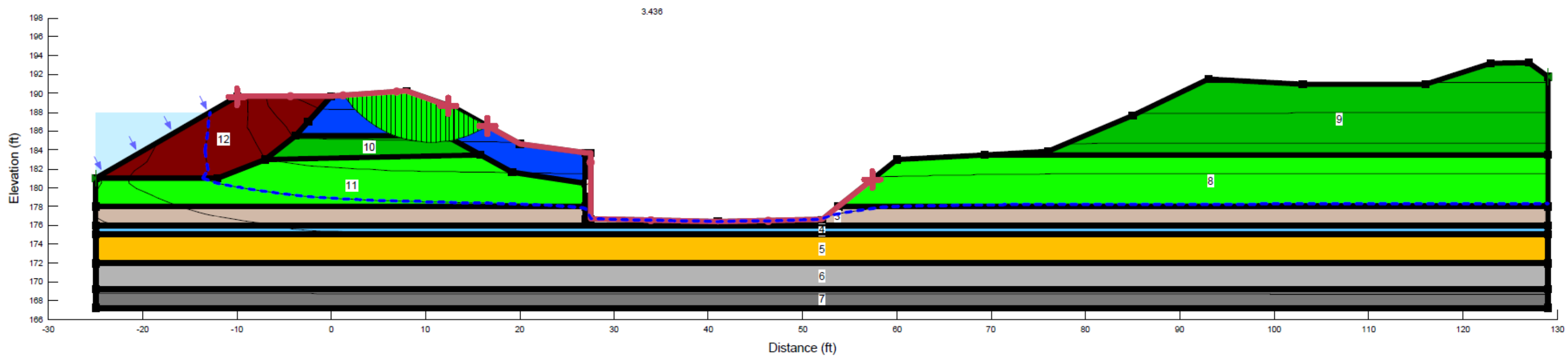
BOB-3 Proposed Geometry Normal Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.9

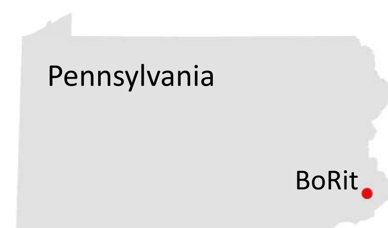
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Bedrock / Retaining wall	N/A	N/A	N/A
Region 2	Clean Silty Sand FILL (Drained)	115	34	0
Region 3	Clayey SAND (Drained)	120	29	0
Region 4	Sandy Lean CLAY (Drained)	124	26	0
Region 5	Poorly Graded SAND (Drained)	120	33	0
Region 6	Silty GRAVEL (Drained)	130	38	0
Region 7	Bedrock / Retaining wall	N/A	N/A	N/A
Region 8	Clayey Sand FILL (Drained)	120	33	0
Region 9	Sandy Lean Clay FILL (Drained)	124	26	0
Region 10	Sandy Lean Clay FILL (Drained)	124	26	0
Region 11	Clayey Sand FILL (Drained)	120	33	0
Region 12	BACKFILL	110	30	0

Legend

FS= 3.44



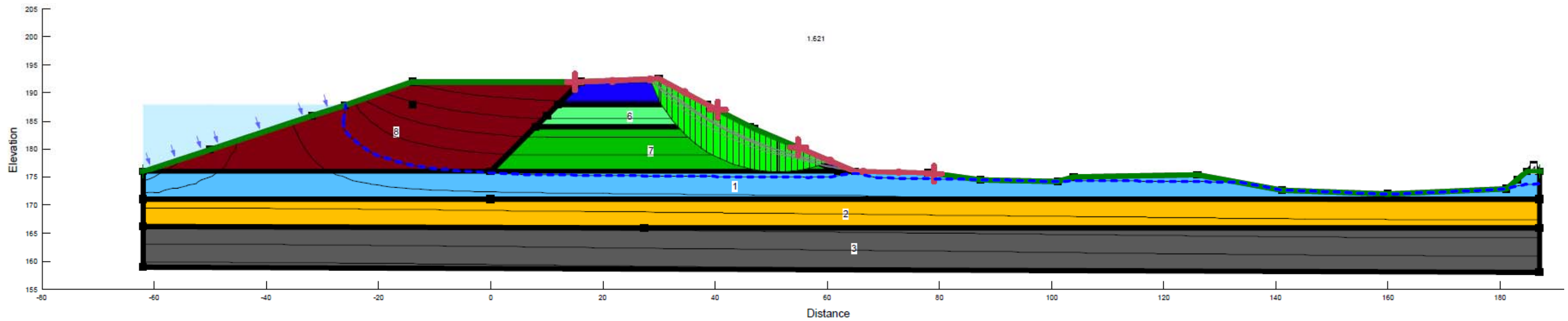
BOB-1 Proposed Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.10

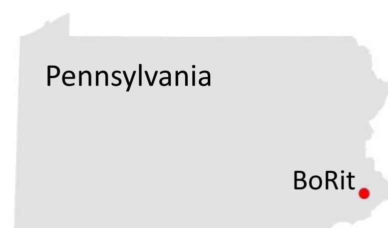
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Sandy SILT (Drained)	115	22	0
Region 2	Poorly Graded SAND (Drained)	120	33	0
Region 3	Bedrock	N/A	N/A	N/A
Region 4	N/A	N/A	N/A	N/A
Region 5	Clean Silty Sand FILL (Drained)	115	34	0
Region 6	Dense Silty SAND (Drained)	125	34	0
Region 7	Loose Silty SAND (Drained)	115	29	0
Region 12	BACKFILL	110	30	0

Legend

FS= 1.62



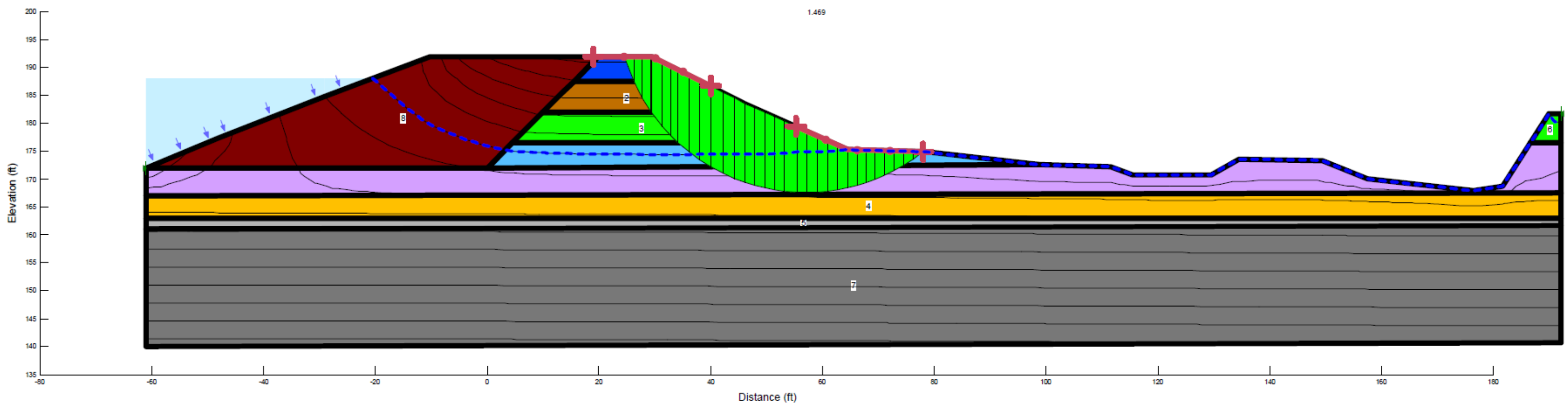
BOB-2 Proposed Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.11

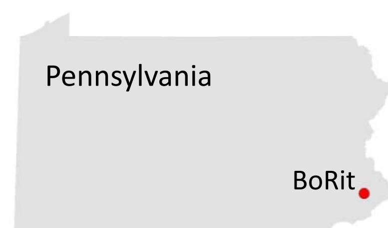
August 2013



Layer	Material	γ (lbs/ft^3)	ϕ(°)	Cohesion (lbs/ft^2)
Region 1	Clean Silty Sand FILL (Drained)	115	34	0
Region 2	Silty Sand FILL (Drained)	120	33	0
Region 3	Silty CLAY with Sand (Fill-Drained)	120	33	N/A
Region 4	Clayey SAND (Drained)	125	36	N/A
Region 5	Silty GRAVEL (Drained)	130	38	0
Region 6	Silty CLAY with Sand (Fill-Drained)	120	33	0
Region 7	Bedrock	N/A	N/A	N/A
Region 8	Red Clay BACKFILL	110	30	0
Region 9	SILT with Sand (Drained) (0)	120	22	0
Region 10	SILT with Sand (Drained)	120	32	0

Legend

FS= 1.47



BOB-3 Proposed Geometry High Head

BoRit Asbestos Superfund Site

Ambler, PA

Figure 4.12

August 2013