Brickyard Area of Lilydale Regional Park

Stormwater Management and Slope-Stability Analysis

Prepared for
City of St. Paul Department of Parks and Recreation

January 28, 2015

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Certifications

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the State of Minnesota.

Jim Herbert, PE PE #: 19926	January 28, 2015 Date

I hereby certify that the geotechnical section of this report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the State of Minnesota.

Bill Kussmann, PE PE #: 47821	January 28, 2015 Date

Brickyard Area of Lilydale Regional Park
Stormwater Management and Slope-Stability Study

Executive Summary

The Brickyard Area of Lilydale Regional Park is an area of both historic and recreational significance for the City of St. Paul. From the 1890s to the 1970s this area was used as a clay-mining and brick-making site. Evidence of that history remains in the three quarry areas (East, Middle, and West Clay Pits) and the ruins of a brick oven. Adjacent to the brick oven is Echo Cave, a man-made feature carved into the white Cambrian sandstone rock. In the early 1900s this rock was mined for its high silica content (used to make glass), supporting the demand for glass bottles from nearby breweries. Four fossil beds near the clay pits offer clues to an even earlier history and are popular with fossil hunters. Recreational features of the Brickyard Area include the popular Brickyard Trail, the Bruce Vento Scenic Overlook, several water falls, and the Middle Clay Pit bluffs which are often used for ice climbing.

The Brickyard Area is characterized by steep slopes, intermittent streams and seeps, and trails and ravines that convey stormwater from the direct and upland tributary areas. Erosion of the ravines and clay pits has led to decreased water quality in downstream Pickerel Lake (an important feature of Lilydale Regional Park) and slope instability. These concerns prompted the City of St. Paul to hire Barr Engineering Co. (Barr) to study erosion and slope-stability issues in the area. The primary objective of this study was to develop concept-level stormwater management, erosion-control, and slope-stability recommendations for City use. Specifically, the study was designed to:

- Help the City and its partners gain a better overall understanding of slope-stability issues in the Brickyard Area, particularly as they relate to proposed park structures and restricted active-use areas.
- Identify and evaluate erosion issues along the Brickyard Trail and in other area ravines.
- Identify and prioritize stormwater management techniques to reduce erosion while maintaining an aesthetic that is compatible with the unique, natural geologic setting of the park.

To formulate recommendations, Barr made two site visits to the Brickyard Area to gather information and document conditions. Geotechnical and stormwater analyses were also performed. A summary of these efforts is provided in the following pages.

Site observations

Barr staff and City personnel performed a field review of site conditions on May 15 and July 2, 2014. The focus of the first visit was to observe and generally inventory the existing ravines, trails, ravine/trail crossings, park amenities, storm sewer inflows, and slope-stability areas of concern. The Figure 1 on the following page shows features of the study area.

The second site visit was prompted by heavy precipitation in June that revealed additional slope-stability issues. The primary focus of this visit was a large slope failure toward the north end of the study area. Additional slope failures and material loss along the Brickyard Trail between the Middle and West Clay Pits and a sinkhole near the intersection of Annapolis Street and Cherokee Heights Boulevard were also examined.

Cherokee Heights Culvert and Ravine

Photo: Ravine slope failure. Significant erosion was observed along the ravine side slopes; there are several active slope failures in the ravine.

Northwest Slope Failure Area and Lower North Stream Channel

Photo: Large slope failure from above. Evidence of historic slope failures was observed. One failure was "reactivated" during a wet period in June 2014; this failure had enough force to topple mature trees along the lower section of the Brickyard Trail.

East, Middle, and West Clay Pits

Photo: Middle Clay Pit wall with fresh soil scarp in upper-right corner. The slopes above the pits are fairly steep with former scarps evident at numerous locations. Soil slopes at the corners of the clay pits seem prone to instability and failure.

Brickyard Trail, Including Bruce Vento Spur

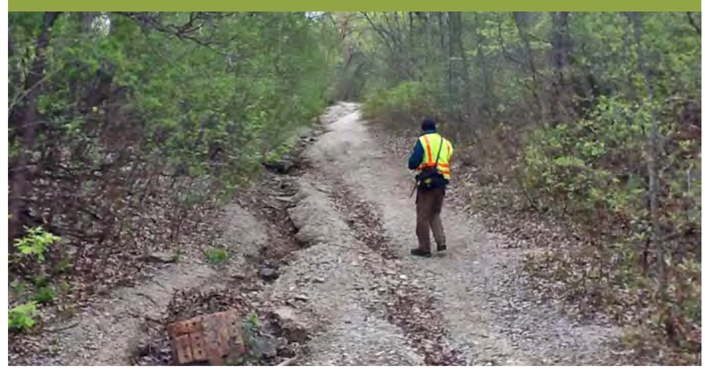

Photo: Erosion on the Brickyard Trail–Fossil/Brick Oven Section. Moderate-to-severe erosion from concentrated stormwater runoff along the straight and steep sections of the Brickyard Trail was observed. A steep slope adjacent to the trail showed evidence of slope failure that was reactivated during a wet period in June 2014.

Bruce Vento Scenic Overlook

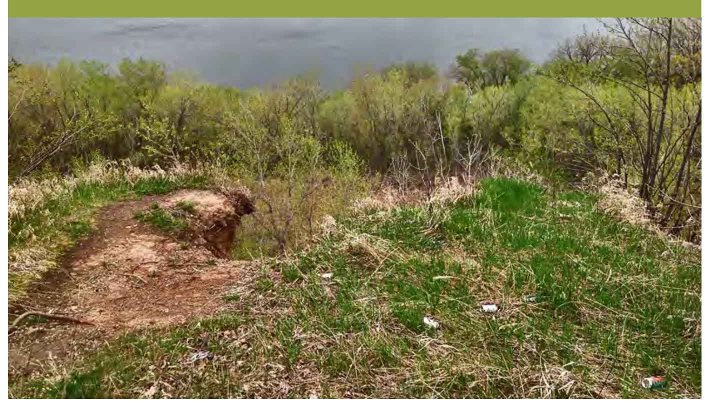

Photo: Soil overhang, from above, at Bruce Vento Scenic Overlook. A mass of overhanging soil, supported by vegetation/root zones was observed. There is potential for this area to fail when the roots eventually give way.

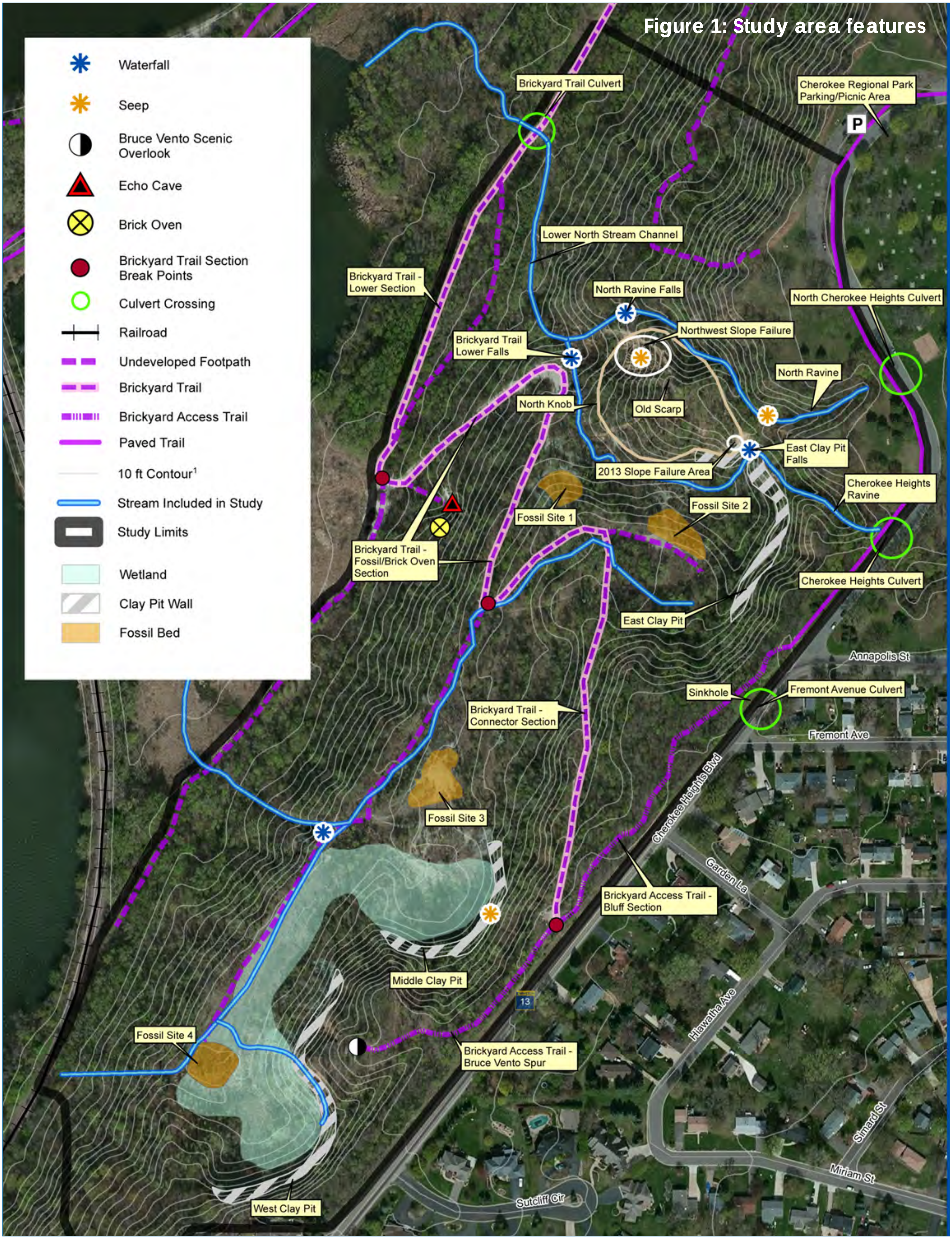

Figure 1: Study area features
Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Brickyard Trail Section Break Points
Culvert Crossing
Railroad
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
10 ft Contour[1]
Stream Included in Study
Study Limits
Wetland
Clay Pit Wall
Fossil Bed
Brickyard Trail Culvert
Cherokee Regional Park Parking/Picnic Area
P
Lower North Stream Channel
Brickyard Trail - Lower Section
North Ravine Falls
North Cherokee Heights Culvert
Brickyard Trail Lower Falls
Northwest Slope Failure
North Ravine
North Knob
Old Scarp
East Clay Pit Falls
2013 Slope Failure Area
Cherokee Heights Ravine
Fossil Site 1
Fossil Site 2
Brickyard Trail - Fossil/Brick Oven Section
Cherokee Heights Culvert
East Clay Pit
Annapolis St
Sinkhole
Fremont Avenue Culvert
Brickyard Trail - Connector Section
Fremont Ave
Cherokee Heights Blvd
Fossil Site 3
Garden La
Brickyard Access Trail - Bluff Section
Middle Clay Pit
13
Hiawatha Ave
Fossil Site 4
Brickyard Access Trail - Bruce Vento Spur
Simard St
Miriam St
Sutcliff Cir
West Clay Pit

Geotechnical analysis

To evaluate the stability of the existing slopes in the Brickyard Area and the effects of water content/saturation, the physical properties of the soil and rock were examined. Samples from five boring locations were analyzed to identify the following soil/rock characteristics: stratigraphy, natural moisture content, unit weight, plasticity, grain size, strength, and permeability. Slope-stability simulation modeling was also performed to evaluate the influence of topography, soil strength, and seepage/saturation on area slope stability and to calculate "factors of safety" (the ratio of resisting forces in the soil to the driving forces that cause slope movement).

Stormwater analysis

To gain a better understanding of drainage patterns within the Brickyard Area and their influence on erosion a stormwater analysis was done. An XP-SWMM hydrologic and hydraulic model was developed to estimate stormwater depths and corresponding flows and velocities in the storm sewer system, channels, and ravines throughout the study area.

More information about hydrology in the Brickyard Area and its impact on slope stability can be found on page 8.

Potential for slope failure

Based on May and July site observations, the results of geotechnical and stormwater analyses, as well as Barr's experience, conditions in the area (at the time of the study) were categorized as low-risk, moderate-risk, or high-risk (see Figure 2). These rating categories are specific to this project and not based on industry standards. The primary factors influencing risk assessment were likelihood for large-volume landslides, likelihood of soils falling from significant heights, likelihood of persons being caught in a slide from above the failure surface, and a history of previous landslides. No area of the park was considered "no-risk." The uncertainties of weather, soil type and strength, and human activity always pose some risk of unexpected soil movement. It is also important to note that this is a constantly changing landscape (as evidenced by site changes between May and July site visits). It is impossible to state, with any degree of certainty, that these slopes will or will not fail over time.

One solution for managing high-risk areas is to limit public access. There are two areas in the park where we recommend that restricted access be considered (see Figure 3, page 7). These areas include only one of the four popular fossil sites identified by the City and do not include the Brickyard Trail.

HIGH RISK

Areas categorized as *high-risk* have the following features or characteristics:

- Likelihood for large volume circular-failure or block-failure landslides
- Likelihood for soils to fall from significant heights
- Likelihood for persons to be caught in a slide from above the failure surface
- History of previous large-volume slides

MODERATE RISK

Areas categorized as *moderate-risk* have the following features or characteristics:

- Likelihood for lesser-volume circular-failure or surficial translational-failure landslides
- Likelihood for soils to fall from lower heights
- History of previous lesser-volume slides

LOW RISK

Areas categorized as *low-risk* have the following features or characteristics:

- Generally flatter grades and minimal likelihood for landslides
- Likelihood for soils to fall from lower heights
- No apparent history or evidence of landslides
- Areas that were not observed during the May and July 2014 site visits, but generally have similar characteristics to other low-risk areas within the study area

No area of the park was considered *no-risk*. The uncertainty of weather; soil type, strength, and stratigraphy; and human activity always pose some risk due to unexpected movement of soils.

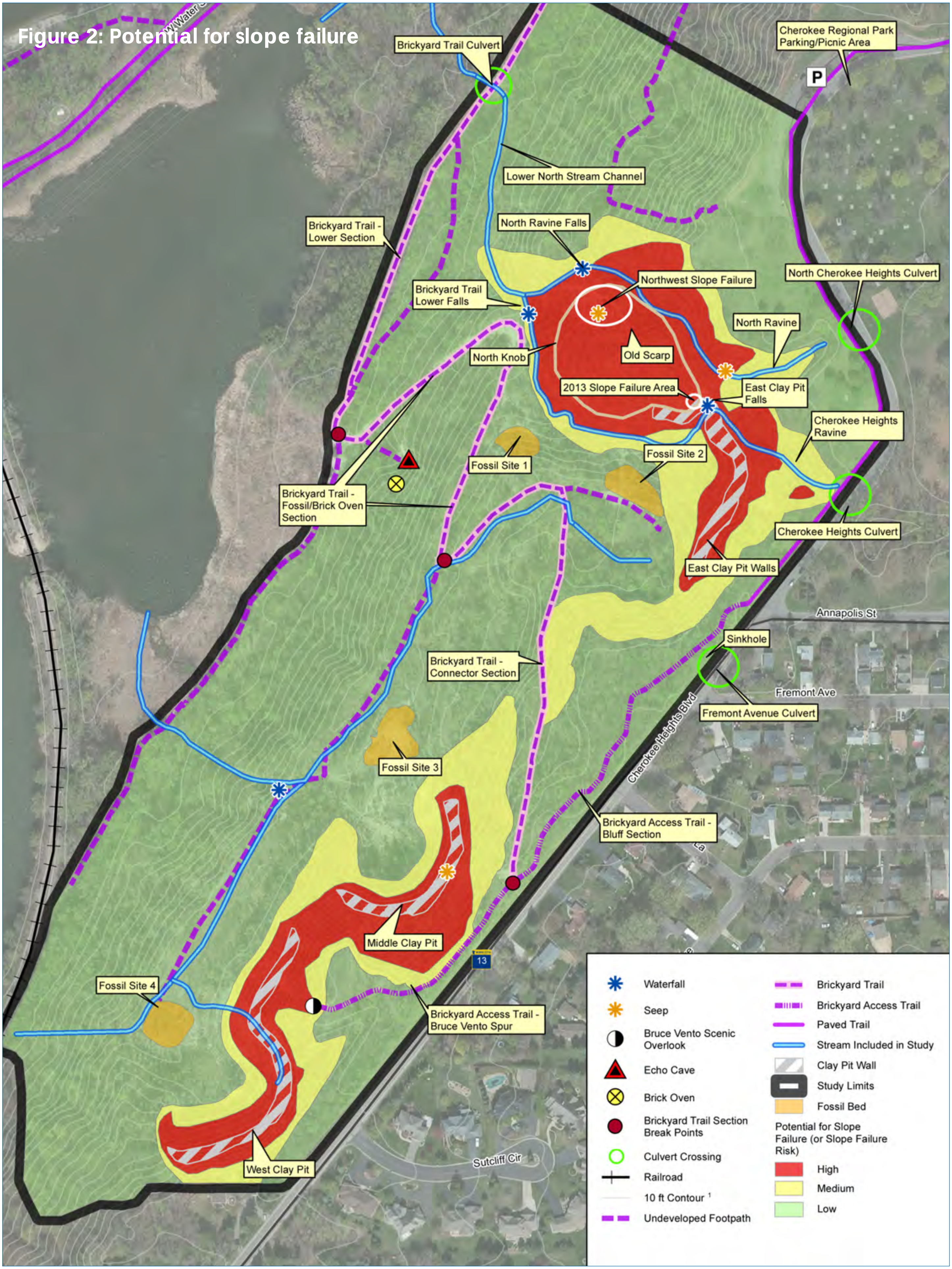

Figure 2: Potential for slope failure
Brickyard Trail Culvert
Cherokee Regional Park Parking/Picnic Area
P
Lower North Stream Channel
Brickyard Trail - Lower Section
North Ravine Falls
Northwest Slope Failure
North Cherokee Heights Culvert
Brickyard Trail Lower Falls
North Ravine
Old Scarp
North Knob
2013 Slope Failure Area
East Clay Pit Falls
Cherokee Heights Ravine
Fossil Site 1
Fossil Site 2
Brickyard Trail - Fossil/Brick Oven Section
Cherokee Heights Culvert
East Clay Pit Walls
Annapolis St
Sinkhole
Brickyard Trail - Connector Section
Fremont Ave
Fremont Avenue Culvert
Cherokee Heights Blvd
Fossil Site 3
Brickyard Access Trail - Bluff Section
Middle Clay Pit
13
Fossil Site 4
Brickyard Access Trail - Bruce Vento Spur
West Clay Pit
Sutcliff Cir
Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Brickyard Trail Section Break Points
Culvert Crossing
Railroad
10 ft Contour [1]
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
Stream Included in Study
Clay Pit Wall
Study Limits
Fossil Bed
Potential for Slope Failure (or Slope Failure Risk)
High
Medium
Low

Recommendations

General recommendations for the Brickyard Area of Lilydale Regional Park are listed below. More specific recommendations related to (1) ravine stabilization/ stormwater management, (2) steep-slope stabilization, and (3) erosion along the Brickyard Trail are outlined in the column at right.

- **Restrict access to high-risk areas of the park—** including Cherokee Heights Ravine, North Ravine, and a portion of the Lower North Stream Channel; the East, Middle, and West Clay Pit areas; and the Bruce Vento Scenic Overlook. These areas are indicated on Figure 3 by a red-dashed line. Only one of four fossil sites is included in these proposed restricted areas.

- **Conduct additional research on industry-accepted best practices for managing risk in park settings.**

- **Stabilize and re-vegetate slopes, where feasible—** including the steep slopes in the northern Brickyard Area and the slopes in the "connector" section of the Brickyard Trail. The Bruce Vento Scenic Overlook and Bruce Vento Spur of the Brickyard Trail could also be mechanically stabilized.

- **Perform inspections—**annually and after significant precipitation events, with subsequent adjustments to access areas. In addition, the Cherokee Heights Ravine, North Ravine, and Lower North Stream Channel should be routinely monitored and inspected for new erosion that could impact downstream areas, including Pickerel Lake.

- **Place barriers and/or signage at access points to restricted areas—**as well as general park access points to alert visitors.

- **Consider monitoring changing conditions in the park with equipment such as tilt meters, inclinometers, piezometers, etc.**

Planning-level opinions of construction costs for alternatives are included in the complete *Brickyard Area of Lilydale Regional Park Stormwater Management and Slope-Stability Study* report. These estimates are included to assist in evaluating and comparing options; they do not represent absolute values for given alternatives.

Regardless of any selected alternative(s), additional site visits, geotechnical investigation, borings, and soils testing must be performed to refine the recommendations for specific park areas and address potential changes to conditions.

Ravine stabilization/stormwater management for Northern Brickyard Area

1. Restrict access to the Cherokee Heights Ravine, North Ravine, and Lower North Stream Channel (area outlined by red-dashed line, Figure 3). Restricting this area includes closing Fossil Site 2.
2. Stabilize the steep slopes in the North Knob.
3. Re-establish and stabilize the Lower North Stream Channel using river-rock riprap. Boulder riffles could potentially be added for aesthetics and to help reduce flow velocities.
4. Once the stream channel is re-established and stabilized, replace the Brickyard Trail culvert with a small span bridge.

Steep-slope stabilization

1. Restrict access to the Middle and West Clay Pit areas and the Bruce Vento Scenic Overlook (area outlined by red-dashed line, Figure 3)
2. Relocate or mechanically stabilize the Bruce Vento Scenic Overlook.
3. Stabilize the section of the Bruce Vento Spur of the Brickyard Trail highlighted on Figure 3.
4. Stabilize a portion of the "connector section" of the Brickyard Trail using vegetated, reinforced soil slopes—assuming the canopy cover does not prevent sunlight penetration. In the interim, remove (or relocate) the park bench downslope of this area. Alternatively, this area could be graded to a stable slope.
5. Stabilize the North Knob by grading to a stable slope.

Brickyard trail erosion

Implement one (or a combination) of the three following erosion-control measures:

1. Install Geoweb to stabilize and reinforce the trail.
2. Repair the trail and install waterbars to deflect water off the trail and reduce future erosion.
3. Install a "side channel" (reinforced ditching) along the side of the trail and resurface this area.

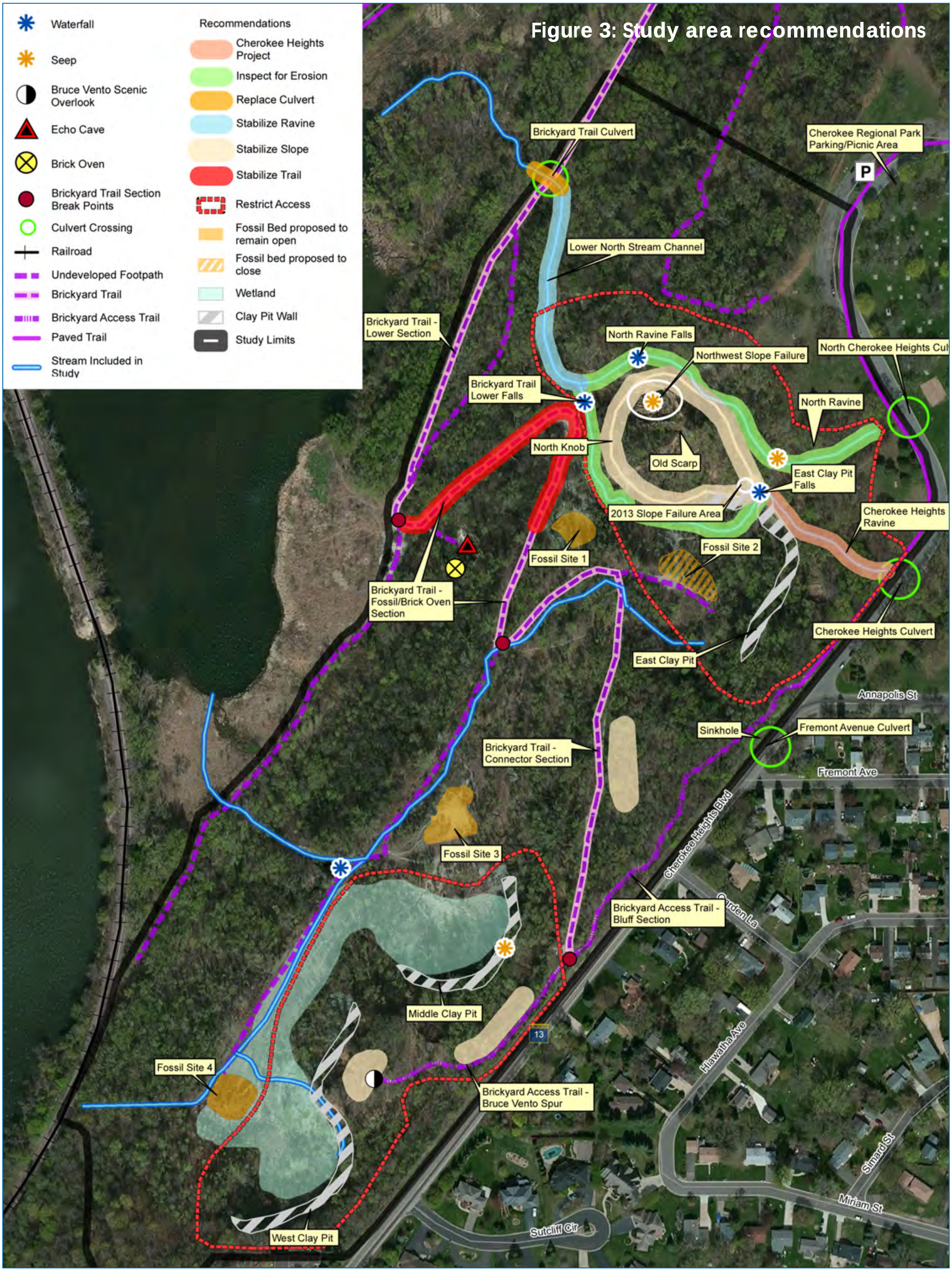

Figure 3: Study area recommendations
Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Brickyard Trail Section Break Points
Culvert Crossing
Railroad
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
Stream Included in Study
Recommendations
Cherokee Heights Project
Inspect for Erosion
Replace Culvert
Stabilize Ravine
Stabilize Slope
Stabilize Trail
Restrict Access
Fossil Bed proposed to remain open
Fossil bed proposed to close
Wetland
Clay Pit Wall
Study Limits
Brickyard Trail Culvert
Cherokee Regional Park Parking/Picnic Area
P
Lower North Stream Channel
Brickyard Trail - Lower Section
North Ravine Falls
Northwest Slope Failure
North Cherokee Heights Cul
Brickyard Trail Lower Falls
North Ravine
North Knob
Old Scarp
East Clay Pit Falls
2013 Slope Failure Area
Cherokee Heights Ravine
Fossil Site 2
Fossil Site 1
Brickyard Trail - Fossil/Brick Oven Section
Cherokee Heights Culvert
East Clay Pit
Annapolis St
Sinkhole
Fremont Avenue Culvert
Brickyard Trail - Connector Section
Fremont Ave
Cherokee Heights Blvd
Fossil Site 3
Garden La
Brickyard Access Trail - Bluff Section
Middle Clay Pit
13
Hiawatha Ave
Fossil Site 4
Brickyard Access Trail - Bruce Vento Spur
Simard St
Miriam St
Sutcliff Cir
West Clay Pit

Hydrology and the Brickyard Area

Figure 4, below, developed by the US Geological Service, shows the earth's water (hydrologic) cycle. Surface runoff, infiltration, seepage, and groundwater (circled in red) all contribute to unstable slopes in the Brickyard Area of Lilydale Regional Park.

- **Surface runoff—**Precipitation that does not infiltrate and contributes to erosion at the toe of the slope (Figure 5)
- **Channelized surface water—**Surface runoff that channelizes in the ravines
- **Groundwater (seepage)—**Precipitation that infiltrates but "seeps" back out when it reaches an impermeable rock layer

Some of the ways this water impacts slope stability are described at right.

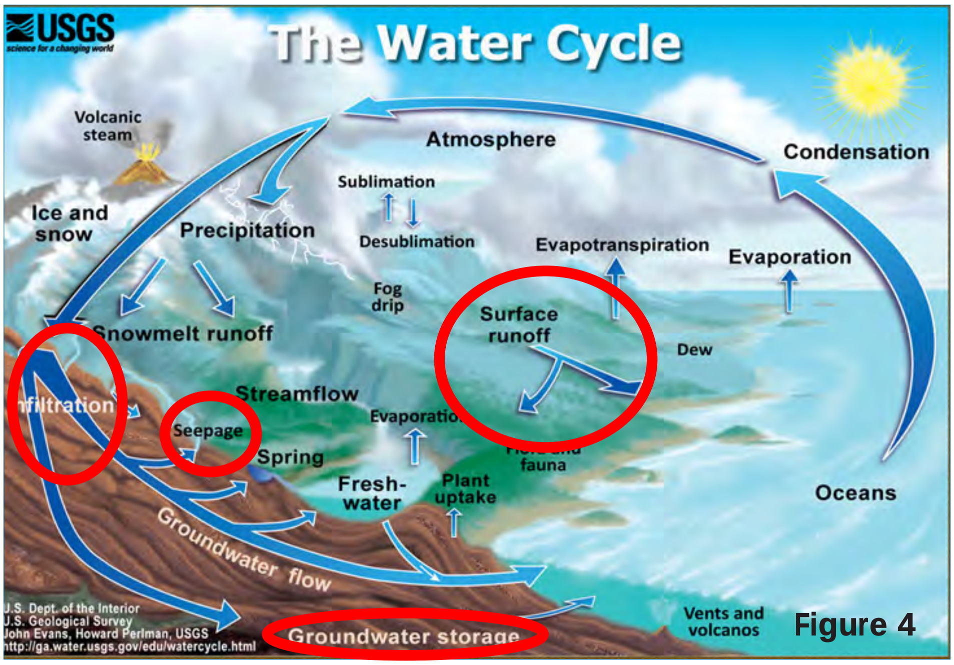

Figure 4

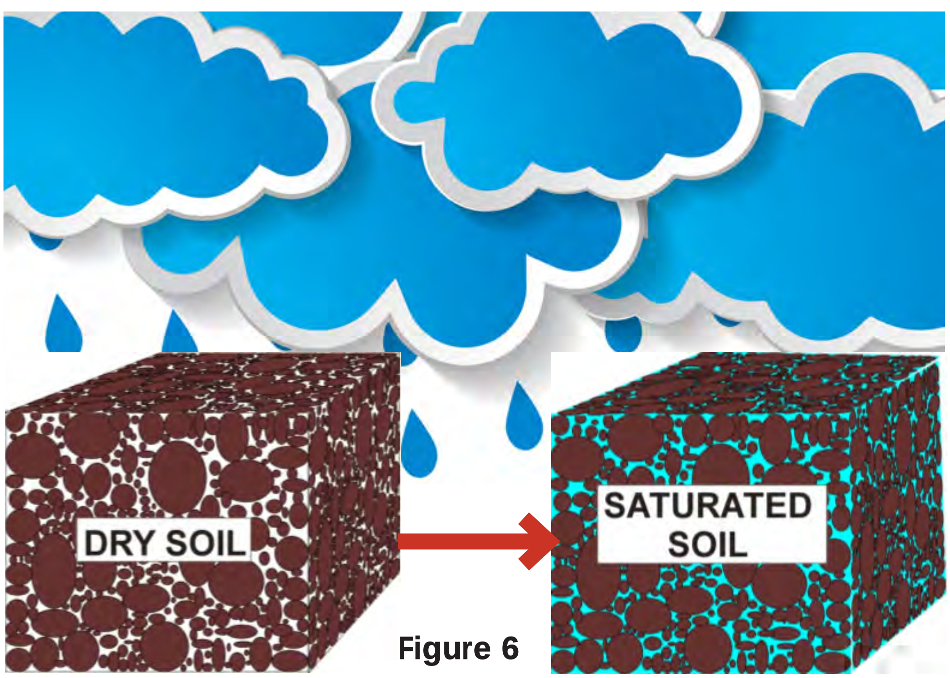

Figure 6

Water and slope stability

Filling the void—When precipitation infiltrates the soil it fills the void spaces between the soil grains (Figure 6). Too much water in these void spaces reduces or eliminates the suction and cohesive forces that hold the grains together.

Changing geometry—Runoff that erodes the toe of the slope may cause unstable conditions by changing the slope's geometry.

Creating pressure—Water adds weight to the soil. If 2 inches of rain infiltrate a 100- x 200-foot slope, the slope weight increases by 200 tons (source: "The Role of Water in Slope Stability," Lecture, Western Washington University).

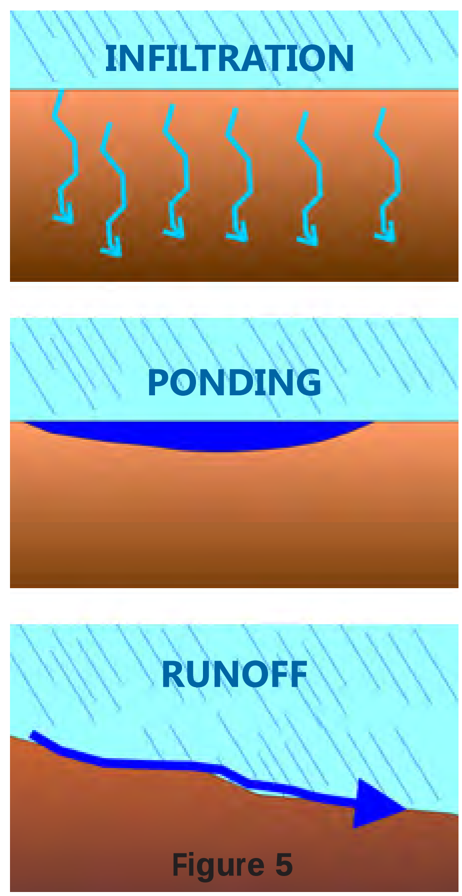

Figure 5

1.0 Background and Objectives

1.1 Background

For several decades (the 1890s to the 1970s) the Brickyard Area of Lilydale Regional Park in St. Paul, Minnesota (Large Figure 1-1), was used as a clay mining and brick-making site. The area is characterized by three quarries (i.e., East, Middle, and West Clay Pits), steep slopes, intermittent streams and seeps, and erosion-prone trails and ravines that convey stormwater from the direct and upland tributary areas. Many historic sites and recreational amenities are located within the Brickyard Area. These include:

- The Brickyard Trail, which extends from the park access at West Water Street near the Mississippi River and the lower brick-making area to the top of the bluff.
- The Bruce Vento Scenic Overlook.
- Three historic clay pits, forming a topographical (near vertical) break between lower park elevations and the upper portion of the park.
- Ruins of a brick oven at the base of the bluff and several old foundations, presumably from quarrying equipment.
- Several water falls.
- Four fossil beds near the clay pits which attract fossil collectors (requiring a permit).
- Echo Cave, a manmade feature carved into the white Cambrian sandstone rock adjacent to the brick oven; in the early 1900s this sandstone was mined for its high silica content (used to make glass), supporting the demand for glass bottles from nearby breweries.
- Bluffs conducive to ice climbing (requiring a permit).

Slope stability and erosion of the ravines and clay pits in the Brickyard Area have been ongoing concerns for the City of St. Paul Department of Parks and Recreation (City) and its partner agencies.

1.2 Study Objectives

In 2014 the City of St. Paul hired Barr Engineering Co. (Barr) to study erosion and slope-stability issues at Lilydale Regional Park. The primary objectives of this study were to develop concept-level stormwater-management, erosion-control, and slope-stability recommendations for the Brickyard Area within the park. More specifically, the study was designed to:

- Help the City and its partners gain a better overall understanding of slope-stability issues in the Brickyard Area, particularly as they relate to proposed park features and restricted, permitted active-use areas.

- Identify and evaluate erosion issues along the Brickyard Trail and in other ravines within the Brickyard Area.
- Identify and prioritize stormwater management techniques to reduce erosion while maintaining an aesthetic that is compatible with the unique natural geologic setting of the park.

The scope of work for this project was developed based on a January 23, 2014, meeting between Barr and City staff and subsequent coordination. Specific work tasks identified to achieve the study objectives are listed in the Table 1-1.

Table 1-1 Summary of Work Tasks from Project Scope of Work

Work Task Description
Compile and review background data
Site review and field survey
Geotechnical analysis (Appendix C)
Meeting #1: Barr and City staff (September 2014)
Stormwater analysis (Appendix D)
Evaluate conceptual stabilization alternatives
Prepare planning-level opinions of construction costs
Meeting #2: Barr and City staff (November 2014)
Prepare draft report
Meeting #3: Barr and City staff (December 2014)
Prepare final report (January 2015)

2.0 Site Observations

The Brickyard was the site of the Twin Cities Brick Company, which was founded in 1894 and continued to make bricks until the 1970s. The interest in brick-making boomed after a number of local villages and cities, constructed primarily of wood, burned during catastrophic fires during the late 1800s. Workers quarried Decorah shale on the bluff above this location and brought it down the steep hillside where it was processed and fired into bricks. Visitors to the site can still see ruins of a brick kiln at the base of the bluff and several quarries higher on the hill. The Twin Cities Brick Company supplied bricks used in building numerous buildings around the Twin Cities, including the St. Paul Hotel. (Source: www.nps.gov)

Barr staff and City personnel performed a field review of site conditions on May 15, 2014. The focus of this visit was to observe and generally inventory the existing ravines, trails, ravine/trail crossings, park amenities, storm sewer inflow, and slope-stability areas of concern. Specifically, the team reviewed the following:

- Cherokee Regional Park (including the 60-inch culvert crossing under Cherokee Heights Boulevard)
- Several ravines, waterfalls, and seeps
- The East, Middle, and West Clay Pits
- The Brickyard Trail (including the bluff section of the trail that runs along Cherokee Heights Boulevard)
- Fossil hunting sites
- The Bruce Vento Scenic Overlook

A second site visit was performed by Barr and City personnel on July 2, 2014, after heavy June precipitation revealed additional slope-stability issues. The main areas of focus during this second visit were a large slope failure toward the north end of the study area, a sink hole near the intersection of Annapolis Street and Cherokee Heights Boulevard, and additional slope failures and loss of material along the Brickyard Trail between the Middle and West Clay Pits

The field visits were specifically focused on and limited to park features within the study area. Potential impacts to infrastructure beyond the boundary of the study area were outside the scope of this study.

Specific observations made during each site visit and subsequent analyses and conclusions are provided in the following sections.

Large Figure 1-2 identifies the park features within the Brickyard Area referenced throughout this report. The Brickyard Trail is labeled with additional section names for report purposes only (e.g., Brickyard Trail–Bluff Section).

The Minnesota Department of Natural Resources 2011 LiDAR elevation data set was used to help characterize the slopes throughout the Brickyard Area. Large Figure 1-3 shows the change in slope throughout the Brickyard Area in terms of "percent rise." The portions of the Brickyard Area shown in orange and red hues on the figure represent the steepest areas (most notably, the clay pit walls). The percent rise becomes increasingly larger as the topography becomes more vertical.

Photo 2-1 West Clay Pit (at right) and area below Bruce Vento Overlook (center) from the air (photo provided by the City of St. Paul)

2.1 Cherokee Heights Culvert and Ravine

Drainage from portions of Cherokee Heights Regional Park and the adjacent residential area discharges through a 60-inch-diameter reinforced-concrete culvert that extends underneath Cherokee Heights Boulevard and into a ravine (Cherokee Heights Ravine on Large Figure 1-2, Photo 2-2). The ravine extends approximately 300 feet to a waterfall near the horseshoe-shaped East Clay Pit. Observation of the ravine reveals significant erosion along the channel invert and side slopes. This is most likely due to high flow rates and velocities in combination with erodible, sandy soils. At the downstream end of the ravine, the channel bottom has been scoured down to the underlying Decorah Shale bedrock.

The channel within the Cherokee Heights Ravine is fairly narrow and meanders slightly between the culvert and the East Clay Pit Falls. There are several active slope failures in the ravine, most notably near the culvert outlet and approximately midway to the East Clay Pit Falls (Photo 2-3). Erosion of the ravine side slopes appears to be contributing to some of the instability—removing material from the toes of the slopes, destabilizing the upper slopes, and causing slides into the ravine.

Just above the East Clay Pit Falls, a berm of soil directs the flow path of the stream roughly parallel to the edge of the East Clay Pit wall. Several sections of broken pipe were observed in this area; two sections appear to be held in place by the roots of a mature tree above the waterfall (Brickyard Trail Lower Falls) and parallel to the stream flow (2013 report by Northern Technologies, Inc. [NTI], Appendix D, photo #9). Although the original purpose and use of the pipe sections is unknown, they no longer convey flow and water spills over the falls to the downstream channel.

Photo 2-2 Erosion adjacent to the storm sewer outlet in Cherokee Heights ravine (May 2014 site visit)

Photo 2-3 Cherokee Heights ravine slope failure (July 2014 site visit)

2.2 Northwest Slope Failure Area and Lower North Stream Channel

During the May 2014 site visit, a slope failure scarp (exposed failure surface) was observed on the north-to-northwest side of a "stranded knob" northwest of the Cherokee Heights Boulevard culvert and stormwater ravine discussed in the previous section (Photo 2-4, Photo 2-5, and Photo 2-6). This scarp is noted on Large Figure 1-2 as the Northwest Slope Failure. As viewed on an aerial photograph, the stranded knob (noted on Large Figure 1-2 as the North Knob) is a rounded area which appears to be cut off from the main bluff by a drainage trench (i.e., "stranded"). It does not appear to be a natural condition. There is evidence of historic slope failure at this location, but nothing to suggest that the soil mass slid all the way to the base of the bluff. This slope failure was best observed from the location of the Brickyard Trail Lower Falls. Historic evidence of this slide area and previous disturbance in this general vicinity (likely due to brickyard operations) could be seen on aerial photographs.

This historic slope failure (or "slide") was reactivated during a wet period in June 2014. A large volume of soil slid from this area, down the base of the bluff, and over the lower section of the Brickyard Trail and culvert leading between the parking lot and the old brick oven (Photo 2-7 and Photo 2-8). The slide went just north of the small falls (Brickyard Trail Lower Falls) and another historic structure/foundation with enough force to topple mature trees and the chain link fence along the trail. It moved enough material to deposit a few inches of soil over the lower section of the Brickyard Trail and completely buried the culvert (Brickyard Trail Culvert) under the trail (Photo 2-9). Soils deposited at the slope toe temporarily blocked the stream. During the July 2014 site visit these soils were seen eroding as the stream attempted to reestablish a channel.

During the July 2014 site visit there appeared to be a concentrated seep about half-way up the newly exposed scarp surface. Viewed from a distance, the seep flow was estimated to be several gallons per minute and appeared to be flowing over the surface of the shale bedrock at the back of the new scarp.

The 2013 slope failure area (Photo 2-10 and Photo 2-11) discussed in the NTI report is generally located at the southeast edge of the North Knob and adjacent to the East Clay Pit waterfall (Large Figure 1-2). The mass of soil slid from the northwest side of the falls as shown in the photos included in Appendix D of the NTI report.

At least two slope failures in the park have been associated with this North Knob area (Large Figure 1-2). This area appears to be unstable and continued use of this area is not recommended.

Photo 2-4 Scarp from pre-2014 slope failure (taken from Brickyard Trail Lower Falls waterfall area during the May 2014 site visit)

Photo 2-5 Large 2014 slope failure from above (July 2014 site visit)

Photo 2-6 Large 2014 slope failure from below with inset showing seepage (July 2014 visit)

Photo 2-7 Large slide, looking up through newly eroded stream channel (July 2014 site visit)

Photo 2-8 Soil deposited at base of slide and newly eroded stream channel (July 2014 visit)

Photo 2-9 **Erosion of the lower section of the Brickyard Trail and plugged culvert, resulting from the Northwest Slope Failure (July 2014 site visit)**

Photo 2-10 **2013 slide area, from top of East Clay Pit Falls, observed during the May 2014 visit**

Photo 2-11 2013 slide area, from below, as observed during the July 2014 site visit

2.3 East, Middle, and West Clay Pits

The former areas quarried as a source of clay for brick-making are now steep-walled bluffs, referred to as clay pits (Photo 2-12). Review of these clay pit walls did not reveal significant evidence of faulting, block failures, bulging, or other signs of slope failures. There was some shale debris located immediately at the base of the clay pit walls, which appeared to be a product of slaking (softening of the clay), likely due to wetting/drying or freeze/thaw cycles.

The soils forming the slopes above the clay pit walls were observed during both the May and July 2014 site visits. The slopes above the clay pits appeared to be fairly steep, and scarps are evident at numerous locations (Photo 2-13). The soil slopes (soil above bedrock) at the ends/corners of the horseshoe-shaped clay pits seemed particularly prone to instability and slope failures; but, within the curved areas of the clay pit bowls, there were also places where tension-cracking or soil movement was evident. In one area, at the south side of the West Clay Pit bowl, a slope failure had removed a tree from the upper soil slope between the May and July 2014 site visits (Photo 2-13).

There were obvious areas of overhanging root mats/vegetation above the clay pit walls (Photo 2-14 and Photo 2-15). This condition was most apparent in the area of the Bruce Vento Scenic Overlook and is discussed in greater detail in Section 2.5.

During both the site visits, water was observed seeping from the slopes at the upper soil/bedrock interface, particularly in the Middle Clay Pit (Photo 2-16). This seepage, which freezes in the winter to allow ice-climbing activities in the Middle Clay Pit (Photo 2-17 and Photo 2-18), illustrates that groundwater infiltrates through the soils but does not readily penetrate the low-permeability shale. Instead, it tends to flow along the surface of the bedrock to the face of the bluffs. The amount of seepage appeared to vary from location to location and is likely influenced by drainage area, upstream collection/piping, general groundwater conditions (i.e., high or low, wet or dry), and bedrock topography.

Photo 2-12 West Clay Pit (May 2014 site visit)

Photo 2-13 Middle Clay Pit wall—with fresh soil scarp in upper right corner (July 2014 site visit)

Photo 2-14 Silty sand soil over shale bedrock in West Clay Pit (May 2014 site visit)

Photo 2-15 Close-up of overhanging soil and root zone in West Clay Pit (May 2014 site visit)

Photo 2-16 Seeping rock outcrop in Middle Clay Pit (July 2014 site visit)

Photo 2-17 Middle Clay Pit with snow/ice (from seepage) on face of shale (May 2014 visit)

Photo 2-18 Middle Clay Pit with snow/ice (from seepage) on face of shale (May 2014 site visit)

2.4 Brickyard Trail Including Bruce Vento Spur Trail

As shown in the figures, the Brickyard Trail is a winding path that leads from the park access at West Water Street near the Mississippi River to the top of the bluff. It continues along the top of the bluff to the trailhead, transitioning to a paved path that extends along Cherokee Heights Boulevard (near Annapolis Street) to the parking areas that serve the picnic grounds of Cherokee Regional Park. The lower section of the Brickyard Trail (west side, Large Figure 1-2) also leads from the old Brick Oven and Echo Cave area to a trailhead along the top of the bluff and above the Middle Clay Pit. Along the way it passes adjacent to the waterfall at the south end of the North Knob (Brickyard Trail Lower Falls, Photo 2-19). The Brickyard Trail ranges from fairly steep to gentle relief and does not appear to exhibit scarps, sloughing soils, or tension cracking on the trail surface. The Bruce Vento Spur Trail extends along the top of the bluff between the Brickyard Trail and the overlook.

A primary concern with the Brickyard Trail is the moderate-to-severe erosion from concentrated stormwater runoff along the straighter and steeper sections of the trail (particularly the Fossil/Brick Oven section of the trail). This has been particularly problematic along the trail's lower reaches. While maintenance has been implemented, sediment has plugged surface drains and culverts (Photo 2-20), and runoff has further scoured the trail and exposed the drainage features (Photo 2-21).

A portion of the upper slope of the Brickyard Trail–Connector Section, on the grade down from the top of the bluff, has exhibited slope failures (Photo 2-22, Photo 2-23, Photo 2-24, and Photo 2-25). During the May 2014 site visit, a few small clods of soil were observed near a park bench along the trail. These clods had slid down from an upper slope between the trail and Cherokee Heights Boulevard. During the July 2014 site visit, the area in the immediate vicinity of the park bench was covered with up to several inches of soil—suggesting that the slide had reactivated.

Significant areas of scarps, sloughing soils, or tension cracking was not observed along the Bruce Vento Spur of the Brickyard Access Trail, or along the segment of the Brickyard Trail at the top of the bluff (Brickyard Access Trail–Bluff Section). This is likely because, for the most part, this trail is located along Cherokee Heights Boulevard—not along the immediate edge of a steep soil slope. However, after the June 2014 rain events, it was evident that failure scarps were starting to encroach near a section of the Spur Trail above the Middle Clay Pit (Photo 2-26). For this reason, soil-boring drillers elected not to use the trail to access a proposed boring location near the Bruce Vento Scenic Overlook, and no sample was collected.

During the July 2014 site visit, Barr staff also observed an apparent sinkhole that had opened up along the Brickyard Access Trail–Bluff Section just north of the intersection of Cherokee Heights Boulevard/Highway 13 and Fremont Avenue (location shown on Large Figure 1-2). The sinkhole, which was about 10 feet deep and 8 feet across, had engulfed the chain-link fence along the road (Photo 2-27).

Review of the site plans and infrastructure indicate that a storm sewer pipe (running beneath Cherokee Heights Boulevard and the Brickyard Access Trail–Bluff Section) extends from the east side of Cherokee Heights Boulevard/TH13 approximately 50 feet north of Fremont Avenue to an outlet on the face of the bluff. The sinkhole along the trail appears to be due to a defect or failure of the storm sewer pipe, allowing soils to infiltrate the pipe. This infiltration removed soils from above/around the pipe and, over time, lessened support of the overlying soils. The overlying soils bridged the infiltrated materials until the cavity grew too large to span. It is our understanding that the Minnesota Department of Transportation is working on repairing this pipe and the associated sinkhole.

Photo 2-19 Brickyard Trail Lower Falls (May 2014 site visit)

Photo 2-20 Brickyard Trail–Fossil/Brick Oven Section, plugged and exposed drain tile and erosion (July 2014 site visit)

Photo 2-21 Erosion on the Brickyard Trail–Fossil/Brick Oven Section, looking uphill from the bottom of the trail (May 2014 site visit)

Photo 2-22 View of slope failure above Brickyard Trail–Connector Section, the source of soil on the trail in Photo 2-23 (May 2014 site visit)

Photo 2-23 Soil on the Brickyard Trail–Connector Section from slope failure shown in Photo 2-22 (May 2014 site visit)

Photo 2-24 **View of slope failure above the Brickyard Trail–Connector Section, the source of soil on the trail in the same location and shown in Photo 2-25 (July 2014 site visit)**

Photo 2-25 **Soil on the Brickyard Trail–Connector Section from slope failure shown in Photo 2-24 (July 2014 site visit)**

Photo 2-26 Slide below the Bruce Vento Spur of the Brickyard Access Trail (July 2014 site visit)

Photo 2-27 "Sinkhole" along Brickyard Access Trail–Bluff Section; note sunken fence post (July 2014 visit)

2.5 Bruce Vento Scenic Overlook

The Bruce Vento Scenic Overlook is located on a point generally between the Middle and West Clay Pits at the southern end of the Bruce Vento Spur of the Brickyard Access Trail (Large Figure 1-2). The overlook site includes a seating area in the hillside, a concrete foundation/structure, and flat viewing area with a fence about 10 to 15 feet from the edge of the bluff.

Approximately 4 feet past the overlook fencing, a mass of overhanging soil was observed (Photo 2-28). The soils at this location look to be entirely supported by vegetation/root zones. While the roots appear to have reinforced the surface of the soils, the soils below the effective root zone were not reinforced and have slid/eroded, leaving the overhang. This overhanging soil mass is a concern and, in our opinion, could fail when the roots eventually give way. The situation is made more serious because the roots are storing materials above the failure, which could increase the volume of a potential slide. The vegetation also masks the presence of the overhang, which could lead to park users inadvertently activating a slide. There are numerous examples of vegetation/root mats holding upper soils in the Brickyard Area, presenting similar risks; however, foot traffic near the Bruce Vento Scenic Overlook is likely more prevalent.

Photo 2-28 Soil overhang, from above, at Bruce Vento Scenic Overlook (May 2014 site visit)

3.0 Geotechnical Analysis

No published national standards exist for data retrieval and geotechnical evaluations. Barr has used the methods and procedures described in detail in Appendix C. In performing its services, Barr used the degree of care, skill, and generally accepted engineering methods and practices ordinarily exercised under similar circumstances, budget, and time constraints by reputable members of its profession practicing in the same locality. Reasonable effort was made to characterize the project site based on limited site review and field work. However, conditions may vary at any of the locations where testing was performed, and further investigation by qualified personnel should be undertaken during preliminary design, final design, and construction of any projects. No warranty, expressed or implied, is made.

3.1 Field Investigation—Soil Borings and Lab Analysis

To evaluate the stability of the existing slopes and the effects of potential changes in water content/saturation, the physical properties of the soil and rock need to be understood. These properties consist of the following:

- Stratigraphy of the soils in the area of interest
- Natural moisture content of the soils
- Unit weight of the soils and rock
- Plasticity of the clay soils/weathered rock
- Grain size of the soils
- Strength of the soils (both undrained/drained and saturated/unsaturated, as appropriate)
- Presence of weak soil/rock layers
- Permeability of the soils

A total of five soil borings were completed (one as part of the previous NTI study, four by Barr). Boring locations are shown on Large Figure 3-1 and described in Appendix C. An additional boring near the West Clay Pit was proposed as part of this study, but was not taken due to access issues (described in Section 2.4). The termination depths of the borings ranged from approximately 50 to 104 feet below existing grade, with most of the borings reaching about 100 feet below existing grade.

Soil samples were transported to Soil Engineering Testing (SET) of Richfield, Minnesota, for laboratory analysis. Results from the laboratory analysis are included in Appendix C.

3.1.1 General Site Geology

The bedrock in the area of Lilydale Regional Park was formed in Cambrian and Ordovician times, when Minnesota was located in a tropical climate near the equator.

The upper bedrock encountered in the park is the lower portion of the Galena Group. The Galena Limestone, a hard, buff-colored limestone rock, is mapped as the top bedrock unit near the park. Based on soil borings performed for this study, the Galena Limestone was very thin to absent. The basal member of the Galena Group is the Decorah Shale, a grayish-green shale rock with a high concentration of fossils encountered below the site soils (Minnesota Geological Survey 1999). This is the primary bedrock unit in the park and forms the walls of the three clay pits in the Brickyard Area. It was also the material mined for brick-making.

3.1.2 Stratigraphy

The stratigraphy (rock and soil layers) of the site generally consists of sandy, glacially derived soils of variable thickness overlying shale, then sandstone bedrock, as described in the site geology section of Appendix C. Occasional clay seams were encountered in the soils and interbedded limestone layers were seen in the Decorah Shale.

Cross sections interpreted from the boring logs are provided in Appendix C to illustrate the inferred subsurface conditions. As an example, Figure 3-1 shows the stratigraphy for the Middle Clay Pit. The other cross sections are similar, but with soil layers varying in order and thickness. (For modeling purposes the presence of the limestone layers inter-bedded with the shale was not included.)

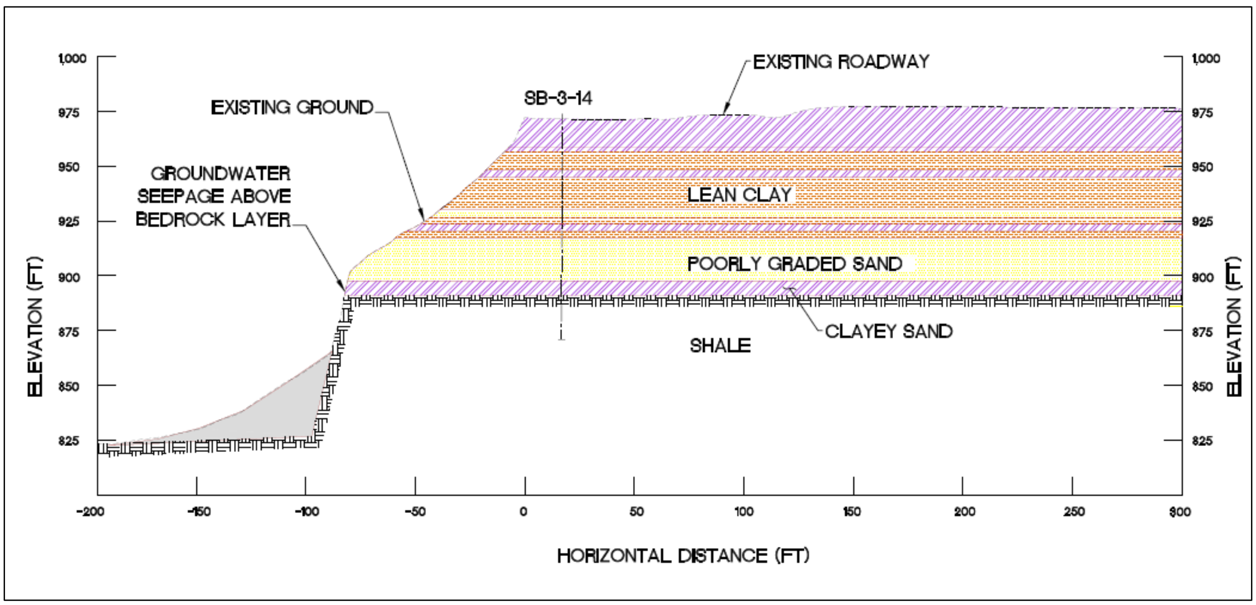

Figure 3-1 Middle Clay Pit modeling cross section showing stratigraphy

3.1.3 Groundwater Conditions

Groundwater was encountered in all of the soil borings directly above the top of the bedrock. In borings performed near the East and Middle Clay Pits, there were several upper soil layers that were saturated. However, there were soils below these layers that did not exhibit elevated moisture content; thus, the upper readings recorded during drilling indicated "perched" water, likely flowing through more permeable soils, as opposed to a solid water table down to bedrock.

Seepage was observed weeping from many of the site slopes at the soil/bedrock interface, but not usually seen higher in the slopes. Therefore, the groundwater was assumed to be generally located at the soil/bedrock interface at most times of the year. Seepage was specifically noted near the top of the bedrock in the Middle Clay Pit and the rock face in the North Ravine near the North Knob.

3.2 Slope-Stability-Simulation Modeling

SLOPE/W and SEEP/W software, part of the GeoStudio 2012 suite of programs, was used to evaluate the influence of existing topography, soil strength, and effects of seepage and saturation on the stability of the slopes within the Brickyard Area. The modeling cross-section locations, shown in Figure 3-1, focused on areas of moderate-to-large potential slope failure (not shallow, surficial sloughing).

Once the cross sections were defined, SLOPE/W (a limit equilibrium slope-stability-analysis program) was used to evaluate stability of the selected critical slope sections.

Since the existing slopes have remained stable for extended periods of time, the failures are likely influenced by the presence of additional soil moisture/saturation, weakening soil and rock, and increased load at the head of the slopes. Therefore, Barr also evaluated the influence of seepage and saturation using the SEEP/W component of the GeoStudio 2012 software suite. This component is specifically designed to perform analysis of seepage, groundwater infiltration, and effects of soil saturation on slope stability.

Detailed modeling methodology and results are provided in Appendix C.

3.2.1 Modeling Factor of Safety

The factor of safety of a slope is defined as the ratio of the resisting forces in the soil to the driving or mobilized forces that cause slope movement. Therefore, the point of stability is considered a factor of safety of 1.0 (driving forces equal to resisting forces). Slopes with a factor of safety less than 1.0 are considered to be unstable and would fail; slopes with a factor of safety higher than 1.0 are considered stable (or marginally stable as the safety factor approaches or hovers close to 1.0).

Natural soil slopes which are stable or marginally stable usually have minimum calculated factors of safety of 1.1 to 1.3. Factors of safety for natural slopes are representative for typical "sunny day" conditions, but may be reduced or even drop below 1.0 in the presence of excess moisture from rainfall, changes in groundwater elevations, etc. Therefore, the factor of safety for a slope should be considered for a range of anticipated conditions to determine the potential for slope failure. Analyses of several different sets of conditions to determine the potential for slope failures along the bluff line within the study area were performed (discussed in more detail in Appendix C).

For a point of reference, Federal Energy Regulation Commission (FERC) guidelines for high-hazard earth dams require slopes with a factor of safety of 1.5 or greater. The U.S. Army Corps of Engineers' levee guidelines recommend factors of safety ranging from 1.3 to 1.5, depending on how long the slope remains in a certain configuration (i.e., a lower factor of safety is required for temporary construction slopes than would be required for permanent embankments). Thus, the minimum acceptable safety factors for an "engineered" slope are often greater than the minimum safety factors observed for natural slopes.

3.2.2 Soil Suction

Review of the topography at the site indicates that the angle of the slopes exceeds the drained friction angle of the soils. If the strength of the soils was governed only by the drained friction angles, the slopes would be unstable and fail. To allow for steep slopes to remain standing, the soils must have additional strength beyond their angle of friction. The soil mechanism allowing this is called soil suction. Soil suction is formed by drying or dewatering the soils, which creates a negative pore pressure in the soil's pore spaces and increases the strength of the soil matrix (or provides an apparent cohesion in the soil in excess of its drained friction angle).

The phenomena of soil suction can be illustrated by thinking of a common sand castle at the beach. Dry sand will only form a conical pile to a certain angle (the material's drained friction angle). However, sand with moderate water content will allow much steeper angles to be achieved. Then, as the castle sits in the sun and dries, the sides of the castle become unstable and slough off. Or, as the tide comes in and the sand at the base of the castle becomes saturated, the sides of the castle slough and collapse. By drying or saturating the soils, the suction force is negated; the soil strengths will be governed by their friction angle and failures will occur.

Modeling of the existing slopes, including suction forces predicted by the physical index characteristics of the clay soils, suggests a factor of safety ranging from about 1.1 to 1.4. However, when the soils are re-saturated the suction force is negated; the soil strengths will be reduced and slope failures will occur.

3.2.3 Saturation and Loss of Stability Due to Rainfall

To determine the effects of rainfall (i.e., saturation of the soils resulting in loss of suction) a unit flux line located at the ground surface in each of the cross sections was used to model the effects of groundwater infiltration. The modeling conservatively assumed full infiltration of 3.5 inches of steady precipitation over a 24-hour period. The modeling also assumed both low and high soil permeability. Lower soil permeability is associated with unsaturated conditions (low moisture content). Very little infiltration occurs in unsaturated soils, which is why flash flooding occurs in desert environments. Higher soil permeability essentially allows the full amount of precipitation to infiltrate the soil.

Modeling results using lower permeability (low infiltration), indicated that a single rainfall event of this magnitude on moderately saturated soils is not, by itself, likely to significantly reduce the stability of the slopes. However, when higher amounts of infiltration are considered, the factors of safety are reduced below stability. This indicates that if soil conditions allow for infiltration of some precipitation, the strength of the natural sand soils is reduced from loss of suction and could result in slope failures.

3.2.4 Saturation and Loss of Stability from Elevated Water Table and Ponding

Loss of suction can also be realized through elevation of the groundwater table following periods of intense rainfall on or upstream of a site within the watershed.

To evaluate the potential for reduction of stability due to loss of suction forces, the groundwater level in the model was incrementally raised (with an upstream boundary condition) until the minimum predicted factor of safety for the slope was 1.0.

The increase in groundwater level modeled to reach a factor of safety of 1.0 was on the order of a few to several feet. Due to the configuration of the slopes, the secondary slopes (Slope 2) for the Waterfall and Cherokee Heights Ravine cross sections were not analyzed for a high groundwater condition.

Infiltration from ponding will also tend to reduce stability of the slopes. A storm event was modeled with both dry (sunny day) and full pond conditions for a potential pond upstream from Cherokee Heights Culvert. Analysis indicates that the stability of the bluff slope is below 1.0 if water is allowed to pond upstream. If the pond is allowed to drain, the stability of the bluff slope is reduced—but still above 1.0.

3.2.5 Role of Vegetation in Stability

There is diverse vegetation on the upper soil slopes of the study area and trees of various sizes—from saplings to mature 40-foot trees. There is also grass/weed vegetation that has formed carpet-like mats on many of the park's slopes.

In certain scenarios, vegetation can help increase slope stability by reinforcing soils and absorbing water that would otherwise increase moisture content. However, trees in the study area have not stabilized the larger slides, as evidenced by the trees caught in the large 2014 landslide. Furthermore, trees that are overhanging or near the edge of slopes may help trigger landslides when undermined, unstable, or blown over—dragging the surrounding soils down the slope.

The root mats formed from the grassy/weed vegetation is effective at stabilizing the surface of the slopes, to a depth of approximately one foot. However, as seen on many of the slopes in the West and Middle Clay Pits, these mats of root-reinforced soils appear to reach a critical condition and result in slope failures. In fact, it appears that the soils on the slopes may actually store materials in the root mats, potentially making the volume of the slides slightly larger than if the soils were allowed to ravel on un-vegetated slopes. Therefore, caution should be exercised below steep, vegetated, natural slopes (i.e., against the steep slopes of the clay pits). And, because the failure surface extends well below the root zones that bind the soils, neither trees nor grass/weed vegetation should be considered to stabilize the upper soil slopes.

Ultimately, some form of surface vegetation should be placed on the park slopes. Otherwise, erosion will create large amounts of downstream sediment that is both costly and time-consuming to manage. If slopes are re-graded or existing vegetation is removed, vegetation that is suitable to park conditions and able to minimize soil erosion is recommended. Removal of larger trees overhanging or near the edge of the soil slopes may also be beneficial, reducing these as a trigger mechanism for slides and/or reducing the volume of slide events.

3.3 Summary of Geotechnical Findings

Seepage and soil saturation (which results in a loss of suction) can reduce stability of the slopes. Geotechnical modeling results indicate that the infiltration of approximately 3.5 inches of water in a 24-hour period is enough to impact soil stability. Loss of suction can also be realized through elevation of the groundwater table following periods of heavy precipitation either at the site or upstream within the watershed. Modeling results also indicate that a rise in the groundwater table caused by seepage (an increase of a few to several feet) can also impact slope stability.

Table 3-1 summarizes the predicted slope stability factors of safety based on modeling various soil conditions at various locations. These factors of safety are based on limited information and intended to be general in nature. Additional subsurface investigation and geotechnical evaluation at these specific locations is necessary to refine these values. As previously discussed, slopes with a factor of safety of less than 1.0 are considered to be unstable; slopes with a factor of safety greater than 1.0 are considered stable or marginally stable; safety factors of engineered slopes are discussed in Section 3.2.1.

Table 3-1 Predicted slope-stability factors of safety, based on modeling various soil conditions

Analyzed Cross Sections	Sunny Day Conditions Factor of Safety[1]		Infiltration of 3.5 Inches of Water in 24 Hours Factor of Safety[1]		Water Table Elevation to Reduce Factor of Safety to 1.0[3] (elevation in feet)
	No Suction	With Suction	No Suction	With Suction	
North end	0.75	1.40	0.75	1.29	921.5
Waterfall Landslide: Slope 1	0.66	1.18	0.59	0.78	855
Waterfall Landslide: Slope 2	0.83	2.34	0.83	1.91	--[3]
Cherokee Heights: Slope 1	0.70	1.53	0.70	1.11	918
Cherokee Heights: Slope 1 (ponding)	0.70	1.03	0.47	0.52	--[3]
Cherokee Heights: Slope 2	1.34	1.53	1.48	2.33	--[3]
Cherokee Heights: Slope 2 (ponding)	1.34	1.53	1.48	2.01	--[3]
Middle Clay Pit	0.68	1.22	0.68	0.92	910.5
West Clay Pit[2]	0.58	1.11	0.58	0.73	901

[1] Factors of safety are based on limited boring/subsurface investigations (May and June 2014) and the assumption that the soil borings referenced in this report are representative of the identified locations.

[2] The boring in the area of the West Clay Pit was not obtained due to access issues; soil conditions in the West Clay Pit were assumed to be similar to the Middle Clay Pit.

[3] The secondary slope (Slope 2) for the Waterfall and Cherokee Heights Ravine cross sections were not analyzed for high groundwater condition. High groundwater condition was also not evaluated in the "ponding" analysis for the Cherokee Heights Ravine section; see Table 4-6, Appendix C.

3.3.1 Potential for Slope Failure

Risk is a difficult concept to quantify, and the term will have different meanings for different people and organizations. The scope of this study was not designed to identify all sources of risk inherent in the use of Lilydale Regional Park, but to evaluate the potentially unstable slopes in the Brickyard Area of the park. It should also be noted that the scope did not include identifying and analyzing every slope or feature within the Brickyard Area.

To evaluate risks associated with areas of the park the following tasks were performed:

- Portions of the study area were observed during two site visits.
- Previous evaluations of slope instability in the park were reviewed.

- Soil borings were completed and laboratory testing was performed to determine the subsurface characteristics.
- Slope-stability modeling was performed using parameters derived from the soil borings and laboratory test results.
- Stormwater modeling was performed.

Based on these factors and engineering judgment gained from experience with slope-stability issues at other project sites, the existing conditions (July 2014) of the study area were categorized as low-risk, moderate-risk, or high-risk. These rating categories are specific to this project and not based on industry standards. They are described below and shown in Large Figure 3-2.

3.3.1.1 High-Risk Areas

Areas categorized as high-risk have the following features or characteristics:

- Likelihood for large-volume circular-failure or block-failure landslides
- Likelihood for soils to fall from significant heights
- Likelihood for persons to be caught in a slide from above the failure surface
- History of previous large-volume slides

3.3.1.2 Moderate-Risk Areas

Areas categorized as moderate-risk have the following features or characteristics:

- Likelihood for lesser-volume circular-failure or surficial translational-failure landslides
- Likelihood for soils to fall from lower heights
- History of previous lesser-volume slides

3.3.1.3 Low-Risk Areas

Areas categorized as low-risk have the following features or characteristics:

- Generally flatter grades and minimal likelihood for landslides
- Likelihood for soils to fall from lower heights
- No apparent history or evidence of landslides
- Areas that were not observed during the May and July 2014 site visits, but generally have similar characteristics to other low-risk areas within the study area

Note that no area of the park was considered "no-risk." The uncertainty of weather, soil type, strength and stratigraphy, and human activity always pose some risk due to unexpected movement of soils.

4.0 Stormwater Analysis

One of the objectives of this study is to identify and evaluate erosion issues along the Brickyard Trail and in other ravines within the Brickyard Area and identify stormwater management techniques to reduce erosion. Understanding drainage characteristics within this area, including stormwater inflow locations, flow rates, and flow velocities, is a key to identifying and addressing erosion problems.

4.1 Stormwater Flow Simulation Modeling

An XP-SWMM hydrologic and hydraulic model was developed to estimate stormwater depths and corresponding flows and velocities in the storm sewer system, channels, and ravines throughout the study area. XP-SWMM uses rainfall and watershed characteristics to estimate local runoff, which is routed through pipe and overland-flow networks. The XP-SWMM hydrologic and hydraulic model was developed to gain a better understanding of drainage patterns throughout the study area and flows and velocities through the ravines and their tributary drainage areas. The model for the drainage area discharging to the 60-inch Cherokee Heights Boulevard culvert was developed in conjunction with the *Cherokee Heights Culvert Analysis and Erosion Control Feasibility Study* commissioned by the Lower Mississippi River Watershed Management Organization.

The drainage area was delineated into subwatersheds that represent major stormwater inflow points at the top of the bluff and along the ravines. The subwatershed divides are shown in Large Figure 4-1. The model includes storm sewer information provided by the contributing cities. There are three culverts under Cherokee Heights Boulevard that serve as the main stormwater discharge points into the Brickyard Area of Lilydale Regional Park. The location of the storm sewer pipes and the three culverts under Cherokee Heights Boulevard are also shown in Large Figure 4-1.

The ravines are modeled using representative natural channel cross sections to reflect the unique shapes of the ravines at specific locations along the bluff and throughout the Brickyard Area, based on 2011 topographic information provided by the Minnesota Department of Natural Resources.

The model was used to simulate the 1-, 2-, 5-, 10-, 50-, and 100-year frequency 24-hour rainfall events based on National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation frequency estimates. Detailed modeling methodology and results can be found in Appendix D.

4.1 Summary of Stormwater Findings

Site observations during the field visits identified erosion issues in some ravines within the Brickyard Area, including significant erosion in the Cherokee Heights Ravine. High flow rates and velocities in this channel, in combination with erodible, sandy soils appear to be (1) contributing to some localized instability of adjacent slopes, (2) removing material from the toes of the slopes, (3) destabilizing the upper slopes, and (4) causing slides into the ravine.

Site observations during the field visits also identified erosion issues along portions of the Brickyard Trail. The erosion problems generally appear to be a result of concentrated stormwater runoff along the straighter and steeper sections of the trail (particularly the Fossil/Brick Oven section of the trail). This has been problematic along the trail's lower reaches.

To adequately address the ravine and trail erosion issues, it is important to understand the flow rates and flow velocities in the various channels throughout the Brickyard Area. Table 4-1 provides a summary of the peak flow rates at the three main stormwater discharge points into the Brickyard Area for various storm events. For all the storm events modeled, 60–75% of the total peak stormwater discharge into the Brickyard Area comes through culvert "B" (Cherokee Heights Culvert) on Large Figure 4-1. This discharges to the Cherokee Heights Ravine.

Table 4-1 Peak flow rates for crossings along Cherokee Heights (locations on Large Figure 4-1)

Atlas 14 24-Hour Storm Event	Precipitation Amount over a 24-Hour Period (inches)	Peak Flow Rates (cfs)		
		A: North Cherokee Heights Tributary Tributary Area: 5 Acres	B: Cherokee Heights Tributary (Main Basin) Tributary Area: 47 Acres	C: Freemont Avenue Tributary Tributary Area: 22 Acres
1 year	2.5	5	54	17
2 year	2.8	7	70	20
5 year	3.5	12	109	42
10 year	4.2	17	116	60
50 year	6.3	31	252	62*
100 year	7.5	37	295	62*

* Capacity limitations of the Fremont Avenue culvert result in surface overflows northward to the 60-inch culvert under Cherokee Heights.

Since there is no known storm sewer pipe system actively conveying water within the Brickyard Area, runoff from the Brickyard Area downstream of Cherokee Heights Boulevard generally flows overland following the slope of the land. The estimated flow velocities within the ravine channels reflect flow from the culverts under Cherokee Heights Boulevard combined with localized runoff from the Brickyard Area.

The peak flow velocities vary by reach, depending on contributing flow rate, channel shape, and channel slope. The highest predicted peak velocities generally correspond with the reaches observed to have the most significant erosion—specifically the 300-foot stretch of Cherokee Heights Ravine downstream of the Cherokee Heights Culvert, the Lower North Stream Channel, and just downstream of the Cherokee Heights Boulevard culvert near Fremont Avenue, all shown in Large Figure 4-1.

5.0 Recommendations

Large Figure 5-1 presents a summary of recommendations for erosion control and alternatives for stabilizing steep slopes or restricting access to those slopes. Also included are recommendations regarding public access to fossil hunting areas. It is important to state that all recommendations in this report are Barr's opinion, based on limited subsurface investigation/soil borings, available topographic and site information, modeling, and site investigations performed in May and July of 2014. Site investigations were general in nature and did not include observations of the entire Brickyard Area and study limits. All figures and recommendations are based on the conditions observed during the site visits. Additional site visits, geotechnical investigation, subsurface investigation/borings, and soils testing must be performed to refine the recommendations at specific areas of the park and address any changed conditions.

5.1 General Recommendations

General recommendations include:

- **Restrict access—**As further discussed in specific recommendations, restricting access to the two areas shown on Large Figure 5-1 is recommended. An additional, parallel approach would be to encourage park patrons to stay within the lowest risk areas of the park. Signage and/or fencing can be used for both approaches.

- **Place barriers and signage—**Institutional controls such as barriers/fencing and/or proper signage should be placed at access points to restricted areas. In addition, appropriate signage should be placed at general park access points to alert patrons about "restricted access" areas.

- **Perform additional research—**The City should conduct research and consult with National Parks staff and/or risk-planning professionals on industry-accepted best practices for managing risk in natural park settings.

- **Re-vegetate slopes—**Where feasible, the slopes of the park should be re-vegetated to minimize erosion of the surface soils. Removing larger trees that overhang or are near the edge of slope crests may also be beneficial. These trees can be a trigger mechanism for slides and/or increase the volume of slide events. If slopes are re-graded or existing vegetation is removed, we recommend that appropriate vegetation (as feasible) be placed to minimize soil erosion and the downstream sediment that compromises water quality in Pickerel Lake.

- **Perform inspections—**Inspections by a geotechnical engineer licensed in the State of Minnesota should be performed at least annually and following significant precipitation events or changes in conditions observed by City staff, with subsequent review of potential slope failure risk areas. The City may want to consider 5-year contracts so consistent annual inspections are performed by a technical team.

- **Update information—**Large Figure 3-2 (potential for slope failure under existing conditions) and other appropriate figures in this report should be re-evaluated and updated, as necessary, following each inspection.

- **Consider monitoring—**The City could consider monitoring techniques (tilt meters, inclinometers, piezometers, etc.) to better evaluate changes in the park, including reductions in slope stability from infiltration or groundwater and movement of slopes. However, costs associated with monitoring equipment extend beyond installation, including maintenance and observation (e.g., regular measurement readings, data download, etc.). Additionally, monitoring is very site-specific; therefore, several monitoring stations (depending on desired spacing along the bluff) would be required to monitor the entire bluff line within the Brickyard Area. More specific recommendations related to (1) ravine stabilization/stormwater management, (2) erosion along the Brickyard Trail, and (3) stabilizing steep slopes are described in the following sections.

5.2 Planning-Level Opinion of Construction Costs

A planning-level opinion of construction cost has been developed for several of the conceptual alternatives that would require significant capital expenditures or construction activities. These are included with site-specific recommendations. The estimated costs should be considered screening-level, order-of- magnitude opinions of costs, based on the current limited level of project definition. These estimates are intended to provide assistance in evaluating and comparing alternatives and should not be assumed as absolute values for given alternatives. These opinions of probable cost generally correspond to a Class-4 estimate based on standards established by the Association for the Advancement of Cost Engineering (AACE). A Class-4 cost estimate is characterized by limited project definition (typically 1–15 percent), wide-scale use of parametric models to calculate estimated costs (i.e., making extensive use of order-of-magnitude costs from similar projects or proposals), and high uncertainty. The expected accuracy range for these point estimates is -30 percent to +50 percent.

All estimated construction costs are presented in 2014 U.S. dollars. Life-cycle analysis—including long-term maintenance and escalation costs, engineering and design, and other non-construction costs—is beyond the scope of this study and not included.

5.3 Ravine Stabilization/Stormwater Management

We recommend that access to the portion of the northern Brickyard Area outlined on Large Figure 5-1 (red-dashed line) be restricted. This is generally a high- or medium-risk area downslope of a high-risk area (Large Figure 3-2). This appears to be an active slide area and is considered unstable; recent slides have resulted in significant amounts of material moving downslope. Restricting access could be accomplished with signage, fencing, or a combination. In addition, the Lower North Stream Channel could be reestablished and stabilized, as long as the upstream ravine areas (including the North Knob area) are inspected consistently for additional erosion and/or are stabilized (see Section 5.5.3 for more specific slope-stabilization recommendations). Once the Lower North Stream Channel is stabilized, the Brickyard Trail Culvert should be replaced with a small span bridge or oversized box culvert. This would be less restrictive of flow and less prone to plugging or washing out, while still providing a stable trail crossing for maintenance vehicles. Specific recommendations for ravine stabilization and stormwater management in this area are listed below, in order of priority and operation. (A complete list of alternatives considered is provided in Appendix A).

1. Restrict access to the Cherokee Heights Ravine, North Ravine, and Lower North Stream Channel area (as shown in Large Figure 5-1). A planning-level cost range for fencing this area is $112,000–$240,000. (Costs are highly dependent on the actual length and type of fencing selected—this estimate assumes fencing for the entire length of the “restrict access” area shown for the northern part of the Brickyard Area). Note that restricting this area includes closing Fossil Site 2. Fossil Site 1 is located outside the “restrict access” area. The “restrict access” area should be reassessed once the following ravine stabilization/stormwater management recommendations have been implemented.

2. Stabilize the steep slopes in this area (as described in Section 5.5.3).

3. Reestablish and stabilize the channel in the Lower North Stream Channel using river rock riprap, as shown in Photo 5-1 (planning-level cost range: $161,000–$345,000). Boulder riffles, as shown in Photo 5-2, could potentially be added for aesthetics and to help reduce flow velocities (planning-level cost range: $9,000–$18,000).

4. Once the ravine is reestablished and stabilized, replace the Brickyard Trail Culvert with a small span bridge, similar to the example shown in Photo 5-3 (planning level cost range: $63,000–$135,000).

The Cherokee Heights Ravine, starting at Cherokee Heights Boulevard (including the culvert) and extending downstream approximately 300 feet, is being addressed through the *Cherokee Heights Culvert Analysis and Erosion Control Feasibility Study,* commissioned by the Lower Mississippi River Watershed Management Organization. The goals of that project are to reduce erosion potential by stabilizing the approximately 300 feet of channel between the 60-inch Cherokee Heights Culvert and the water fall and reducing peak flow rates and velocities, as feasible. Therefore, no recommendations for this portion of the Cherokee Heights Ravine are provided in this report. However, it is important to note the difference between the slope-stability issues in this area and the ravine/channel erosion due to stormwater. It is our opinion that even if erosion due to stormwater runoff is addressed in this stretch of the Cherokee Heights ravine, the potential for slope failure still exists, as reflected in Large Figure 3-2.

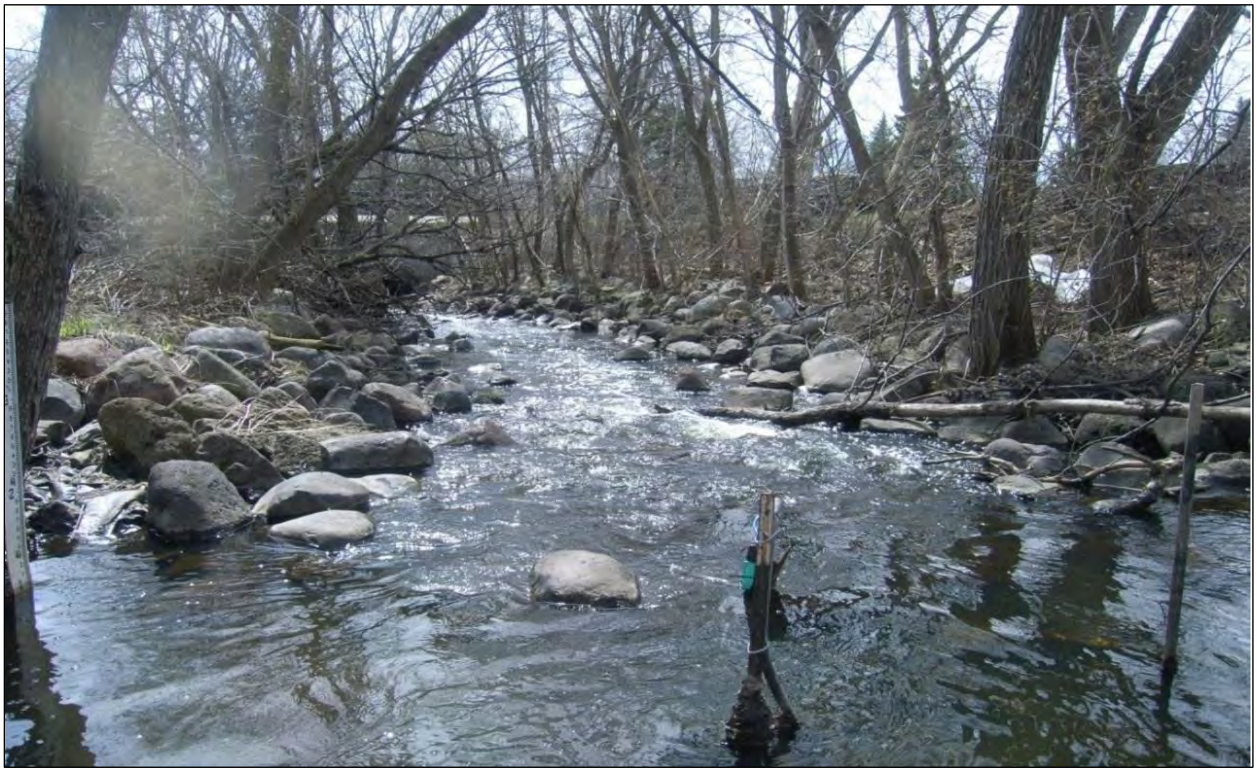

Photo 5-1 Example of riprap

Photo 5-2 Example of a boulder riffle

Photo 5-3 Example of a small span bridge at a creek crossing

5.4 Brickyard Trail Erosion

The most significant erosion on the Brickyard Trail is a portion of the Fossil/Brick Oven section highlighted in solid red on Large Figure 5-1. This section stretches from the lower portion of the Brickyard Trail to the "connector" section of the trail. It has steeper slopes than other portions of the trail and is located such that stormwater drains on and along the trail. While considered a low-risk area for slope failure, it has been impacted by erosion caused by stormwater runoff. Since this section of the trail is part of the main thoroughfare—connecting the lower portion of the park to the upper/bluff portion—we recommend stabilizing it and encouraging park patrons (using signage, fencing, or other measures) not to leave this trail. One or more of the following options is recommended for stabilizing, reinforcing, and/or reducing future erosion of this portion of the trail. Continued maintenance is important for all options.

1. Install Geoweb (examples shown in Photo 5-4, Photo 5-5, and Photo 5-6) to stabilize and reinforce the trail (planning-level cost range: $77,000–$164,000).

2. Repair the trail and install waterbars (conceptual drawing shown in Figure 5-1) to deflect water off the trail and reduce future erosion (planning-level cost range: $42,000–$90,000).

3. Install a "side channel" (reinforced ditching) along the side of the trail and resurface this area (planning-level cost range: $79,000–$170,000).

Photo 5-4 **Example of Geoweb erosion control *(Source: www.prestogeo.com,* used with permission)**

Photo 5-5 **Cross section view of Geoweb *(Source: www.prestogeo.com,* used with permission)**

Photo 5-6 **Example of Geoweb on a steep slope (prior to infill) *(Source: www.prestogeo.com,* used with permission)**

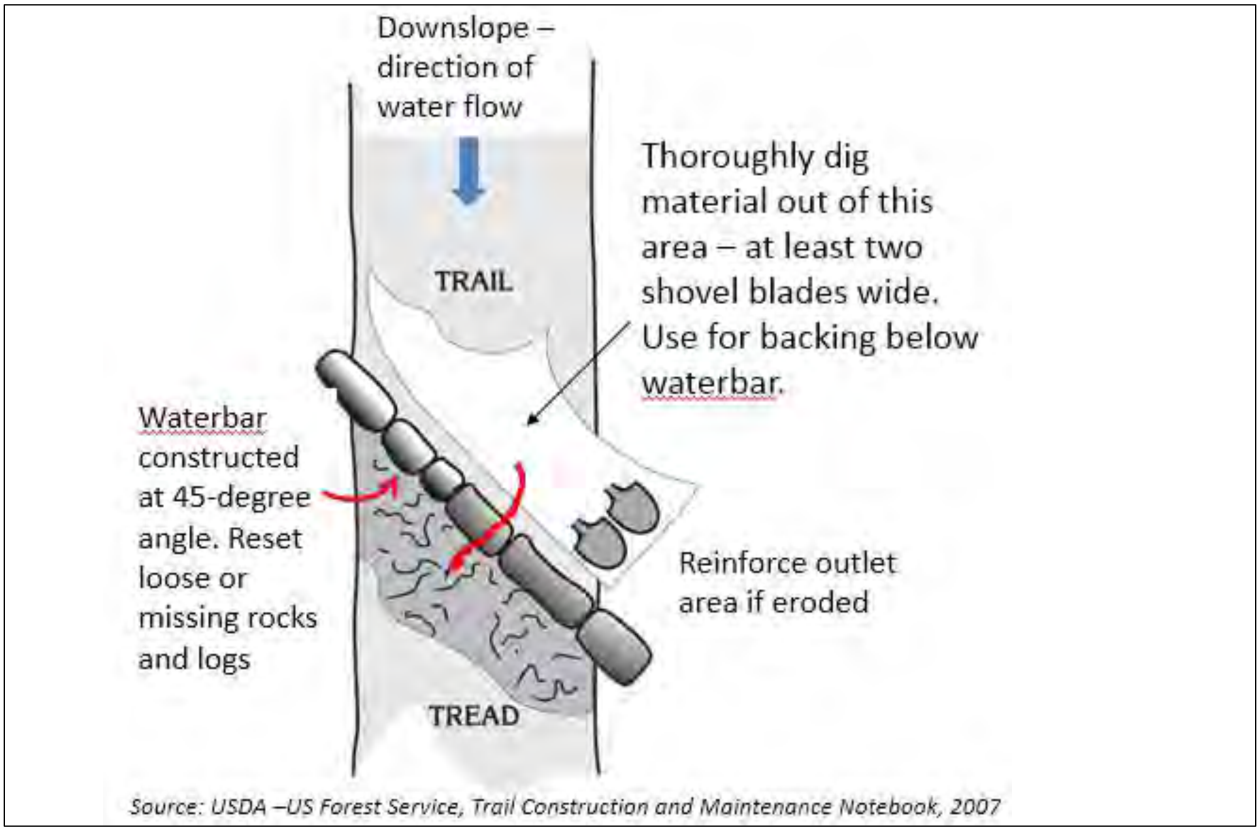

Figure 5-1 Conceptual drawing of a waterbar

5.5 Steep-Slope Stabilization

5.5.1 Middle and West Clay Pits, Bruce Vento Scenic Overlook, and Bruce Vento Spur of the Brickyard Access Trail (Southern Brickyard Area)

The southern portion of the Brickyard Area is characterized by steep slopes at or near the Middle and West Clay Pits and the Bruce Vento Scenic Overlook. These are considered high-risk areas. Restricting access to this portion of the park is recommended within the area outlined by a red-dashed line on Large Figure 5-1. The "restrict access" line on Large Figure 5-1 extends to the junction of the Bruce Vento Spur of the Brickyard Access Trail and the Bluff Section of the trail—the areas of highest risk. Restricting access in and around these clay pits and the scenic overlook could be accomplished using signage, fencing, or a combination. Fossil Sites 3 and 4 are both outside the "restrict access" area.

If the City would prefer that these currently high-risk areas remain open to park patrons, we recommend using mechanical slope stabilization. Mechanical slope-stabilization options include grading to a stable slope (conceptual drawing shown in Figure 5-2), soil nailing (conceptual drawing shown in Figure 5-3; example shown in Photo 5-7), piling (e.g., "H" piles, as shown in Figure 5-4 and Photo 5-8), or placing sheetpile walls, often in combination with grading (conceptual drawing shown in Figure 5-2). Additional information regarding mechanical slope-stabilization options, presented to City staff at a September 2014 meeting, is included in Appendix B. Mechanical slope-stabilization options are expensive, and the design and cost of these options are highly dependent on specific site characteristics, desired aesthetics, and project limits (e.g., Cherokee Heights Boulevard). Planning-level construction costs (not including engineering and design) can range from several hundred thousand to several million dollars. Additional testing and analyses, as described in Section 5.0 of Appendix C, should be considered during final design if mechanical steep-slope-stabilization methods are pursued.

The Bruce Vento Scenic Overlook (described in Section 2.5) is considered a high-risk area due to the potential instability of the steep slopes on the west side of the overlook (Large Figure 3-2). We recommend that this area be closed or the slopes below the trail be stabilized due to the potential risk of slope failure. Another option would be to relocate the overlook further back toward Cherokee Heights Boulevard (Highway 13) in the wider area of land between the Middle and West Clay Pits and restrict access closer to the edge of the bluffs. While there appears to be enough stable area to relocate and reconstruct the overlook, it is possible that the slope failures may eventually encroach. Therefore, it would be important to continually monitor the area to track encroachment of unstable slopes. If the overlook is relocated, we recommended that the Bruce Vento Spur of the Brickyard Access Trail also be stabilized or a new access trail constructed.

5.5.2 Brickyard Trail—Connector Section

There are also steep slopes that run between the Middle and East Clay Pits, crossing the connector section of the Brickyard Trail. This area is not part of a clay pit; it does not contain cliff faces/drop-offs and is not downslope of a high-risk area. It does, however, exhibit a steep enough slope to lead to less severe slope failures. For this reason, it is considered a medium-risk area (shown in yellow on Large Figure 3-2). While this is not part of the recommended “restrict access” area, a portion of the connector section of the Brickyard Trail (location shown on Large Figure 2-1, Photo 2-24) is located downslope of a medium-risk area. We recommend stabilizing that particular section of slope. In the interim, we also recommend removing or relocating the park bench along this section of the Brickyard Trail.

This steep slope could be stabilized using vegetated reinforced soil slopes (VRSS). VRSS is well-suited to trail edges; but, because natural materials are used, sunlight is required to support plant growth. Examples of VRSS are shown in Photo 5-9, Photo 5-10, and Photo 5-11. There may be sufficient space in this area to grade the uphill slopes to a stable angle, similar to the “grading-to-stable-slope” option recommended for the North Knob Area and discussed in the next section.

5.5.3 The North Knob Area

This area has been the location of two recent large-volume slides and is considered high-risk for slope failure; therefore, restricting access to this area of the park is recommended.

In addition, seepage was observed emerging from the fresh scarp following the slide observed during the July 2014 site visit (Photo 2-6). It may be beneficial to reduce this seepage, which may have been a factor in the observed failure and a potential contributor to future failures. Typical methods for controlling seepage include using graded filters or armored channels.

If the City would prefer that this area remain open to park patrons, we recommend using mechanical slope-stabilization options—specifically, grading to a stable slope. In most areas of the park, the proximity of surrounding infrastructure (roads, buildings, trails, etc.) is relatively close to the soil slopes that require stabilization. In these areas there may not be sufficient space to flatten the grade of the slopes without using additional stabilization measures (e.g., grading to a stable slope in conjunction with a sheetpile wall). The North Knob area, however, is further from the general bluff line, offering greater opportunity to grade soils without affecting surrounding infrastructure. Grading the North Knob area to a stable slope and providing erosion protection would likely reduce sediment loading to downstream water bodies. Successfully stabilizing this area may also reduce the recommended "restrict access" areas of the park.

5.5.4 Summary of Steep-Slope-Stabilization Recommendations

Following is a summary of the steep-slope-stabilization recommendations:

1. Restrict access to the Middle and West Clay Pit areas and the Bruce Vento Scenic Overlook (as shown in Large Figure 5-1). A planning-level cost range for fencing this area is $84,000–$180,000. (Costs are highly dependent on the actual length and type of fencing selected—this estimate assumes fencing for the entire length of the "restrict access" area shown for the southern portion of the Brickyard Area.) The "restrict access" area should be reassessed following implementation of the following steep-slope recommendations.

2. Relocate or mechanically stabilize the Bruce Vento Scenic Overlook.

3. Mechanically stabilize the section of the Bruce Vento Spur of the Brickyard Access Trail highlighted in Large Figure 5-1.

4. Stabilize a portion of the connector section of the Brickyard Trail using VRSS, assuming the canopy cover is not too dense for sunlight penetration (planning-level cost range: $20,000–$50,000). This area could also be stabilized by grading to a stable slope. In the interim, remove (or relocate) the park bench downslope of this area.

5. Stabilize the North Knob by grading to a stable slope. Although developing this alternative and providing a planning-level construction cost is beyond the scope of this study, the minimum cost is expected to be several hundred thousand dollars. Evaluating and addressing seepage concerns in this area would not to be included in this stabilization option.

6. Additional testing and analyses, as described in Section 5.0 of Appendix C, should be considered during final design if mechanical steep-slope-stabilization methods are pursued.

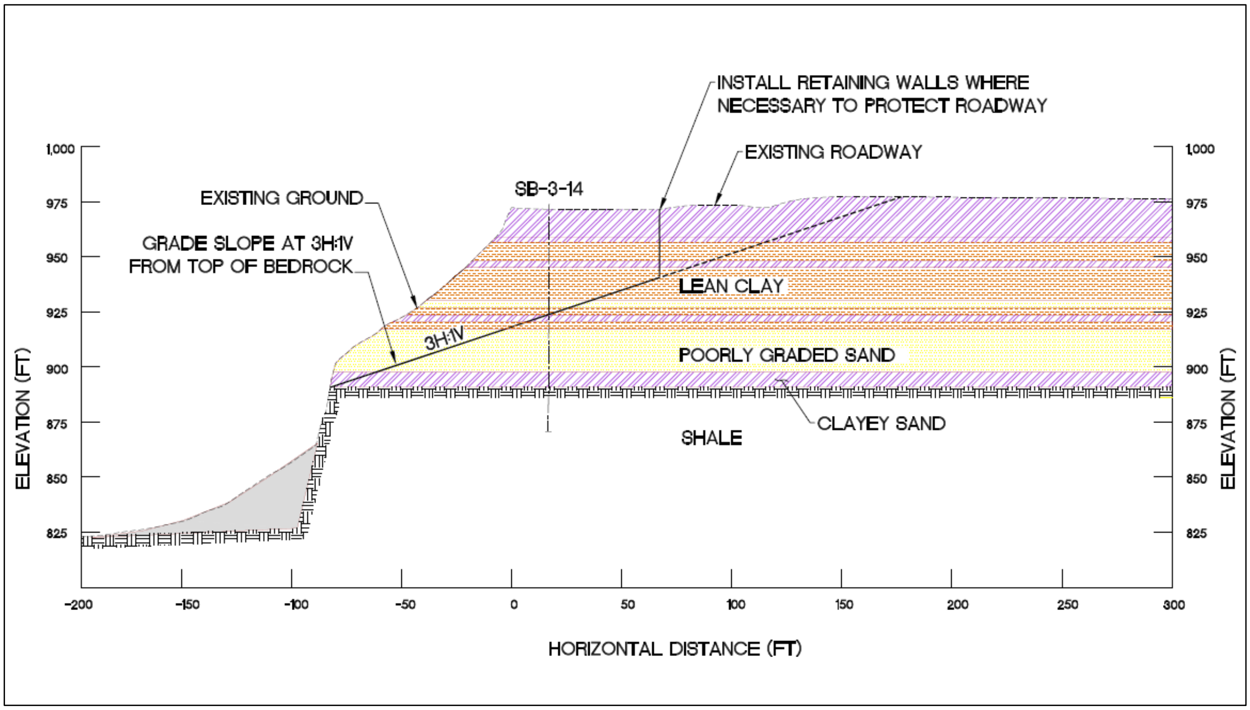

Figure 5-2 **Conceptual example of grading to a stable slope and installing a sheetpile wall to protect the roadway**

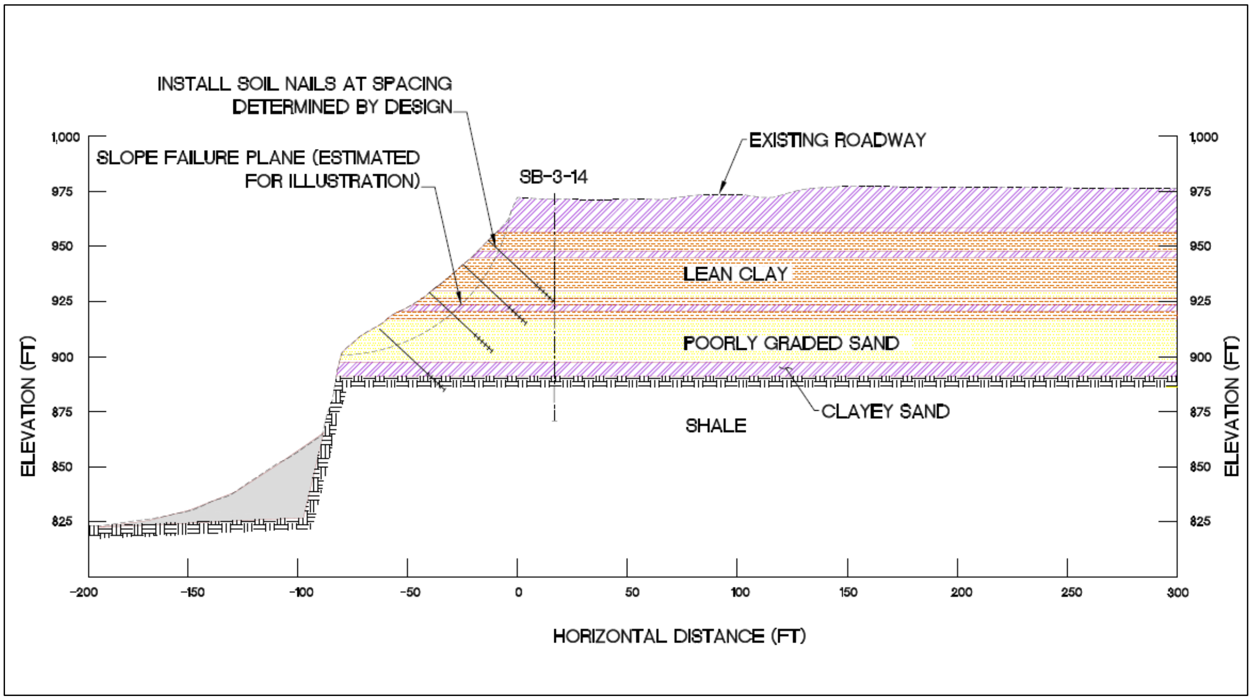

Figure 5-3 **Conceptual example of soil nailing**

Photo 5-7 **An example of soil nailing *(Source: Nicholson Construction Company, used with permission)***

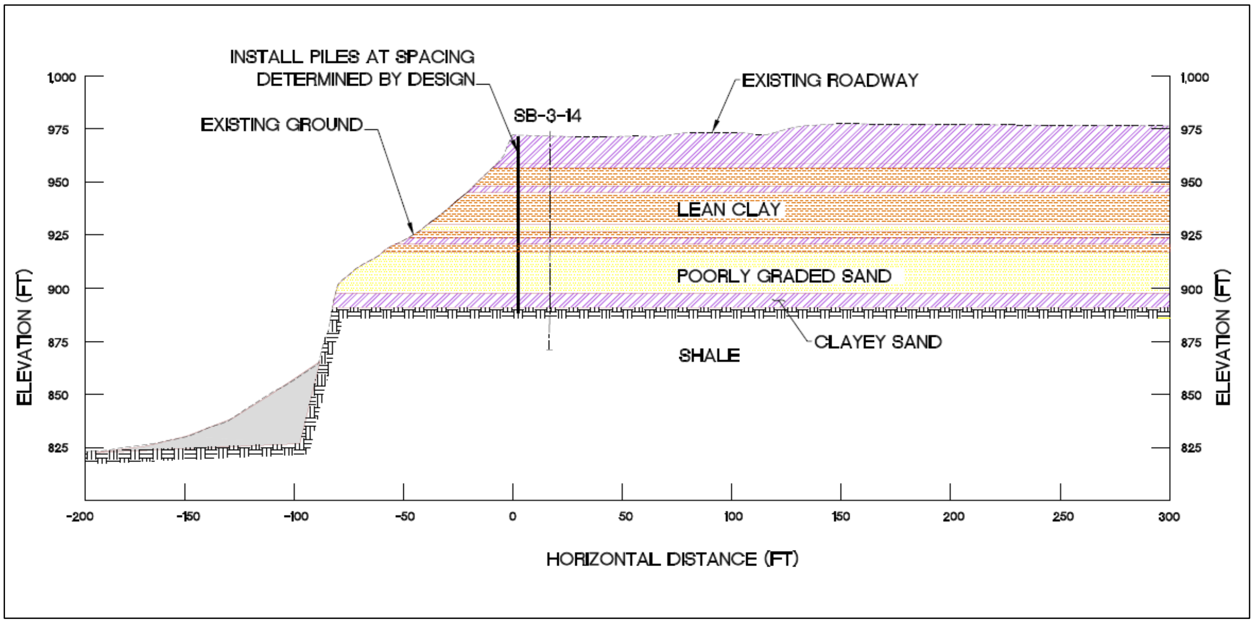

Figure 5-4 **Conceptual example of soldier piling**

Photo 5-8 Photo of soldier piling along the Mississippi River in Minneapolis

Photo 5-9 Example of vegetated reinforced soil slope (VRSS) before vegetation reestablishes

Photo 5-10 Example of VRSS (note vegetation stakes)

Photo 5-11 Example of VRSS after vegetation has grown

6.0 References

American Engineering Testing. 2010. *Report of Geotechnical Exploration and Review, Cherokee Regional Trail Widening.* St. Paul : American Engineering Testing, 2010.

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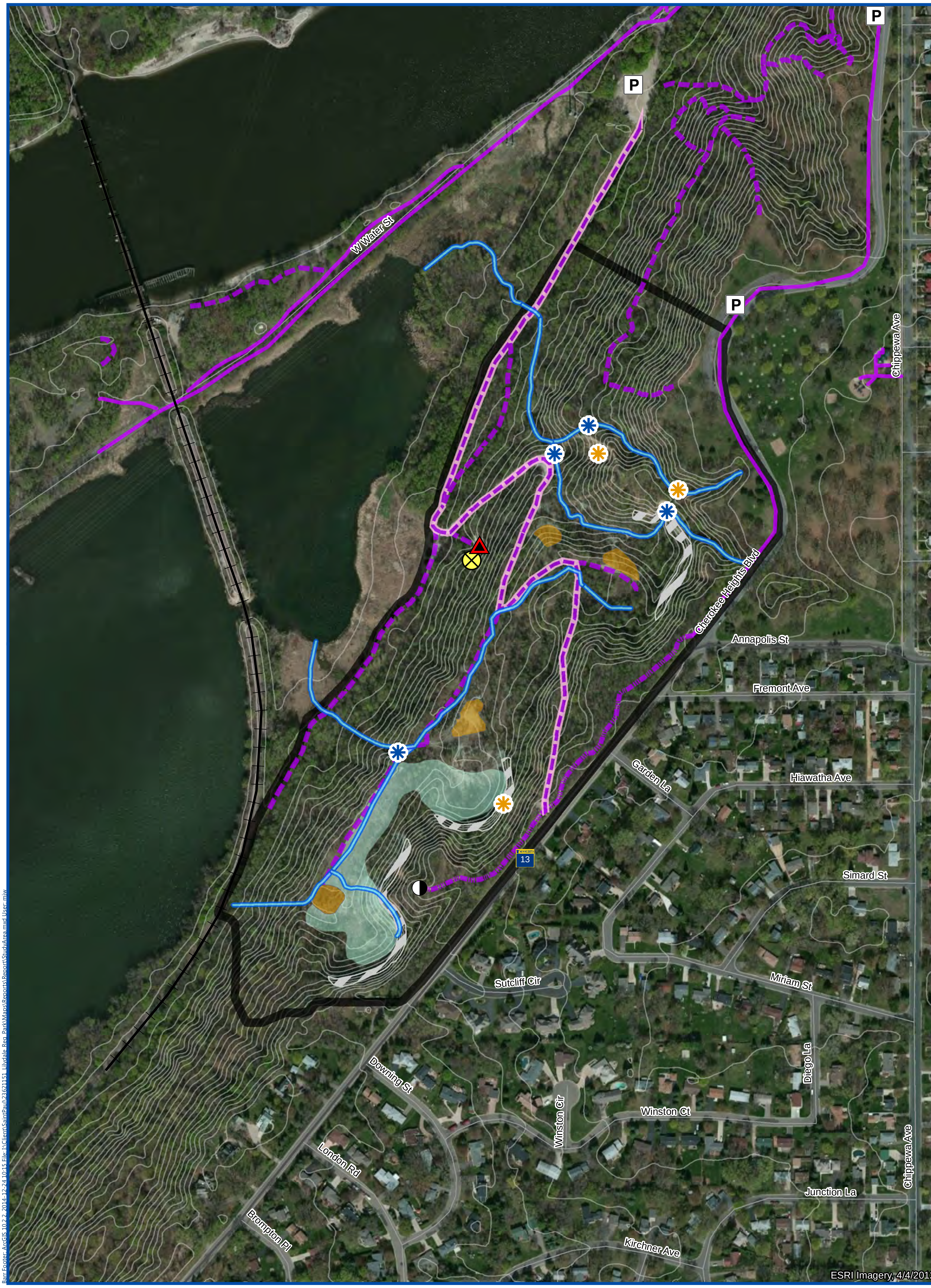
Large Figures



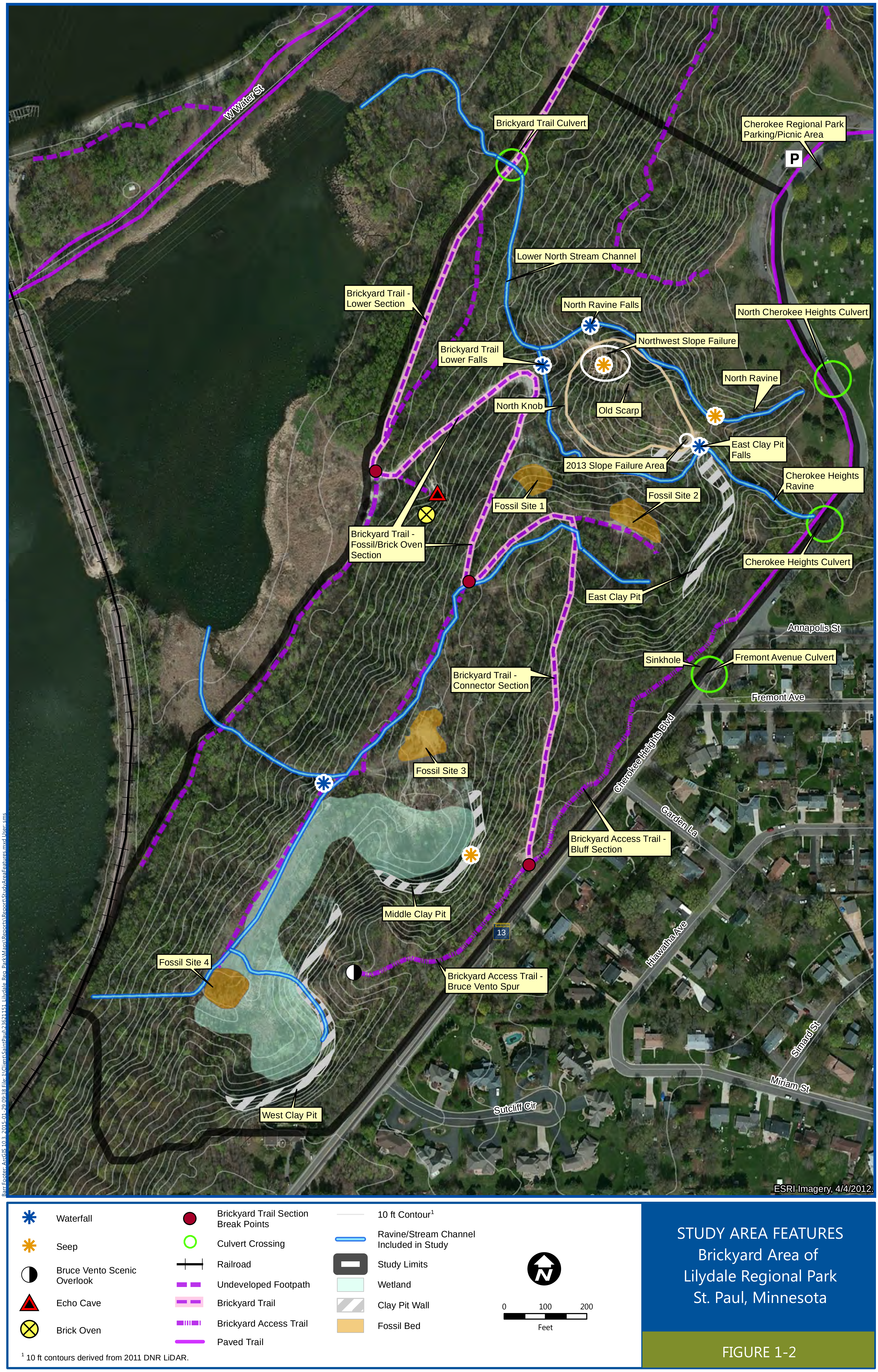
Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Railroad
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
10 ft Contour[1]
Ravine/Stream Channel Included in Study
Study Limits
Wetland
Clay Pit Wall
Fossil Bed

0 150 300
Feet

[1] 10 ft contours derived from 2011 DNR LiDAR.

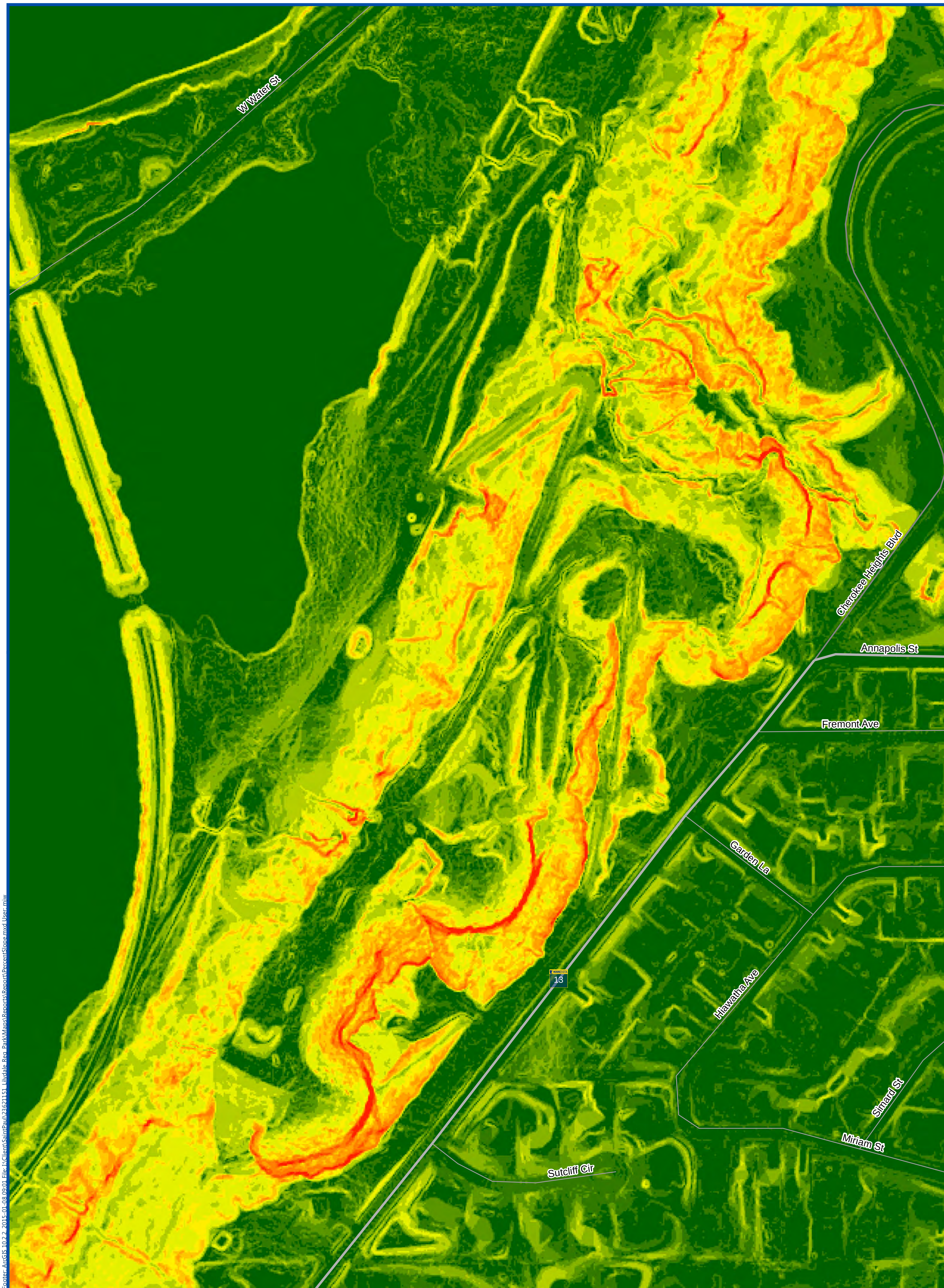
STUDY AREA
Brickyard Area of
Lilydale Regional Park
St. Paul, Minnesota

FIGURE 1-1



STUDY AREA FEATURES
Brickyard Area of
Lilydale Regional Park
St. Paul, Minnesota

FIGURE 1-2



Percent Rise[1] (derived from 2011 DNR LiDAR)

- < 5%
- 5 - 10%
- 10 - 15%
- 15 - 25%
- 25 - 45%
- 45 - 65%
- 65 - 75%
- 75 - 90%
- 90 - 110%
- 110 - 150%
- 150 - 200%
- >200%

0 100 200
Feet

[1] For percent rise, the range is 0 to essentially infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise become increasingly larger.

CHANGE IN SLOPE (PERCENT RISE)
Brickyard Area of Lilydale Regional Park
St. Paul, Minnesota

FIGURE 1-3

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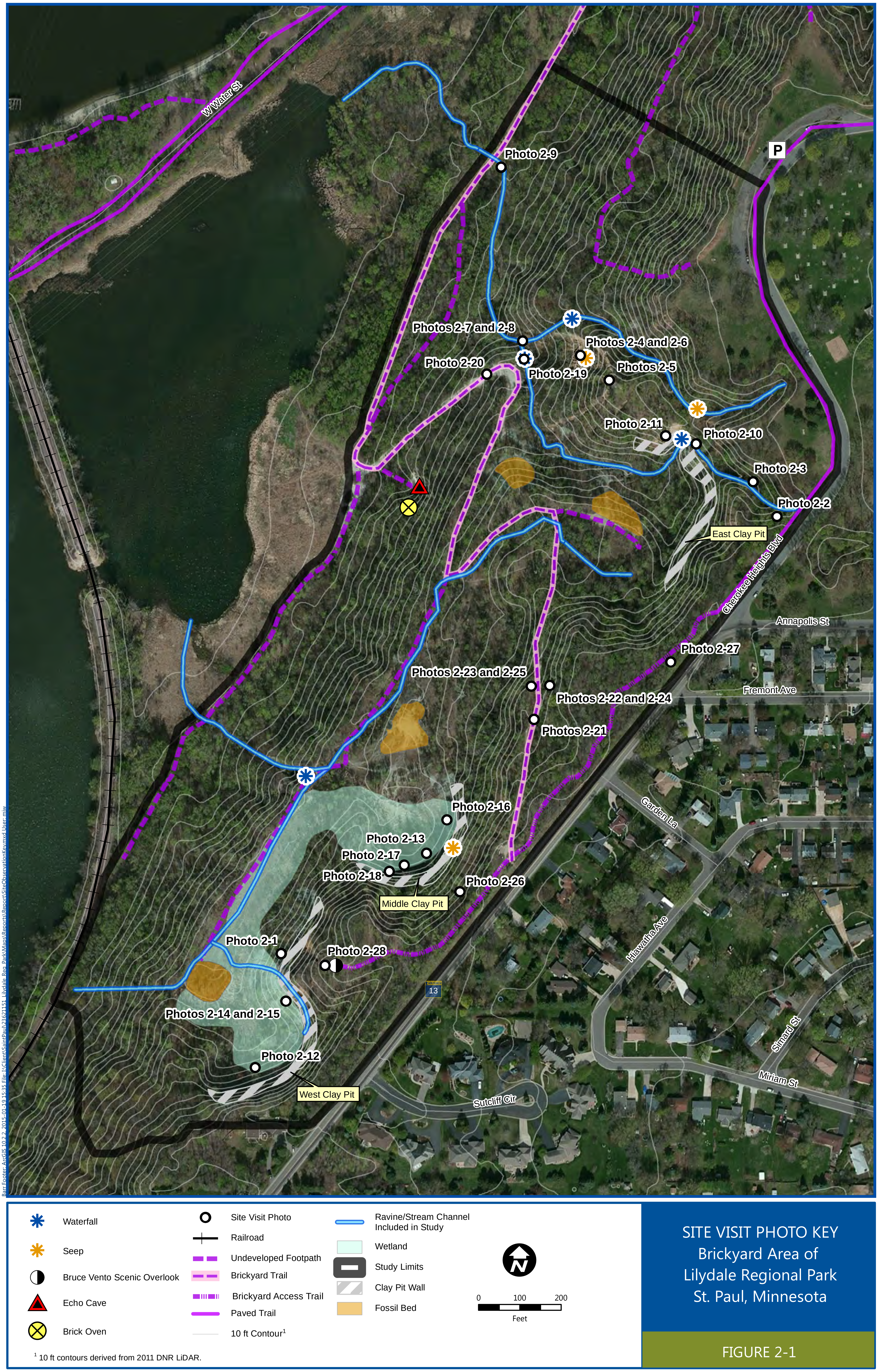
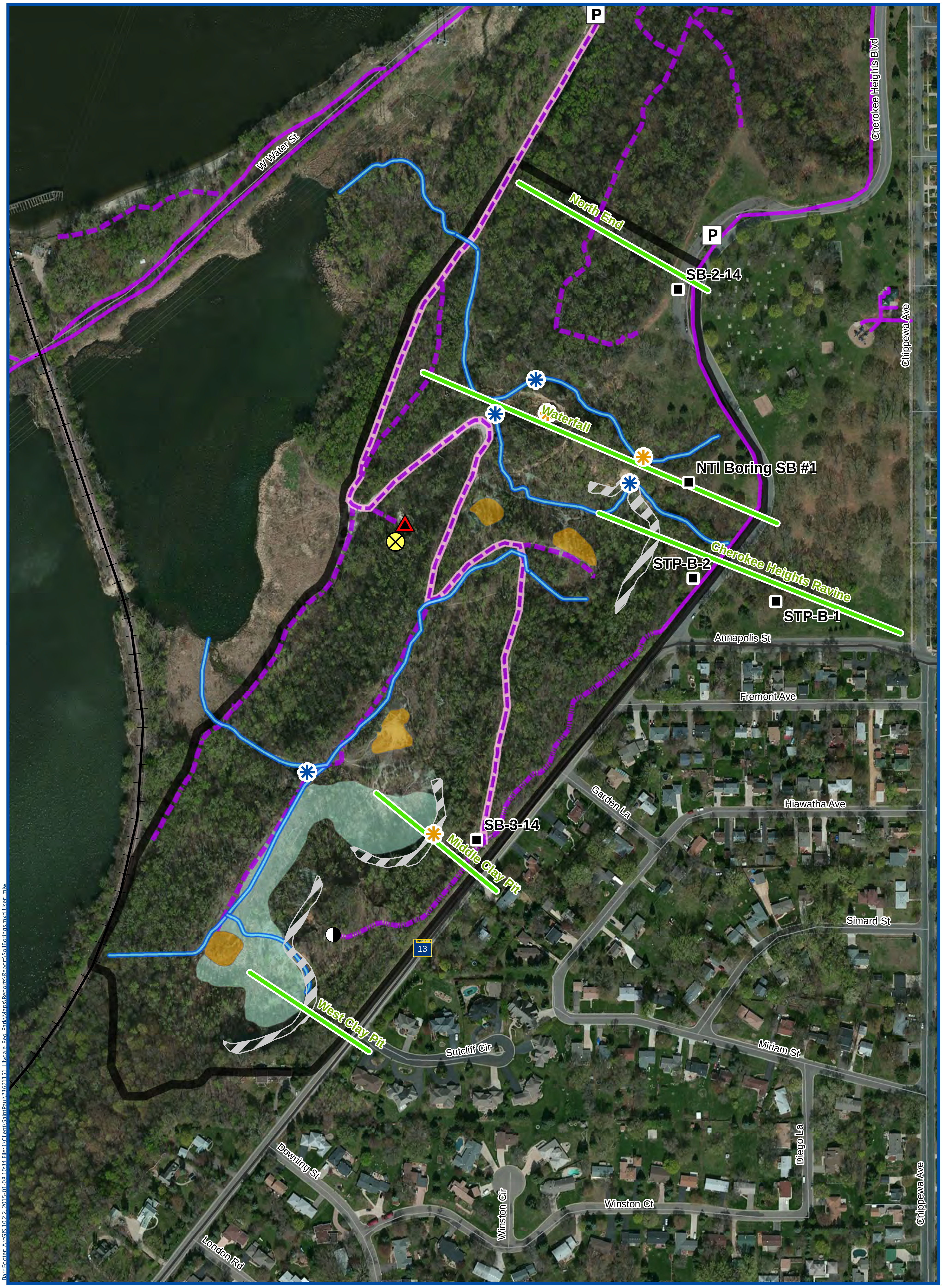


SITE VISIT PHOTO KEY
Brickyard Area of
Lilydale Regional Park
St. Paul, Minnesota

FIGURE 2-1



Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Soil Boring

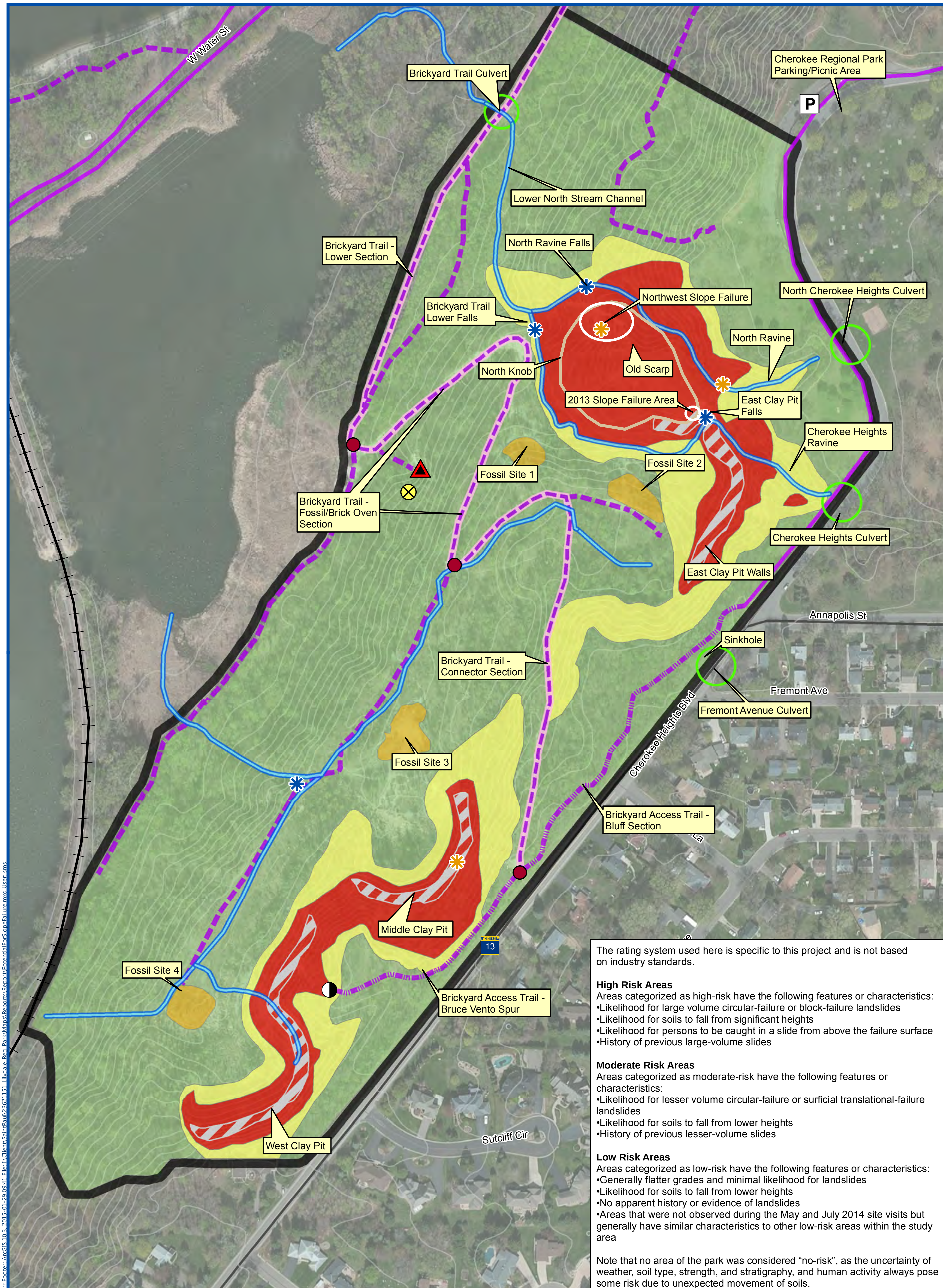
Railroad
Geotechnical Modeling Cross-Section
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
Ravine/Stream Channel Included in Study

Study Limits
Clay Pit Wall
Wetland
Fossil Bed

0 125 250
Feet

SOIL BORINGS AND MODELED GEOTECHNICAL CROSS-SECTIONS
Brickyard Area of Lilydale Regional Park
St. Paul, Minnesota

FIGURE 3-1



The rating system used here is specific to this project and is not based on industry standards.

High Risk Areas
Areas categorized as high-risk have the following features or characteristics:
- Likelihood for large volume circular-failure or block-failure landslides
- Likelihood for soils to fall from significant heights
- Likelihood for persons to be caught in a slide from above the failure surface
- History of previous large-volume slides

Moderate Risk Areas
Areas categorized as moderate-risk have the following features or characteristics:
- Likelihood for lesser volume circular-failure or surficial translational-failure landslides
- Likelihood for soils to fall from lower heights
- History of previous lesser-volume slides

Low Risk Areas
Areas categorized as low-risk have the following features or characteristics:
- Generally flatter grades and minimal likelihood for landslides
- Likelihood for soils to fall from lower heights
- No apparent history or evidence of landslides
- Areas that were not observed during the May and July 2014 site visits but generally have similar characteristics to other low-risk areas within the study area

Note that no area of the park was considered "no-risk", as the uncertainty of weather, soil type, strength, and stratigraphy, and human activity always pose some risk due to unexpected movement of soils.

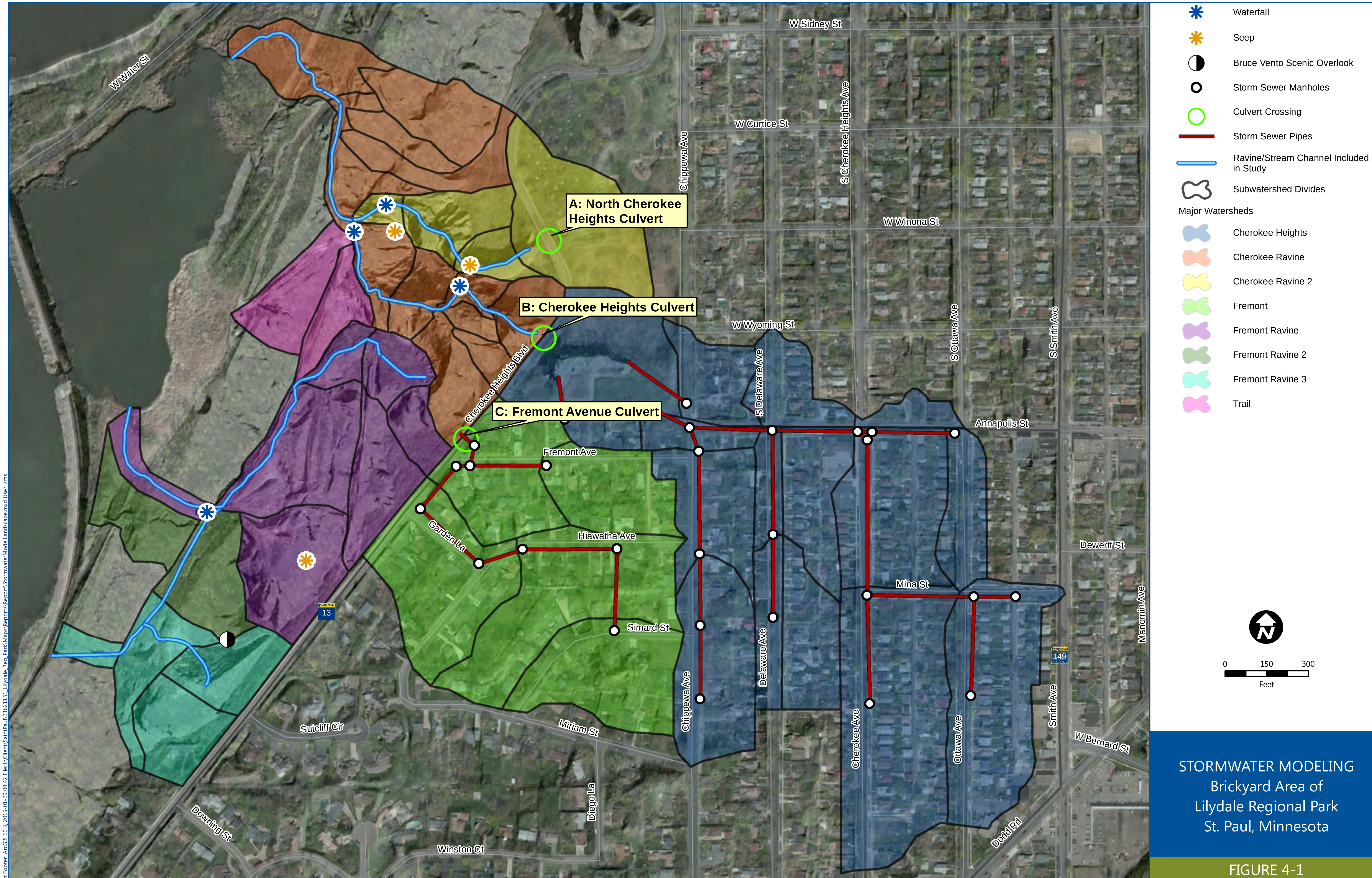
Waterfall
Seep
Bruce Vento Scenic Overlook
Echo Cave
Brick Oven
Brickyard Trail Section Break Points
Culvert Crossing
Railroad
10 ft Contour [1]
Undeveloped Footpath
Brickyard Trail
Brickyard Access Trail
Paved Trail
Ravine/Stream Channel Included in Study
Clay Pit Wall
Study Limits
Fossil Bed
Potential for Slope Failure (or Slope Failure Risk)
High
Medium
Low

0 100 200
Feet

[1] 10 ft contours derived from 2011 DNR LiDAR.

POTENTIAL FOR SLOPE FAILURE (BASED ON JULY 2014 SITE CONDITIONS)
Brickyard Area of Lilydale Regional Park
St. Paul, Minnesota

FIGURE 3-2



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RECOMMENDATIONS
Brickyard Area of
Lilydale Regional Park
St. Paul, Minnesota

FIGURE 5-1

Appendix A

Ravine Stabilization and Stormwater Management Alternatives

Prepared for
City of St. Paul Department of Parks and Recreation

January 28, 2015

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: 952.832.2600
Fax: 952.832.2601

Appendix A

Ravine Stabilization and Stormwater Management Alternatives

January 28, 2015

List of Tables

List of Photos

List of Figures

Table A-1 Summary of ravine stabilization and stormwater management alternatives

Option #	Option Description	Pros	Cons	Relative Cost	Ideal Sites
1	Riprap channel and toe protection (Photo A-1and Figure A-1)	• Relatively easy installation • Not dependent on sun/plants • Flexible—can adapt to disturbance	• Can appear artificial • Subject to vandalism	$	Ravine or channel edges in shady areas
2	Geoweb (Photo A-2, Photo A-3, Photo A-4, and Figure A-2)	• Relatively easy installation • Allows plant growth (or can be filled with rock) • Provides greater stability than turf reinforcement mat	• Subject to exposure, less desirable aesthetics • Less effective for channelized flow • Subject to undermining • Sunlight needed for plant growth (but can be filled with rock instead)	$	Ravine or channel edges in shady areas
3	Turf reinforcement mat (Photo A-5 and Figure A-3)	• Relatively easy installation • Allows plant growth	• Usually temporary (5-year life) • Less effective for channelized flow • Subject to undermining • Sunlight needed for plant growth	$	Erosion protection on slopes while vegetation becomes established
4	Vegetated reinforced soil slopes (Photo A-6, Photo A-7, Photo A-8, and Figure A-4)	• Stabilizes steep slopes using natural materials • Aesthetics	• Requires sunlight to support plant growth • More difficult to install • Higher cost	$$	Stabilization of steep slopes with good sun exposure; well-suited to trail edges
5	Boulder riffle (Photo A-9 and Figure A-5)	• Provides grade control within ravines or channels • Not dependent on sun/plants • Natural materials	• More difficult to install • Higher cost	$$	Suited to ravines or channels that are subject to downcutting
6	Rock steps (Figure A-6)	• Helps prevent trail erosion • Aesthetics • Safety	• Higher cost • Often warrants railing to prevent side trails from forming	$$	Suited to very steep trails that are subject to erosion
7	Sheetpile wall (Photo A-10)	• Long-lasting • Largely subsurface and hidden • Low-maintenance	• High cost • Subject to exposure (concrete cap is an option)	$$$	Stabilization of steep hillslopes adjacent to trails or other public areas

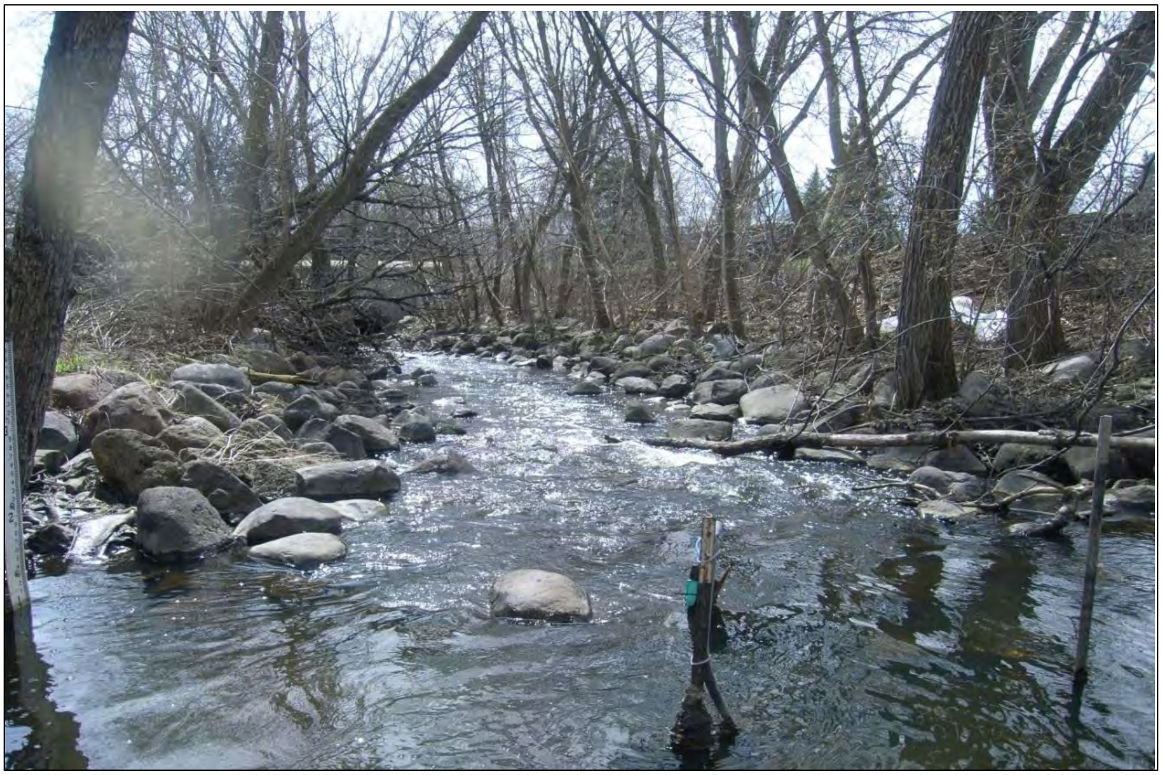


Photo A-1 Example of riprap

Photo A-2 Example of geoweb erosion control (source: *www.prestogeo.com*, used with permission)

Photo A-3 Cross section view of geoweb (source: www.prestogeo.com, used with permission)

Photo A-4 Example of geoweb on a steep slope, prior to infill (source: www.prestogeo.com, used with permission)

Photo A-5 Example of a turf-reinforcement mat

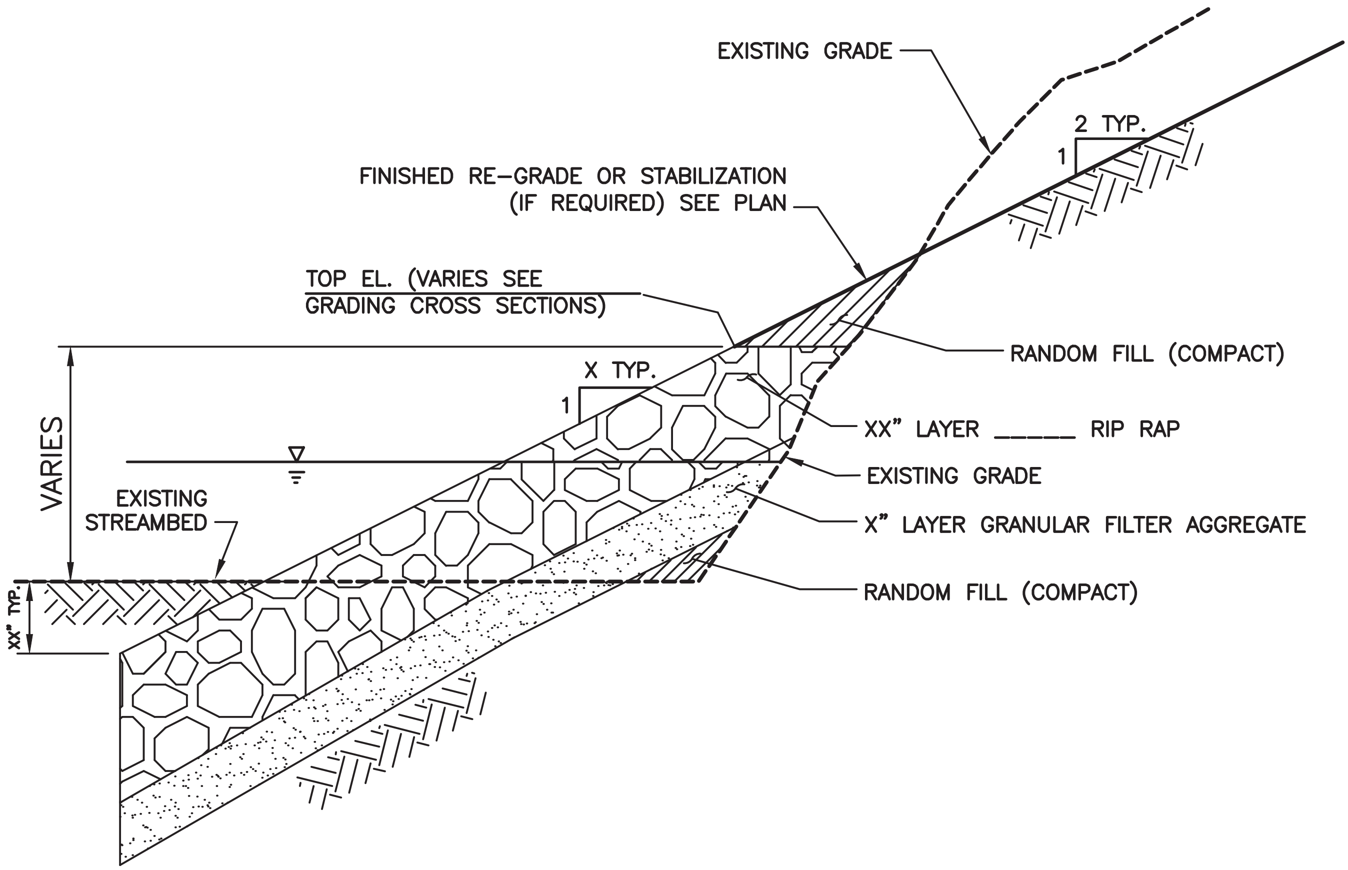
Photo A-6 Example of vegetated reinforced soil slope (VRSS) before vegetation re-establishes

Photo A-7 Example of VRSS (note vegetation stakes)

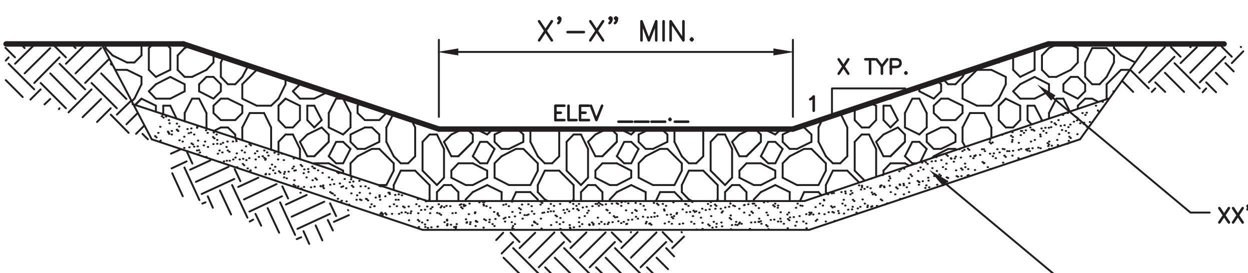
Photo A-8 Example of VRSS after vegetation has grown

Photo A-9 Example of a boulder riffle

Photo A-10 Example of sheetpile wall



DETAIL: RIP RAP TOE PROTECTION
NOT TO SCALE



SECTION: RIPRAP CHANNEL
NOT TO SCALE

CADD USER: Sarah E. Ash FILE: W:\BUSINESS UNITS\WR\TECHNICAL TOPICS\STREAMS AND GEOMORPHOLOGY CLASSIFICATION\STREAM PROJECTS SPECS\STANDARD DETAILS\STREAM_RESTORATION_STANDARD_PLATES.DWG PLOT SCALE: 1:1 PLOT DATE: 7/18/2013 1:27 PM

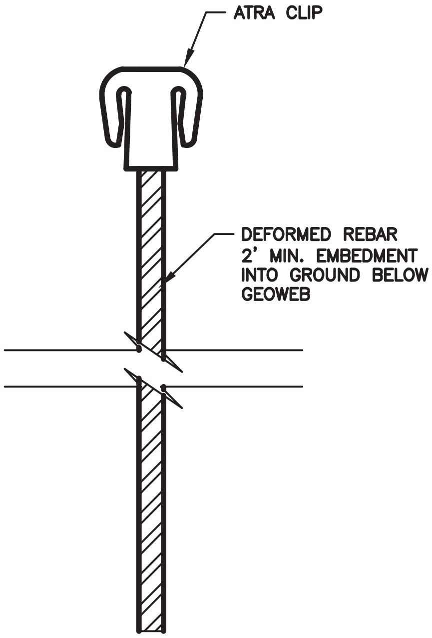
SPEC #: ___

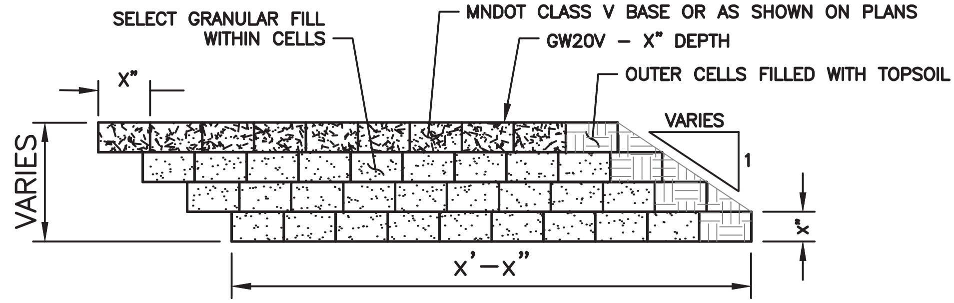
BARR ENGINEERING COMPANY
4700 W 77th Street
Minneapolis, MN 55435–4803
P: (952) 832–2600

Figure A-1

STREAM RESTORATION STANDARD PLATES
|| RIPRAP: Channel & Toe Protection ||

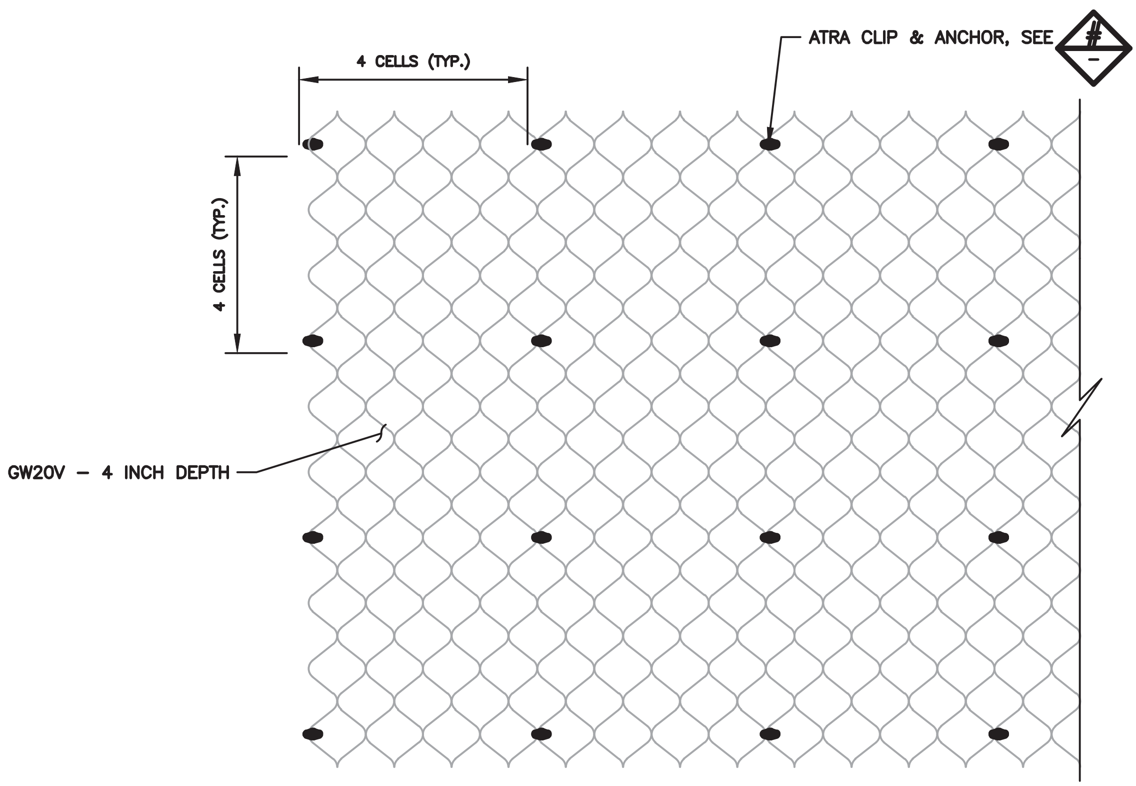
This template is for REFERENCE ONLY and should be carefully considered and edited to match the project's specific situation.





DETAIL: GEOWEB TRAIL REINFORCEMENT (TYP.)

DETAIL: ATRA CLIP & ANCHOR



DETAIL: GEOWEB ANCHOR LAYOUT

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Figure A-2

STREAM RESTORATION STANDARD PLATES
|| GEOWEB ||

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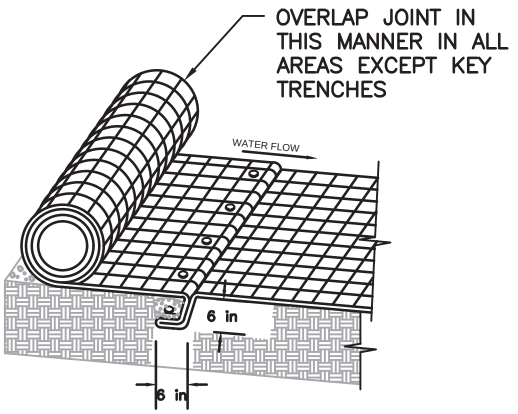
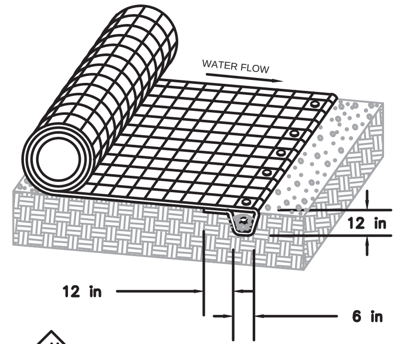
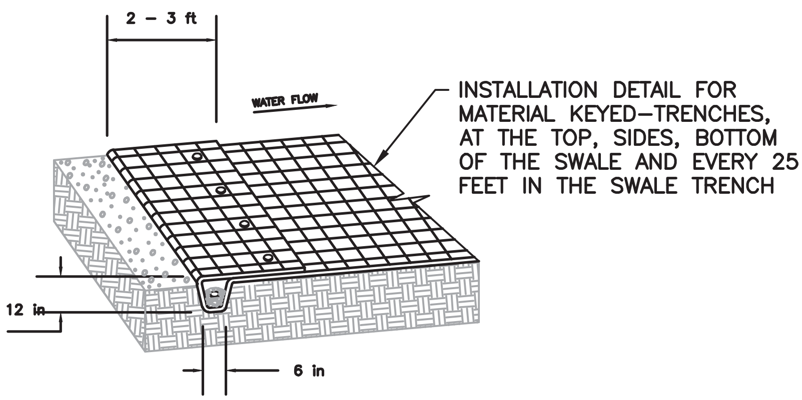


DETAIL: INTERMITTENT CHECK SLOT
NOT TO SCALE



DETAIL: INITIAL ANCHOR TRENCH
NOT TO SCALE



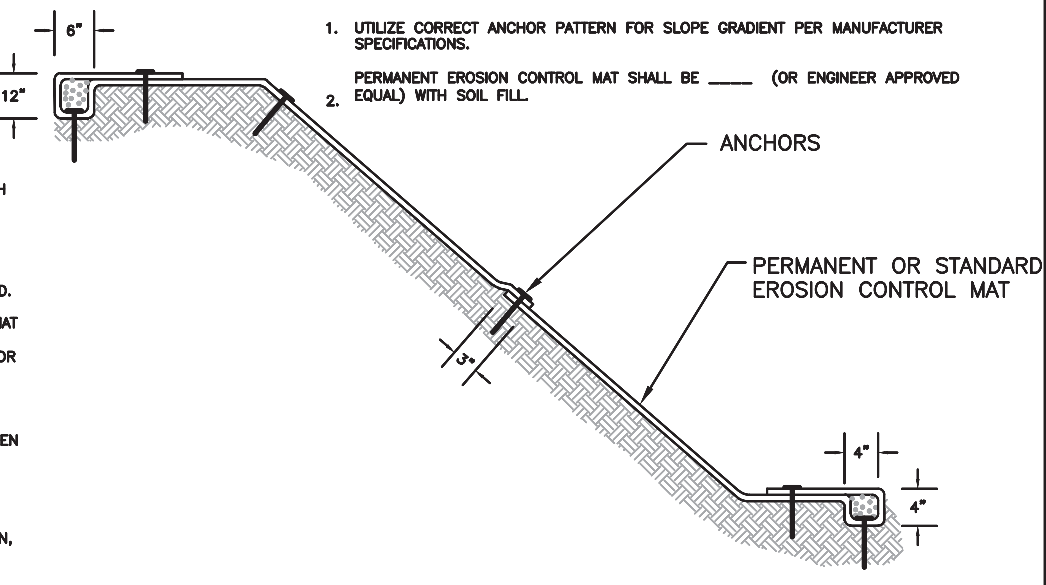
DETAIL: TERMINAL CHANNEL ANCHOR TRENCH
NOT TO SCALE

NOTES:

1. A REPRESENTATIVE OF THE HPTRM MANUFACTURER OR SUPPLIER SHOULD BE PRESENT AT THE PRE–CONSTRUCTION MEETING, IF POSSIBLE.
2. SITE PREPARATION:
   - 2.1. GRADE AND COMPACT APPLICATION AREA. SUBGRADE SHALL BE UNIFORM AND SMOOTH. REMOVE ALL ROCKS, CLADS, VEGETATION OR OTHER OBJECTS SO THE INSTALLED MAT WILL HAVE DIRECT CONTACT WITH SOIL SURFACE.
   - 2.2. PREPARE SEEDBED BY LOOSENING THE TOP 2–3" (MIN) OF SOIL.
   - 2.3. INCORPORATE AMENDMENTS SUCH AS LIME AND FERTILIZER AND/OR WET THE SOIL, IF NEEDED.
   - 2.4. DO NOT MULCH AREAS WHERE MAT IS TO BE PLACED.
3. SEEDING:
   - 3.1 APPLY SEED TO SOIL SURFACE BEFORE INSTALLING MAT ACCORDING TO SPECIFICATIONS.
   - 3.2 CONSULT PROJECT PLANS AND/OR SPECIFICATIONS FOR SEED TYPES AND APPLICATION RATES.
4. GROUND PINNING DEVICES:
   - 4.1 METAL PINS SHOULD BE AT LEAST 0.20" (5 MM) IN DIAMETER STEEL WITH A 1.5" STEEL WASHER AT THE HEAD OF THE PIN. METAL PINS SHOULD BE DRIVEN FLUSH TO THE SOIL SURFACE. PINS SHOULD BE BETWEEN 6–24" LONG AND HAVE SUFFICIENT GROUND PENETRATION TO RESIST PULLOUT. LONGER PINS MAY BE REQUIRED FOR LOOSER SOILS. HEAVIER METAL STAKES MAY BE REQUIRED IN ROCKY SOILS. DEPENDING ON SOIL PH AND DESIGN LIFE OF THE PIN, GALVANIZED OR STAINLESS STEEL PINS MAY BE REQUIRED. CONSULT PROJECT PLANS AND/OR SPECIFICATIONS FOR TIE DOWN DEVICE DETAILS.
5. TRM= TURF REINFOCEMENT MAT SHAL BE IN ACCORDANCE W/ MnDOT _____ CLASS _.
   HPTRM= HIGH PERFORMANCE TURF REINFORCEMENT MAT SHALL BE IN ACCORDANCE WITH MnDOT _____ CLASS _.
6. TRM AND HPTRM SHALL BE INSTALLED IN ACCORDANCE WITH THE MANUFACTURER'S RECOMMENDATIONS.

NOTES:

1. UTILIZE CORRECT ANCHOR PATTERN FOR SLOPE GRADIENT PER MANUFACTURER SPECIFICATIONS.
2. PERMANENT EROSION CONTROL MAT SHALL BE _____ (OR ENGINEER APPROVED EQUAL) WITH SOIL FILL.



DETAIL: TYPICAL SLOPE CROSS SECTION
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STREAM RESTORATION STANDARD PLATES
|| TURF REINFORCEMENT MAT ||

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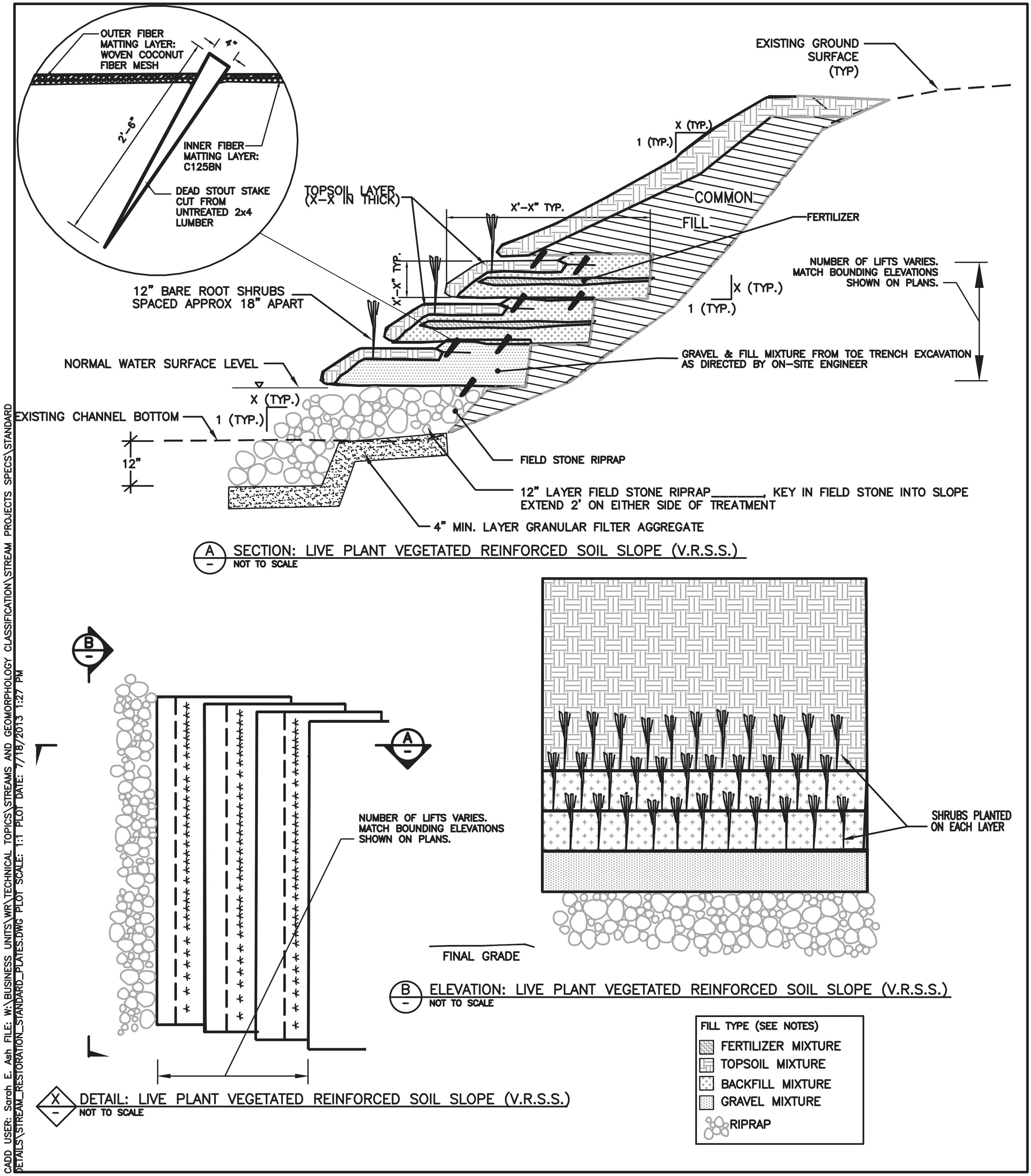

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Figure A-4

STREAM RESTORATION STANDARD PLATES

|| VEGETATED REINFORCED SOIL SLOPES ||

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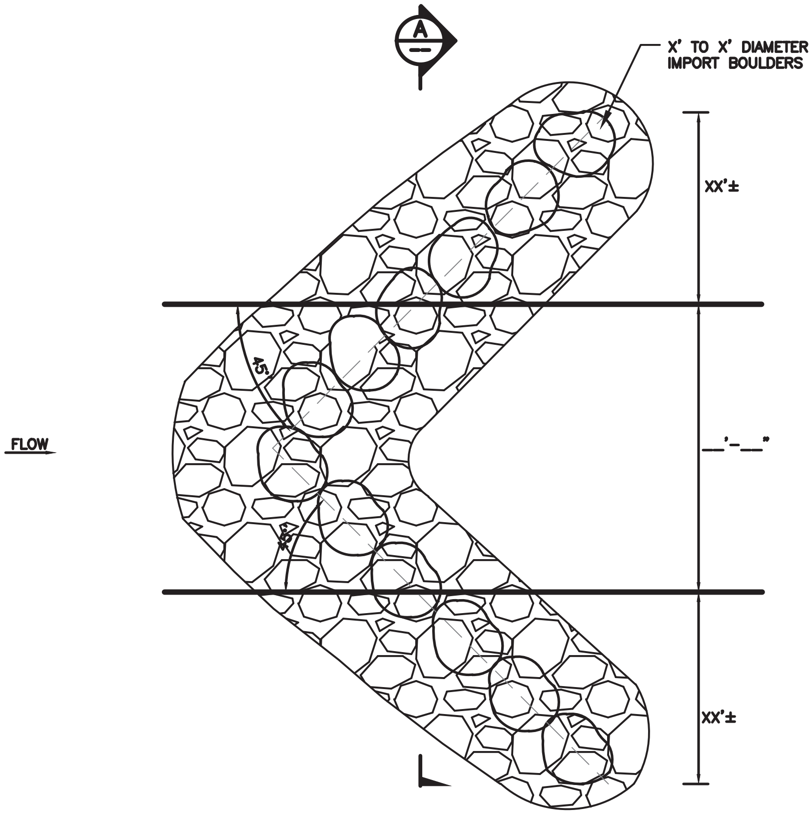

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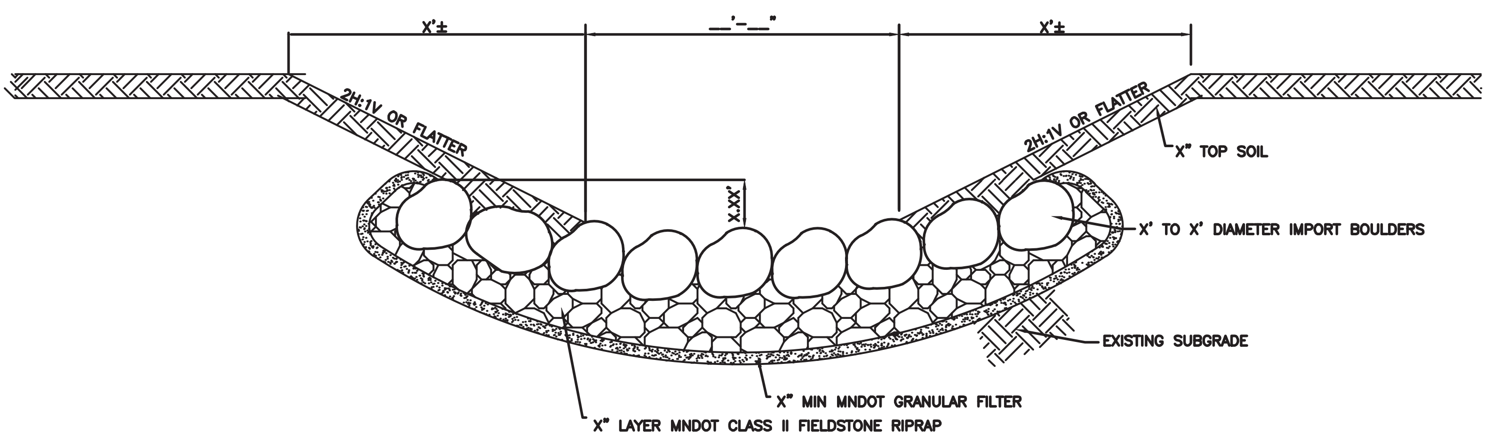
NOT TO SCALE



SECTION: BOULDER RIFFLE
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Figure A-5

STREAM RESTORATION STANDARD PLATES
|| BOULDER RIFFLE (single row) ||
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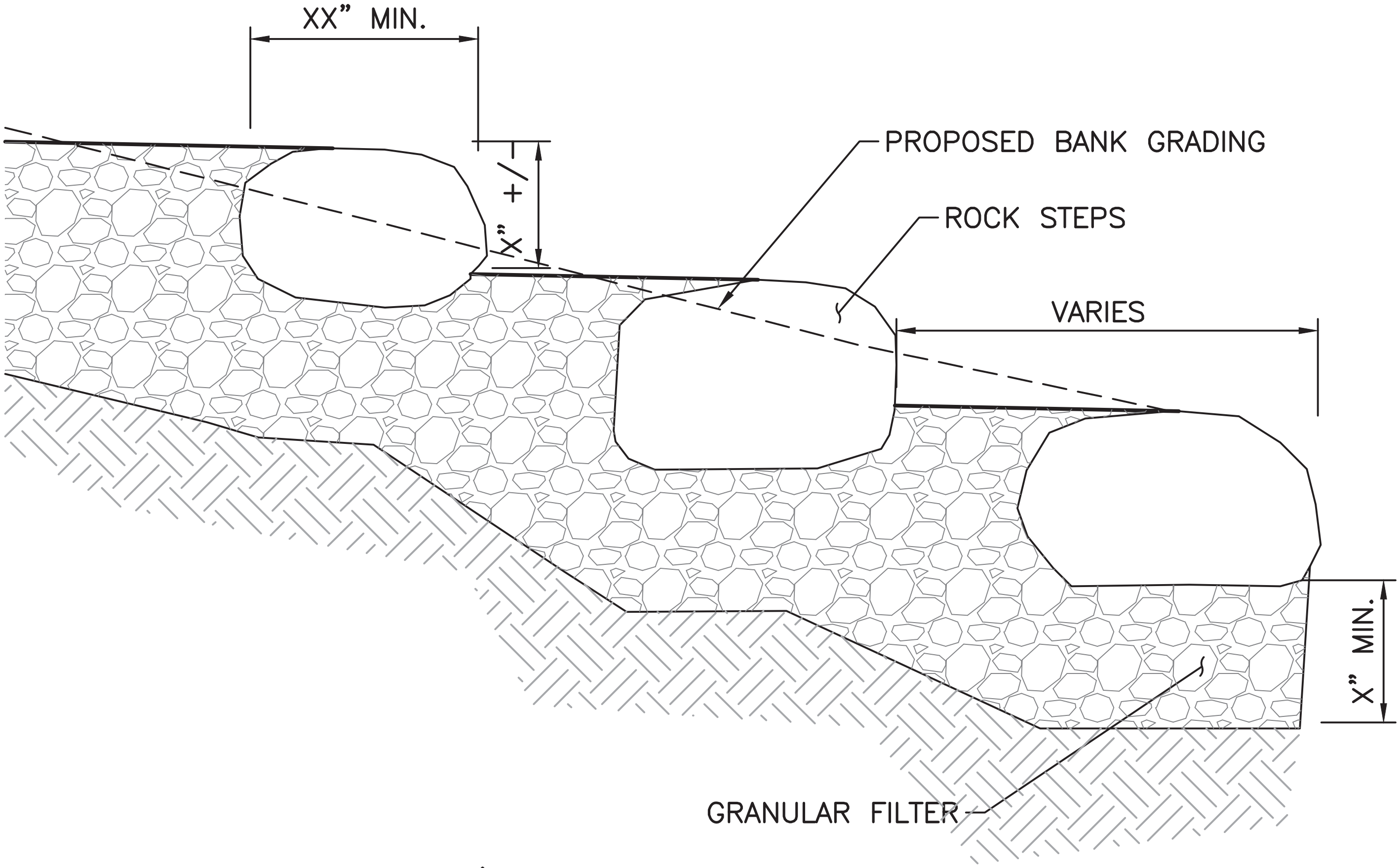
NOTE: ROCK STAIRS SHALL BE A MINIMUM OF 3 FEET WIDE.



#/-- DETAIL: ROCK STEPS
NOT TO SCALE

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Figure A-6

STREAM RESTORATION STANDARD PLATES
|| ROCK STEPS ||

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Appendix B

Steep-Slope Stabilization Options

Prepared for
City of St. Paul Department of Parks and Recreation

January 28, 2015

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Minneapolis, MN 55435-4803
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Appendix B

Steep-Slope Stabilization Options

January 28, 2015

Contents

List of Tables

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List of Photos

Table B-1 Summary of mechanical slope-stabilization options

Option	Type	Option Description	Pros	Cons	Relative Cost Range
1	Mechanical	Grading to stable slope (Figure D-1)	• Simple approach to grade to stable slope • Moderate cost, locally available equipment	• Most areas do not have enough room for grading • Will remove most/all trees from the slopes • Will require erosion control to be maintained	$$$
2	Mechanical	Slurry trench or seepage cut-off wall	• Moderate cost option • Will cause less disturbance to site features	• Will only reduce underground seepage issue • Will not treat direct rainfall • Will require water management plan to outlet water • May not mate fully with bedrock surface • Trickiest engineering solution	$$$$
3 & 4	Mechanical	Physical stabilization - anchored into bedrock (e.g., soil nail, soldier pile) (Photo D-1 and Figures D-2 and D-3)	Most active treatment of instability conditions	• Very costly • Requires specialized equipment • Removal of some to most trees	$$$$$

1.0 Grading to a Stable Slope

The simplest solution for reducing the potential for slope instability is reducing the grade of the slope to a gentler more stable configuration. This can typically be achieved with conventional machinery and local, non-specialty contractors.

Upon final grading, soil cover to prevent erosion should be installed (likely consisting of vegetation that performs well on partially drained slopes). A potential drawback to extensive grading would be the loss of the mature trees on the native soil slopes to be graded, which may not be desirable for a park.

To provide a rough estimate of potential quantities for earthwork, Barr projected the conceptual recommended slope angle from the top edge of the shale outcrops within the study area. When projecting these slopes, it became apparent that grading to these slopes would envelop most of Cherokee Heights Boulevard and Highway 13 at the top of the bluff, as well as a portion of some of the closer neighboring properties. Therefore, grading to a stable slope angle does not appear feasible unless it is incorporated with retaining walls to reduce the amount of space needed for grading. But by incorporating retaining wall structures into the design, the costs for grading would increase substantially and some specialized technology may be needed to design for long-term stability or allow for the structures to be constructed (i.e., anchored sheet piles or soldier piles).

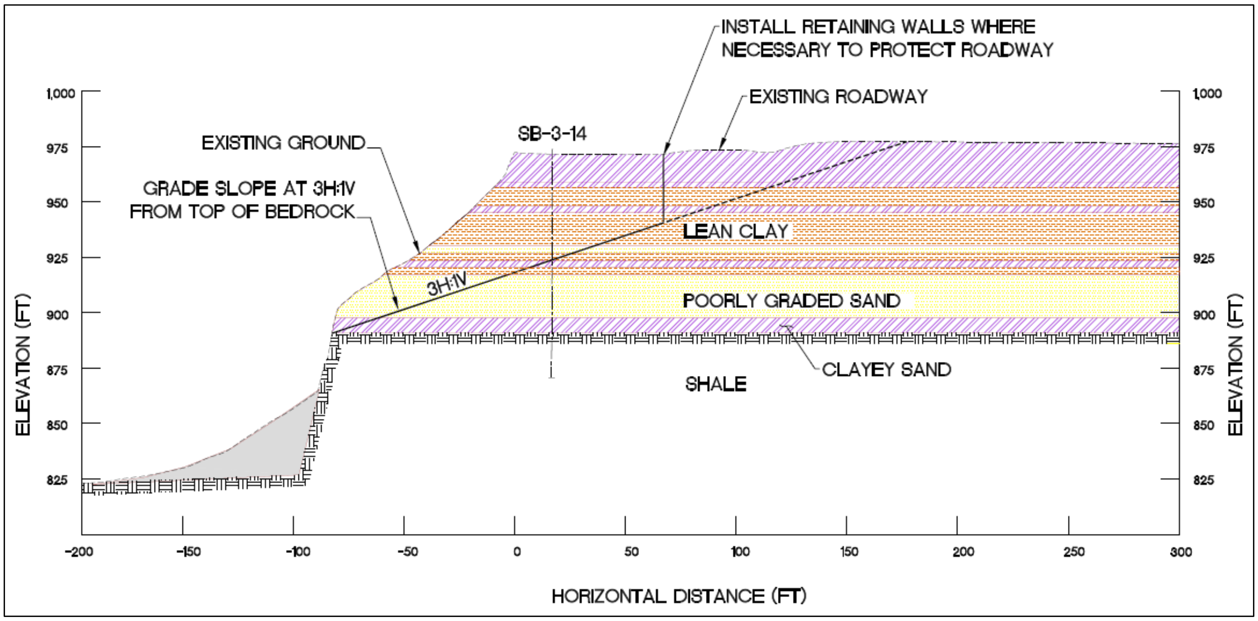

Figure B-1 **Conceptual example of grading to a stable slope with installation of a sheetpile wall to protect the roadway**

2.0 Slurry Trench or Seepage Cut-Off Wall

Slurry trenches or cutoff walls typically consist of a low permeability material (bentonite, grout, concrete, etc.) installed in a narrow trench to create a barrier to groundwater flow. Recent developments in machinery and grout technology have reduced the costs associated with slurry trench construction.

However, cutting off of groundwater flow from the higher areas above the bluff may help reduce some potential for slope instability, but since this technology will not prevent soil saturation from rainfall and infiltration downstream of the cut-off wall it may not be fully effective in reducing slope stability issues. Also, since the slurry trench is intended to reduce or eliminate flow across the trench, water which used to flow toward and over the bluffs may build up behind the wall and need to be drained or removed (or at least planned for where the water can be discharged without causing other problems).

For these reasons, a slurry trench or cutoff wall does not appear to be the best choice to reduce the potential for slope stability at this site.

Photo B-1 Photo of slurry trench

3.0 Soil Nailing

Soil nailing is another common method of active slope stabilization. With soil nailing, small diameter corrosion resistant elements (nails, helical anchors, etc.) are installed at an angle through the soils, extending far enough into the soil to penetrate past the failure plane. The resistance generated by the nail behind the failure plane pins the soil mass in place not allowing it to slide.

Costs associated with soil nailed can get high, especially with limited site access. However, there are some specialized rigs that can install soil nails from an extendable arm which can reach down from the top of the slope. This would reduce the need for grading in a working area at the base of the area, which would be somewhat difficult with the location of the steeper clay pits at the toe of the natural soil slopes. This work should typically be performed by a specialty contractor.

Once the soil nails are installed, some slope facing material is usually applied. This typically consists of a wire mesh held in place with shot-crete; however, in natural settings a turf-reinforcing mat which can allow for vegetation growth may be suitable depending on the design requirements.

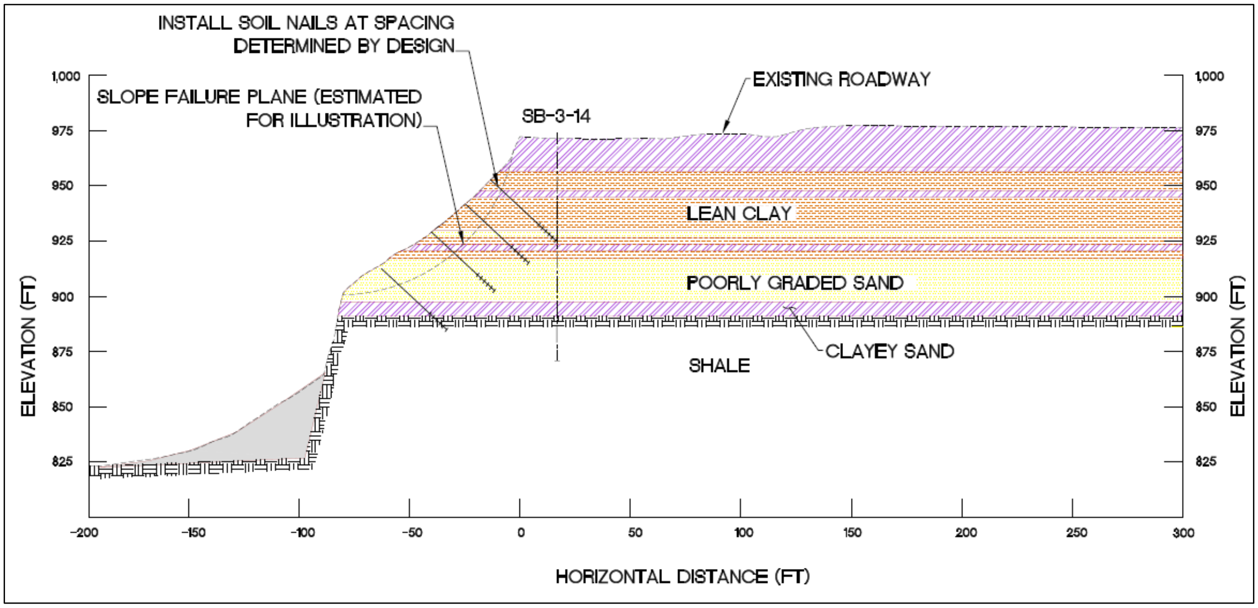

Figure B-2 Conceptual example of soil nailing

4.0 Soldier Piling

Soldier piling typically consists of steel piles spaced at 5 to 10-foot intervals along the slope and placed into more competent materials, such as very stiff clay, dense sand, or bedrock. The spaces between the piles are then filled with lagging (some form of concrete or wood plank walls) to retain the soil and prevent failures. For this study area, soldier piles would likely need to be socketed at least 10 to 15 feet into the shale bedrock to provide the capacity to retain the upper soils. However, additional site investigation must be performed to design the repairs.

Soldier piling work would typically be performed by a specialty contractor, and would have similar site access issues as soil nailing.

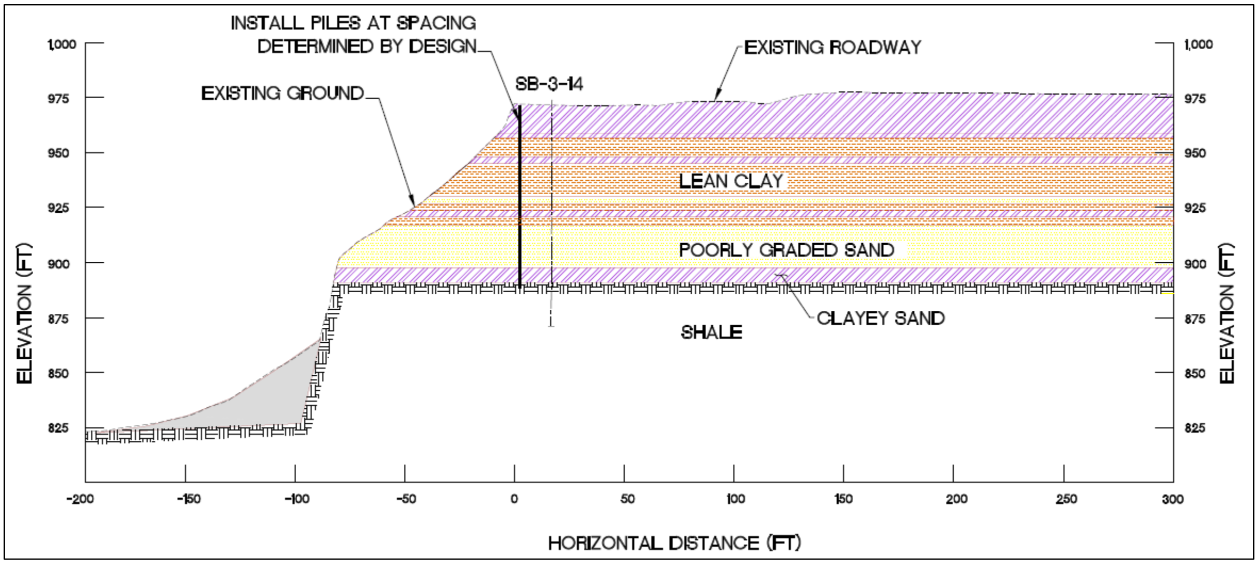

Figure B-3 Conceptual example of soldier piling

Photo B-2 Photo of soldier piling along Mississippi River in Minneapolis

BARR

Appendix C: Geotechnical Evaluation

Existing Slopes
Brickyard Area of Lilydale Regional Park

Prepared for
City of St. Paul Department of Parks and Recreation

January 28, 2015

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Appendix C: Geotechnical Evaluation
Existing Slopes
Brickyard Area of Lilydale Regional Park

January 28, 2015

Contents

List of Tables

List of Attachments

Certifications

I hereby certify that this geotechnical report was prepared by me or under my direct supervision and that I am a duly licensed Professional Engineer under the laws of the State of Minnesota.

January 28, 2015

Bill Kussmann

PE #: 47821

Date

1.0 Introduction

The focus of this geotechnical evaluation was the Brickyard Area of Lilydale Regional Park. Many historical and recreational amenities are located within the Brickyard Area, including the Brickyard Trail that extends from the park access at West Water Street near the Mississippi River to the top of the bluff, a scenic overlook (Bruce Vento Scenic Overlook), the historic clay mining quarries (i.e., the East, Middle, and West Clay Pits), several waterfalls, ruins of a historic brick oven and other structures, and four fossil beds.

Barr Engineering Co. (Barr) was contracted to perform site observations, soil borings, laboratory testing, geotechnical modeling, and analysis to evaluate potential slope-stability issues for key features in the Brickyard Area of the park. The results of the geotechnical evaluations are provided here and have been used as the basis for recommendations provided to the City in the concurrent report: *Brickyard Area of Lilydale Regional Park—Stormwater Management and Slope-Stability Study* (Main Report), also prepared by Barr.

1.1 Site Location and Topography

Lilydale Regional Park is located on bluffs along the south side of the Mississippi River in St. Paul, Minnesota. State Highway 13 and Cherokee Heights Boulevard form the park boundary near the top of the bluff. Cherokee Heights Park is located across Cherokee Heights Boulevard, as shown on Large Figures 1-1 and 1-2 of the Main Report.

The Minnesota Department of Natural Resources 2011 LiDAR elevation data set was used to help characterize the slopes throughout the Brickyard Area. Large Figure 1-3 of the Main Report shows the change in slope throughout the Brickyard Area by presenting the “percent rise,” which increases as the topography becomes more vertical. The portions of the Brickyard Area shown in orange and red hues on the figure represent areas that are the steepest (most notably, the clay pit walls).

1.2 Former Facilities

The Brickyard was the site of the Twin Cities Brick Company, which was founded in 1894 and continued to make bricks until the 1970s. The interest in brick-making boomed after a number of local villages and cities, constructed primarily of wood, burned during catastrophic fires during the late 1800s. Workers quarried Decorah shale on the bluff above this location and brought it down the steep hillside where it was processed and fired into bricks (Reference (1)).

Currently, there are ruins of a brick oven at the base of the bluff, several old foundations (presumably from quarrying equipment), and three main quarries (termed “clay pits”) forming a topographical (near vertical) break between the lower park elevations and the upper portion of the park. There is one main trail extending from the lower brick-making area to the upper bluffs, winding its way between the East and Middle Clay Pits.

There is also a large cave (Echo Cave) carved into the white Cambrian sandstone rock located adjacent to the brick oven. It is assumed that this "cave" is a manmade structure mined for its high-silica-content sandstone (used to make glass).

1.3 Site Geology

The bedrock in the area of Lilydale Regional Park was formed in Cambrian and Ordovician times, when Minnesota was located in a tropical climate near the equator.

The upper bedrock in the park is the lower portion of the Galena Group. The Galena Limestone, a hard buff-colored limestone rock, is mapped as the top bedrock unit near the park. Based on soil borings performed for this investigation, the Galena Limestone was very thin to absent. The basal member of the Galena Group is the Decorah Shale, a grayish-green shale rock with a high concentration of fossils (Reference (2)) encountered below the site soils. This is the primary bedrock unit in the park and the material that forms the walls of the formerly mined clay pits. There are a few more resistant limestone layers within the Decorah Shale. These more resistant layers can be seen in the clay pit walls.

The Galena Group is underlain by the Platteville Limestone (a thin buff-to-gray limestone layer), followed by the Glenwood Shale (a soft, greenish-gray shale), and then the St. Peter Sandstone, which is a nearly pure, quartz-rich, beach-deposited sandstone (Reference (2)). At Minnehaha Falls, the Platteville Limestone forms the resistant cap rock, protecting the underlying Glenwood Shale and St. Peter Sandstone. This creates the escarpment and the falls (Reference (3)). St. Peter Sandstone was observed along the Lower Brickyard Area, particularly Echo Cave.

The overlying soils were deposited when the Superior Lobe of the Wisconsinan glacial episode flowed into the area from the Lake Superior basin, blanketing the area with sandy glacial drift (Reference (3)).

1.4 Previous Investigations

Several previous geotechnical and natural resource reports for the park were reviewed:

- Northern Technologies, Inc., *Lilydale Regional Park Slope Failure Investigation*, August 21, 2013 (Reference (4))
- American Engineering Testing, Inc., *Report of Geotechnical Exploration and Review*, *Cherokee Regional Trail Widening along Cherokee Heights Boulevard*, May 11, 2011 (Reference (5))
- American Engineering Testing, Inc., *Report of Geotechnical Exploration and Review, Cherokee Regional Trail Widening*, October 4, 2010 (Reference (6))
- Bonestroo, *Lilydale Regional Park Natural Resources Management Plan*, May 2009 (Reference (7))

2.0 Geotechnical Investigation

2.1 Field Work

Barr's geotechnical investigation consisted of hollow-stem auger (HSA) borings with standard penetration testing (SPT) and diamond-bit rock coring at several locations along the top of the bluff. This supplemented the soil boring previously done by NTI at the top of the bluff.

Large Figure 3-1 of the Main Report shows the boring locations. Boring location coordinates and elevations were surveyed by Barr for the project.

2.1.1 Borings

A total of five borings were completed (one as part of the previous NTI study, four by Barr). The borings were located as shown on Large Figure 3-1 of the Main Report and results are summarized in Attachment A. A sixth boring was planned by Barr, but a safe path to the location was not available following June 2014 rains and subsequent slope failures.

Soil borings were drilled using rotary-type drill rigs and advanced using hollow-stem auger techniques until bedrock was encountered. After bedrock was reached, diamond-bit rock coring was done for two borings to a termination depth of approximately 100 to 104 feet below existing grade. Two other Barr borings were completed as part of the adjacent *Cherokee Heights Culvert Analysis and Erosion Control Feasibility Study* (which did not require coring) and were terminated 50 to 71 feet below existing grade. Costs and information from these two borings were shared with the Lower Mississippi River Watershed Management Organization, which commissioned the Cherokee Heights study.

Soil samples in the hollow-stem auger portion of the borings were obtained by split-barrel sampling procedures in general accordance with American Society for Testing and Materials (ASTM) D1586, "Standard Test Method for Standard Penetration Test (SPT) and Split Barrel Sampling of Soils." Shelby tube samples were also obtained for laboratory testing. The bedrock was cored with a double tube-type barrel using wireline coring methods. The soil borings were completed by NTI, American Engineering and Testing (AET), and Glacial Ridge Drilling.

The boring log information includes materials encountered, penetration resistances, test results, and pertinent field observations made during the drilling operations. All soil samples were classified in general accordance with the Unified Soil Classification System. The boring logs for both the NTI and Barr investigations have been included in Attachment B of this Appendix.

Samples were transported to Soil Engineering Testing (SET) of Richfield, Minnesota, for laboratory testing. The soil samples obtained from split-spoon sampling were sealed in plastic bags or jars in the field to allow for easy transport and to retain natural moisture content. Shelby tube samples were sealed and placed in a protective shipping container for transport to the laboratory. Results are included in Attachment C.

2.2 Laboratory Testing

The following tests were performed by SET on soil samples collected during the NTI and Barr investigations:

- Moisture content tests in accordance with ASTM D2216, "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass," including dry density measurements
- Grain-size analyses in accordance with ASTM D422, "Standard Test Method for Particle-Size Analysis of Soils"
- Percent fines (silt and clay) in accordance with ASTM D1140-00, "Standard Test Method for Amount of Material in Soils Finer Than the No. 200 Sieve"
- Atterberg limits tests in accordance with ASTM D4318, "Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils"
- Unconfined compressive strength of soil in accordance with ASTM D2166, "Standard Test Method for Unconfined Compressive Strength of Cohesive Soil"
- Triaxial compressive strength in accordance with ASTM D2850-03a, "Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils"
- Friction angle of soil determinations in accordance with ASTM D3080, "Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions"
- Unconfined compressive strength of soil in accordance with ASTM D7012, "Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature"
- Unit weight tests in accordance with ASTM D7263 "Standard Test Method for Laboratory Determination of Density (Unit Weight) of Soil Specimens"
- Falling head permeability testing on clay to clayey sand samples in accordance with ASTM D-5084, "Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter"
- Visual soil classification in accordance with ASTM D2488, "Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)"
- Fully softened strength in accordance with ASTM D6467, "Standard Test Method for Torsional Ring Shear Test to Determine Drained Residual Strength of Cohesive Soils"

Laboratory test results are provided in Attachment C and summarized in Table 3-2.

2.3 Site Inspections

Barr and City personnel performed a review of site conditions on May 15, 2014. The visit focused on the Cherokee Heights Culvert and Cherokee Heights Ravine; the East, Middle, and West Clay Pits; the 2013 slide area; the Brickyard Trail from the bluff down to the old brick ovens (Brickyard Trail–Connector Section and Brickyard Trail–Fossil/Brick Oven Section); the upper bluff trail (Brickyard Access Trail–Bluff Section and Brickyard Access Trail–Bruce Vento Spur); and the Bruce Vento Overlook.

Barr and City personnel visited the site again on July 2, 2014, to evaluate changes in conditions following a significant, prolonged period of rainfall. The main focus of this trip was a large slide toward the north end of the park, a sinkhole which had developed near Annapolis Boulevard, and additional slides (with material loss) along the trail between the Middle and West Clay Pits.

The observations made during each visit, as well as the analysis and conclusions based on these visits, are detailed in the Main Report. Photographs are provided in Attachment D and in the Main Report.

3.0 Investigation Results

A description of the field investigation and material-testing procedures has been provided in Section 2.0. Section 3.0 presents the results of the investigation and testing.

3.1 Stratigraphy

The stratigraphy of the site generally consists of variable thicknesses of primarily sandy, glacially derived soils overlying primarily shale—followed by sandstone bedrock, as described in Section 1.3. Occasional clay seams and interbedded limestone layers were also encountered, as seen in the photographs of the clay pit walls.

Although additional borings and investigation would aid in developing a more detailed stratigraphy, the sections of this Appendix provide a generalized summary of the soils found in site borings, beginning at the surface and generally proceeding downward.

3.1.1 Surficial Topsoil

Topsoil was found in each of the borings, extending to depths of about 12 inches below ground surface.

3.1.2 Upper Silty Sand to Clayey Sand

In all of the borings the upper soils generally comprised silty sand to clayey sand soils extending to the top of the shale bedrock at depths ranging from 45.5 to 82 feet below ground surface.

Standard penetration test (SPT) N values in the silty to clayey sand soils ranged from 14 to 67, with a typical range of 15 to 25 blows per foot. In boring SB-3-14 there was an SPT N value of 1 blow per foot at a depth of 52 feet. This was a locally saturated soil layer. The SPT N values indicate most of the surficial materials are in a medium-dense to dense condition.

Moisture contents of the upper silty to clayey sand soils ranged from about 6.3 to 13.7 percent. Dry unit weights ranged from 104.7 to 130.5 pounds per cubic foot (pcf). In situ (moist) unit weights calculated from the dry density test results and corresponding moisture contents ranged from about 119.0 to 143.1 pcf. Grain-size tests indicated the upper clayey sand soils had 30.8 to 38.5 percent fines (silt and clay).

Friction angles derived from laboratory direct shear testing ranged from 31.3 to 32.7 degrees for the silty sand soils and from 33.2 to 33.4 for the clayey sand soils.

3.1.3 Lean Clay to Clayey Silt

Some of the glacially derived soils were also classified as brown-to-gray, very lean clay soils or clayey silt soils interbedded with the upper silty to clayey sand soils.

SPT N values for the surficial lean clay to clayey silt materials had a range of 3 to 71 blows per foot, with typical values ranging from 8 to 35.

The moisture content of the lean clay/silt soils ranged from about 5.2 to 26.7 percent, with a typical range of 12 to 25 percent. Dry unit weights ranged from 98.1 to 127.4 pcf. In situ (moist) unit weights calculated from the dry density test results and corresponding moisture contents ranged from about 122.9 to 142 pcf.

Atterberg limit test results on the clay and silt soils showed liquid limits ranging from about 22 to 43.5 percent, plastic limits ranging from about 10 to 20 percent, and a plasticity index ranging from about 4.6 to 29.5 percent. According to the USCS classification system (Reference (8)) these soils plot as CL (lean clay soils) or CL-ML (clayey silt soils).

Laboratory unconfined compressive strength and unconsolidated undrained (UU) triaxial test results ranged from 0.65 (shallow) to 5.33 tons per square foot (tsf), with most of the values ranging from about 1 to 2.2 tsf. Unconfined compressive strengths from field pocket penetrometer testing generally ranged from 0.5 to 2.5 tsf, with typical values ranging from 1 to 2.75 tsf. The range of unconfined compressive strengths between the laboratory and pocket penetrometer testing agreed fairly well.

3.1.4 Poorly Graded Sand Soils

Intermittent layers of poorly graded (lower fines content) sand soils were found interbedded with the upper silty to clayey sand soils. Most of these layers were relatively thin (on the order of a few feet thick or less).

SPT N values in the cleaner sand soils ranged from 10 to 49, with a typical range of 15 to 34 blows per foot. The SPT N values indicate that most of the surficial materials are in a medium-dense to dense condition, similar to the silty to clayey sand soils.

Moisture in the sand soils with lower fines content ranged from about 1.3 to 16.6 percent. Dry unit weights ranged from 97.8 to 118.3 pcf. In situ (moist) unit weights calculated from the dry density test results and corresponding moisture contents ranged from about 102.3 to 132.7 pcf. Grain-size tests indicated the upper silty sand soils had 8.2 to 22.5 percent fines (silt and clay).

Friction angles derived from laboratory direct shear testing ranged from 28.5 to 33.7 degrees.

3.1.5 Shale Bedrock

Shale bedrock was encountered in all of the borings completed by Barr below the glacial soils at depths ranging from 45.5 to 82 feet below grade. Shale bedrock was also encountered at a depth of 60 feet in the NTI boring. The shale bedrock was generally field-classified as greenish-gray, thinly bedded/laminated softer shale with limestone interbeds. Bedding planes observed in the cores appeared to be roughly horizontal. A limestone layer capping the shale was encountered at only one location (SB-2-14) drilled adjacent to the picnic area parking lot. There was no limestone cap at the top of the shale bedrock at the other boring locations.

Diamond-bit rock coring was done at the two boring locations near the edge of the bluff to better evaluate the shale; recovery percent and rock quality designation (RQD) were recorded in the field. The samples were placed in boxes specifically designed to store rock cores and sent to the laboratory for further analysis. There were a few more weathered/clayey layers encountered during drilling, but most of the shale was recovered as intact rock.

Percent recover for the rock cores generally ranged from about 58 to 100 percent. RQD values ranged from 33 to 100 percent, with typical values of 60 to 85 percent. There were a few more clayey layers encountered during drilling, but even some of these remained intact in the core barrel.

Standard penetration test (SPT) N values in the shale for borings STP B-1 and STP B-2, where rock coring was not performed, ranged from 101 blows per foot to 100 blows for only 2 to 3 inches of split-spoon penetration (considered split-spoon refusal).

Moisture contents of the shale ranged from about 6.5 to 19 percent. Dry unit weights ranged from about 119 to 140 pcf. In situ (moist) unit weights calculated from the dry density and corresponding moisture content test results ranged from about 135 to 149 pcf.

One sample of the thin limestone layers was also tested. This had a moisture content of 2.1 percent, a dry density of 156.8 pcf, and a moist density of 160 pcf.

Atterberg limit test results for a zone of the more weathered/clayey shale showed a liquid limit of 54 percent, a plastic limit of 21.8 percent, and a plasticity index of 32.2 percent. According to the USCS classification system (Reference (8)), these materials plot near the transition between CH (fat clay) and CL (lean clay).

Laboratory unconfined compressive strength test results on the shale ranged from 4.9 tsf to 21.8 tsf. The lower end of this range is representative of the more weathered/clayey shale layers (and a strength value similar to very stiff soils). The upper end of the range is more representative of intact soft rock.

One test was also performed on a sample of the limestone interbed layers. Test results indicated an unconfined compressive strength of 210.6 pounds per square foot (psf), which corresponds to strong rock.

3.2 Groundwater Conditions

Groundwater was encountered in all of the soil borings directly above the top of the bedrock. In borings performed near the East and Middle Clay Pits, there were several upper soil layers that were saturated. However, there were soils below these layers that did not exhibit elevated moisture content; thus, the upper readings recorded during drilling indicated "perched" water, likely flowing through more permeable soils, as opposed to a solid water table down to bedrock.

Seepage was observed weeping from many of the site slopes at the soil/bedrock interface, but not usually seen higher in the slopes. Therefore, the groundwater was assumed to be generally located at the soil/bedrock interface at most times of the year. Seepage was specifically noted near the top of the bedrock in the Middle Clay Pit and the rock face in the North Ravine near the North Knob.

Groundwater levels recorded during and upon completion of drilling and the depth to bedrock are provided in Table 3-1.

Table 3-1 Summary of groundwater levels from soil borings

Boring ID	Phase of Drilling	Groundwater Depths from Soil Borings: Depth While Drilling (feet)	Groundwater Depths from Soil Borings: Depth upon Completion (feet)	Depth to Bedrock
SB1	NTI	58	Note 1	60
SB2-14	Barr	65	Note 1	68
SB-3-14	Barr	44–45 50–53 70–81.5	Note 1	81.5
STP B-1	Barr*	21.5–38 63.5–67	Not encountered above cave depth	67
STP B-2	Barr*	Intermittent, 15–45.5 feet	Not encountered above cave depth	45.5 (weathered) 50 (intact)

* Borings performed for the adjacent *Cherokee Heights Culvert Analysis and Erosion Control Feasibility Study* commissioned by the Lower Mississippi River Watershed Management Organization.

Note 1—Due to the addition of drilling fluid, groundwater readings could not be obtained upon completion of drilling.

At three boring locations drilling fluid was added to the boreholes to facilitate rock coring. The addition of this fluid prevented an accurate measurement of groundwater levels when drilling was completed.

At the face of the bluff, water seepage is typically seen very close to the bedrock interface (wet areas, dripping soils, ice formations observed in pictures). Groundwater seepage over bedrock was seen in the North Ravine near the North Knob and in the Middle Clay Pit. Water leaving the Cherokee Heights Ravine and forming the East Clay Pit Falls also flows directly on bedrock.

Groundwater levels at the site will tend to vary over time in response to rainfall events, seasonal fluctuations, and local conditions. Water levels will likely be higher during times of more frequent or intense precipitation. Additional groundwater monitoring during different times of the year or following heavy precipitation events would need to be performed to gain a better understanding of the groundwater levels at the site.

3.3 Moisture Content, Plasticity, Grain Size, and Unit Weight

Moisture content, Atterberg limit, grain-size analysis, and unit-weight testing were performed on multiple soil samples from the investigation locations. NTI performed testing on soil samples collected as part of their investigation. Testing of soil samples for this investigation was performed by SET. The laboratory test results are summarized in Table C-1 and provided in Attachment C.

The results of the laboratory testing were used to determine the soil parameters for seepage modeling, stability modeling, and the analysis described in the following sections of this Appendix.

3.4 Soil Parameter Determinations

The soil parameters used for seepage and stability modeling were determined by laboratory testing. Laboratory testing is provided in Attachment C. The following sections of this Appendix discuss the soil strengths in terms of unit weight, friction angle (for granular soils), rock strength, and unsaturated soil suction values.

3.4.1 Dry Density and In Situ Unit Weight

A total of 24 dry density tests were performed on split-spoon samples, Shelby tube samples, and rock cores. Moist (in situ) unit weights were calculated from the dry density test results and the corresponding moisture contents. Generally, the cleaner, poorly graded sand had the lowest unit weights, followed by the silty to clayey sands and lean clays; shale and limestone bedrock had higher unit weights. Unit weight values for each predominant soil type are provided in Table 3-2.

Table 3-2 Summary of unit weights by soil type from laboratory testing

Soil Type	Approximate Range of Dry Unit Weights (pcf)	Approximate Range of Moist Unit Weights (pcf)	Selected Moist Unit Weights* (pcf)	Assumed Saturated Unit Weight** (pcf)
Poorly graded (clean) sand	98–118	102–132.5	109	119
Clayey/Silty sand	105–130.5	119–143	137	147
Lean clay	98–127.5	123–142	133	143
Shale (weathered)	119–140	135–149	130	140

* Low average unit weight values were selected for slope-stability modeling.

** Saturated unit weights for modeling were selected based on laboratory moisture contents, moist unit weights, and engineering judgment

The overall average in situ (moist) unit weight result for all of the project tests is approximately 137.7 pcf.

Test results for the individual soil strata are discussed in Section 3.1. Unit weight test and lab test results are provided in Attachment C.

3.4.2 Drained Friction Angle Determination

Direct shear testing was performed in the laboratory on five samples collected by Barr to evaluate the friction angle of these materials for foundation design. One direct shear test on the silty sand soils was also performed by NTI, showing a friction angle of 35.2 degrees. The friction angle values for each soil type are provided in Table 3-3.

Table 3-3 Summary of friction angle values from laboratory testing

Soil Type	Range of Measured or Calculated Friction Angle Values Lab Testing (degrees)	Selected Design Friction Angle Parameter (degrees)
Poorly graded (clean) sand	28.5–33.7	29
Clayey/Silty sand	33.2–35.2	33
Lean clay	31.3	30

The design values recommended for each soil type are provided in Table 3-3.

3.4.3 Undrained Shear Strength Determination

The undrained shear strength values were derived from unconfined compressive strength testing on Shelby tube samples from the borings and rock cores. Undrained shear strength values are considered to be half of the unconfined compressive strength of cohesive soils. For the soil profile at the site, only the highly weathered shale can be considered a cohesive soil.

The undrained shear strengths for the clay soil types are provided in Table 3-4:

Table 3-4 Summary of undrained soil strength of fine-grained soils from laboratory testing

Soil Type	Range of Unconfined Compressive Strengths	Range of Undrained Shear Strengths	Recommended Undrained Shear Strength Design Value
Weathered Shale	4.9 to 21.8 tsf	4,900 to 21,800 psf	4,900 psf

* Undrained shear strengths are considered to be half of the laboratory unconfined compressive strength of soils

The recommended design value is the minimum test result value for the weathered shale, and is on the order of strength for a very stiff cohesive soil.

3.4.4 Rock Strength

Rock coring and laboratory unconfined compressive strength testing were performed as part of Barr's investigation. Compressive strengths on the shale ranged from 4.9 tsf to 21.8 tsf. The unconfined compressive strength on the limestone was about 210 tsf—much higher than the strength of the shale. However, since the majority of the soil profile is weathered shale, the lower bound strength of 4,900 psf was used to model the entire bedrock layer for the project.

Torsional ring shear testing was performed as part of the NTI investigation to determine the fully softened and residual friction angles of the shale. The shale was assigned an undrained fully softened friction angle of 26 degrees (peak) with cohesion of over 600 psf. The residual friction angle of the shale was determined to be 16 degrees with cohesion of over 500 psf.

3.4.5 Soil Suction

3.4.5.1 Soil Water Characteristic Curve

The saturated-unsaturated soil properties take the form of non-linear functions estimated from measured water content versus soil suction relationships (i.e., soil-water characteristic curves [SWCC]). The SWCC shows the relationship between the amount of water in a soil and the suction developed within the pore space of the soil. As a function of moisture content (i.e., saturation level), the soil-water retention curve indicates how strongly water is held between soil particles—and how difficult it is to push water out of the pore spaces in the soil.

The SWCC of two soils typically found onsite (i.e., clayey sand and silty sand) were measured using the HyProp device, manufactured by Decagon Devices in Pullman, Washington. The HyProp device is capable of measuring suction within the capillary regime (saturation to approximately 2000 psf) using two tensiometers. The evaporation method and the readings from these two tensiometers are used to develop the SWCC. In HyProp testing, the soil specimen is placed on a cell which is closed at the bottom and opens at the top; suction is measured as pore water evaporates from the top of the specimen and moisture content is calculated from the measured overall changes in sample weight. The HyProp device uses evaporation to develop the SWCC with the following three important assumptions:

1. Moisture content and water tension distribution is linear in the sample. The specimen is wettest at the bottom and driest at the top.
2. Water flow is mostly vertical. Horizontal water movement is not significant.
3. Water tension and specimen weight changes are linear between calculation/evaluation points.

The measured initial density and saturated volumetric water content for the two samples tested were verified, with index testing completed by an independent laboratory.

3.5 Permeability

Saturated hydraulic conductivity testing was performed on intact Shelby tube samples to evaluate the permeability of the in situ soils. The samples were extruded into the testing apparatus in in-situ condition (i.e., they were not remolded for testing). The hydraulic conductivity of each material is provided in Table 3-5.

Table 3-5 Summary of soils permeability from laboratory testing

Soil Type	Saturated Permeability Values from Lab Testing (cm/sec)	Design Saturated Permeability Values (ft/sec)
Poorly graded (clean) sand	1.6×10^{-4}	5.2×10^{-6}
Clayey/Silty sand	2.0×10^{-6}	6.6×10^{-8}
Lean clay	2.8×10^{-7}	9.2×10^{-9}
Shale	--	3.3×10^{-10}

3.5.1 Slaking Durability and Softening

Slaking potential is a measure of the soil's ability to soften with prolonged wetting/drying cycles. Slaking is a common slope-stability problem with shale bedrock, particularly in clayey shales. Slaking can be significant (particularly in arid to semi-arid regions) and can jeopardize the stability of rock canyon walls (Reference (9)).

Based on a review of the project site, there appears to be some slaking along the faces of the clay pit walls, evidenced by the talus piles of weathered rock materials along the toe of the steep slopes. However, the rate of slaking does not appear sufficient to cause routine, large-scale slides.

The effects of slaking or just softening of the shale materials into weaker clays may be more prevalent where the waterfalls provide a constant source of moisture to the rock faces. Therefore, caution should be used immediately below the site's waterfalls, and plunge pools should be protected to minimize undercutting at the base of the falls.

4.0 Analysis Results

Results of the field and laboratory investigations have been presented in Section 3.0. Section 4.0 provides modeling results and analysis of slope stability based on these investigations.

4.1 Design Parameters

4.1.1 Slope Geometry

Geometry of the soil slopes was obtained from cross sections primarily derived from LiDAR (Minnesota DNR LiDAR Elevation Data Set 2011) and supplemented by Barr site survey to identify boring locations and other site features of interest. Modeling was focused on the primary soil slopes above the clay pit walls at the site. For the Waterfall and Cherokee Ravine cross sections, the secondary (and typically shallower) slopes in the cut east of the North Knob were also modeled.

4.1.2 Soil Stratigraphy

Soil stratigraphy was identified by the borings completed by NTI and Barr. As discussed in Section 3.1, the stratigraphy of the site generally consists of a variable thickness of primarily sandy, glacially derived soils overlying primarily shale, followed by sandstone bedrock.

Borings and site surveys were limited in some areas due to safety or accessibility issues. As such, for the seepage and stability modeling, it was assumed that the soil and bedrock layers were essentially flat to moderately sloping.

Also, because drilling planned adjacent to the West Clay Pit could not be performed, it was assumed that the soil stratigraphy in this area was the same as the Middle Clay Pit (the closest boring to the West Clay Pit).

4.1.3 Soil Parameters

Results of the laboratory testing, discussed in Section 3.0, were used to determine the soil parameters used for seepage and stability modeling. These are summarized in Table 4-1.

Table 4-1 Summary of material properties for stability modeling

Material Description	Material Property	Soil Parameter Values
Poorly graded (clean) sand soils	Saturated permeability	5.2×10^{-6} ft/sec
	Drained friction angle	29 degrees
	Cohesion	0 psf
	Moist unit weight	109 pcf
	Saturated unit weight	119 pcf
Clayey to silty sand soils	Saturated permeability	6.6×10^{-8} ft/sec
	Drained friction angle	33 degrees
	Cohesion	0 psf
	Moist unit weight	137 pcf
	Saturated unit weight	147 pcf
Lean clay	Saturated permeability	9.2×10^{-9} ft/sec
	Drained friction angle	30 degrees
	Cohesion	0 psf
	Moist unit weight	133 pcf
	Saturated unit weight	143 pcf
Weathered shale bedrock	Saturated permeability	3.3×10^{-10} ft/sec
	Drained friction angle	0
	Cohesion (inherent strength)	4,900 psf
	Moist unit weight	120 pcf
	Saturated unit weight	130 pcf

psf = pounds per square foot
pcf = pounds per cubic foot

4.2 Groundwater and Rainfall for Modeling

4.2.1 Typical Groundwater Elevations

Seepage was observed weeping from many of the site slopes at the soil/bedrock interface but not, generally, higher in the slopes. Therefore, the groundwater was assumed to be located at the soil/bedrock interface at most times of the year.

4.2.2 Elevated Groundwater Elevations

At the time of this report, Barr was not aware of any monitoring wells in the vicinity of the project area. Therefore, Barr did not consider it feasible to gain a significant understanding of seasonal fluctuations in groundwater or elevated groundwater elevations following storm events.

To determine the effects of groundwater levels on slope stability (with suction forces), the groundwater level used in the model was raised from the expected level near the bedrock interface to a level associated with a factor of safety of 1.0.

4.2.3 Rainfall

To evaluate the effect of rainfall, Barr reviewed rainfall records between the May and July site visits when additional slope failures were noted (Reference (10)). Based on the records reviewed, the highest rainfall amount in a 24-hour period was 3.17 inches. Based on NOAA's Atlas 14 rainfall information (Reference (11)), that rainfall amount was essentially the equivalent of the 5-year 24-hour storm (3.5 inches in a 24-hour period).

A transient model with rainfall applied for a period of 24 hours (in the form of a unit flux boundary condition placed along the ground surface) was used to evaluate the effect of infiltration on slope stability (again using the previous model with soil suction). A unit flux of 3.38×10^{-6} ft/sec was applied.

Once the design rainfall is established, the amount of infiltration needs to be determined. Some portion of the water will infiltrate the pore spaces of the soil and increase its moisture content, while the rest will run along the ground surface (i.e., runoff). The amount of infiltration can be difficult to determine because it depends on the moisture content of the soils at the time of the rainfall (defined by the soil-water characteristic curve described in Section 3.4.5). Soils with very low moisture content have very low permeability; most precipitation on this soil will run off the slopes. (This is why flash flooding occurs in desert environments with low soil moisture). Conversely, soils with higher moisture content have a higher permeability and allow more of the precipitation to infiltrate. Therefore, storm events of the same magnitude and duration can produce significantly different amounts of runoff and infiltration depending on the soil's moisture content at the time of the storm.

Due to the uncertainty of the site conditions, the amount of infiltration from the 5-year 24-hour storm event was evaluated in two ways: (1) using the soil-water characteristic curve to estimate permeability from modeled conditions or (2) assuming that no runoff was experienced and all precipitation infiltrated the soils.

4.3 Slope-Stability Analysis

4.3.1 Embankment-Stability Analysis

SLOPE/W and SEEP/W software, part of the GeoStudio 2012 suite of programs, was used to evaluate the influence of existing topography, soil strength, and effects of seepage and saturation on the stability of the slopes within the Brickyard Area.

Spencer's method was used for the analysis and considers both force and moment equilibrium in the analysis. The potential slip surfaces were evaluated using the entry and exit method to locate the practical minimum slope-stability factor of safety associated with failures extending through the overburden soils or upper portion of the bedrock

The factor of safety of a slope is defined as the ratio of the resisting forces in the soil to the driving or mobilized forces that cause slope movement. Therefore, the point of stability is considered a factor of safety of 1.0 (driving forces equal to resisting forces). Slopes with a factor of safety less than 1.0 are considered to be unstable and would fail; slopes with a factor of safety higher than 1.0 are considered stable (or marginally stable as the safety factor approaches or hovers close to 1.0).

Natural soil slopes which are stable or marginally stable usually have minimum calculated factors of safety of 1.1 to 1.3. These factors of safety are representative of typical "sunny day" conditions, but may be reduced or even drop below 1.0 in the presence of excess moisture from rainfall, changes in groundwater elevations, etc. Therefore, to determine the potential for slope failure, the factor of safety should be considered for a range of anticipated conditions. Analyses of several different sets of conditions within the study area were performed to determine the potential for slope failure along the bluff line.

For a point of reference, Federal Energy Regulation Commission guidelines for high-hazard earth dams require slopes with a factor of safety of 1.5 or greater. U.S. Army Corps of Engineers' levee guidelines recommend factors of safety ranging from 1.3 to 1.5, depending on how long the slope remains in a certain configuration (i.e., a lower factor of safety is required for temporary construction slopes than for permanent embankments). Thus, the minimum acceptable safety factors of an "engineered" slope are often greater than the minimum safety factors observed for natural slopes.

4.3.2 Stability Analyses

For long-term stability analysis, a drained condition is used. This involves using the drained friction angles of sands (sometime thought of as the soil's angle of repose, or the angle that dry grains of soil will pile up to). If the angle of the slope exceeds the soil's friction angle, this style of stability analysis will indicate that the slope is unstable. In the case of the upper soil slopes at the site, the natural ground surface slope exceeds the drained friction angle. If soil strength was dictated solely by the drained friction angle, the soil could not maintain these slopes —but the site slopes remain standing. This means the soils must have additional strength beyond their angle of friction, and this style of analysis is not fully representative of the conditions observed at the site.

Barr performed several types of analyses to evaluate stability of the slopes under an anticipated range of conditions. Because there was limited information regarding the variability of groundwater levels at the site, some assumptions were made for the modeling performed. To design any slope-stabilizing methods, as discussed in Section 5.0, additional explorations would be recommended.

4.3.2.1 Drained Friction Angle

Modeling of the upper sand slopes using only the drained friction angles for the sand and an inherent soil strength (modeled as cohesion) for the weathered shale was performed to evaluate stability of the slopes without the effects of any apparent cohesion. The factors of safety of the existing slopes are significantly less than 1.0 (stability) and all failure surfaces are located within the upper natural soil portion of the slope (i.e., the failure surfaces do not extend through the shale bedrock).

Table 4-2 Summary of stability results for drained friction angle (phi) only

Analyzed Cross Section	Type of Failure Surface	Minimum Factor of Safety Figure	Minimum Factor of Safety	Stability (FS=1.0) Factor of Safety Figure
North end	Entry/Exit (circular surface)	E-1	0.75	E-2
Waterfall (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-7	0.66	E-8
Waterfall (Slope 2–back surface)	Entry/Exit (circular surface)	E-13	0.83	E-14
Cherokee Heights Ravine (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-18	0.70	E-19
Cherokee Heights Ravine (Slope 2–back surface)	Entry/Exit (circular surface)	E-29	1.34	--
Middle Clay Pit	Entry/Exit (circular surface)	E-37	0.68	E-38
West Clay Pit	Entry/Exit (circular surface)	E-43	0.58	E-44

4.3.2.2 Peak and Residual Friction Angles for the Shale

In lieu of using inherent strength (modeled as cohesion) for the shale bedrock, Barr also used peak and residual soil strengths from the strength parameters provided in the NTI report. These were determined by torsional ring shear testing. Using these strengths for the shale, the minimum factors of safety were identical to those provided above (since these are governed by the soils, not the rock). However, the failure surfaces corresponding to a factor of safety of 1.0 extend well down into the shale bedrock, which does not correspond to the failure surfaces observed at the site. Therefore, the peak and residual friction angles for the shale have not been used in subsequent modeling for the project.

4.3.2.3 Suction

As previously discussed, a review of the topography at the site indicates that the angle of the slopes exceeds the drained friction angle of the soils. If the strength of the soils was governed only by the drained friction angles, the slopes would be unstable and fail. To allow for steep slopes to remain standing, the soils must have additional strength beyond their angle of friction. The soil mechanism allowing this is called soil suction. Soil suction is formed by drying or dewatering the soils, which creates a negative pore pressure in the soil's pore spaces and increases the strength of the soil matrix (or provides an apparent cohesion in the soil in excess of its drained friction angle).

The phenomena of soil suction can be illustrated by thinking of a common sand castle at the beach. Dry sand will only form a conical pile to a certain angle (the material's drained friction angle). However, sand with moderate water content will allow for much steeper angles to be achieved. Then, as the castle sits in the sun and dries, the sides of the castle become unstable and slough off. Or, as the tide comes in and the sand at the base of the castle becomes saturated, the sides of the castle slough and collapse. By drying or saturating the soils, the suction force is negated; the soil strengths will be governed by their friction angle and failures will occur.

Since the suction forces are considered critical to understanding the stability of the soil slopes on the site, Barr performed laboratory testing to evaluate the soil suction in the unsaturated portion of the clayey sand and silty sand soils, as discussed in Section 3.4.5. Soil suction for the cleaner sands and clay soils, which will provide a lesser amount of soil suction than the silty and clayey sand soils, was determined using index property testing and typical soil-suction functions contained in the GeoStudio software package.

Modeling of the existing slopes, including suction forces predicted by the physical index characteristics of the clay soils, produces a factor of safety ranging from about 1.1 to 1.4, as summarized in Table 4-3. However, when the soils are re-saturated the suction force is negated; the soil strengths will be reduced and slope failures will occur.

Table 4-3 Summary of stability results for drained friction angle with suction

Analyzed Cross Section	Type of Failure Surface	Figure	Minimum Factor of Safety
North end	Entry/Exit (circular surface)	E-3	1.40
Waterfall (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-9	1.18
Waterfall (Slope 2–back surface)	Entry/Exit (circular surface)	E-15	2.34
Cherokee Heights Ravine (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-20	1.53
Cherokee Heights Ravine (Slope 2–back surface)	Entry/Exit (circular surface)	E-30	1.53
Middle Clay Pit	Entry/Exit (circular surface)	E-39	1.22
West Clay Pit	Entry/Exit (circular surface)	E-45	1.11

4.3.2.4 Block Failure Surfaces

For soil profiles consisting of soil over bedrock, a block-failure surface is typically evaluated. Barr performed block-style failure analyses by setting the bedrock as “impenetrable” in the model and determining the factors of safety for the slopes. However, even incorporating soil suction into the model for the upper-sand soils, the results of the modeling showed factors of safety of about 1.0 or less than 1.0 for block failures at the modeled cross sections.

This indicates that the slopes should not be stable even under sunny-day conditions, which is not the case. Also, the top of the block-failure surfaces, as predicted by the modeling, develop far from the edge of the bluff. This was also not typically observed at the site. This may be due to the fact that the upper surface of the bedrock is weathered and acts more as stiff clay, making the contrast between soil and bedrock characteristics less sharp.

Therefore, the circular failure surfaces for soils, incorporating suction forces and sunny-day factors of safety ranging from 1.1 to 1.3, will be used for subsequent analysis. It is possible that smaller-scale block failures may occur at the site; but, at this time, the modeling is not predicting stable slopes or failure surfaces in agreement with Barr's site observations. If additional investigations, analyses, and modeling produce results that better match observed conditions, block-style analysis may be considered for final design of soil-stabilization methods.

4.3.2.5 Saturation and Loss of Stability Due to Rainfall

To determine the effects of rainfall (i.e., saturation of the soils resulting in loss of suction) a unit flux line located at the ground surface in each of the cross sections was used to model the effects of groundwater infiltration. The modeling conservatively assumed full infiltration of 3.5 inches of steady precipitation over a 24-hour period. The modeling also assumed both low and high soil permeability. Lower soil permeability is associated with unsaturated conditions (low moisture content). Very little infiltration occurs in unsaturated soils, which is why flash flooding occurs in desert environments. Higher soil permeability essentially allows the full amount of precipitation to infiltrate the soil.

Modeling results using lower permeability (low infiltration), indicated that a single rainfall event of this magnitude on moderately saturated soils is not, by itself, likely to significantly reduce the stability of the slopes. However, when higher amounts of infiltration are considered, the factors of safety are reduced below stability. This indicates that if soil conditions allow for infiltration of some precipitation, the strength of the natural sand soils is reduced from loss of suction and could result in slope failures.

Table 4-4 Summary of stability results for infiltration of 3.5 inches of water in 24 hours

Analyzed Cross Section	Type of Failure Surface	Figure	Phi Angle Only Factor of Safety	Figure	Phi Angle and Suction Factor of Safety
North end	Entry/Exit (circular surface)	E-4	0.75	E-5	1.29
Waterfall (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-10	0.59	E-11	0.78
Waterfall (Slope 2–back surface)	Entry/Exit (circular surface)	E-16	0.83	E-17	1.91
Cherokee Heights Ravine (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-21	0.70	E-22	1.11
Cherokee Heights Ravine (Slope 2–back surface)	Entry/Exit (circular surface)	E-31	1.48	E-32	2.33
Middle Clay Pit	Entry/Exit (circular surface)	E-40	0.68	E-41	0.92
West Clay Pit	Entry/Exit (circular surface)	E-46	0.58	E-47	0.73

Modeling indicates that the stability of the slopes is not changed much using soil strengths without suction forces, but the factors of safety are reduced below stability for the soil slopes incorporating suction forces. This indicates that if conditions allow for infiltration of some precipitation, the strength of the natural sand soils is reduced from loss of suction, possibly resulting in slope failures.

4.3.2.6 Saturation and Loss of Stability from Elevated Water Table

Loss of suction can also be realized through elevation of the groundwater table following periods of intense rainfall on or upstream of a site within the watershed.

To evaluate the potential for reduction of stability due to loss of suction forces, the groundwater level in the model was incrementally raised (with an upstream boundary condition) until the minimum predicted factor of safety for the slope was 1.0. The required increases in water table to reduce the factors of safety to 1.0 are summarized in Table 4-5.

The increase in groundwater level modeled to reach a factor of safety of 1.0 was on the order of a few to several feet. Due to the configuration of the slopes, the secondary slopes (Slope 2) for the Waterfall and Cherokee Heights Ravine cross sections were not analyzed for a high groundwater condition.

Table 4-5 Summary of stability results for elevated groundwater levels

Analyzed Cross Section	Type of Failure Surface	Figure	Elevation of Water Table to Reduce Factor of Safety to 1.0
North End	Entry/Exit (circular surface)	E-6	921.5
Waterfall (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-12	855
Cherokee Heights Ravine (Slope 1–bluff surface)	Entry/Exit (circular surface)	E-23	918
Middle Clay Pit	Entry/Exit (circular surface)	E-42	910.5
West Clay Pit	Entry/Exit (circular surface)	E-48	901

It is understood that options for detaining stormwater upstream of the project are being considered within Cherokee Heights Park. Because the ravine on the other side of Cherokee Heights Boulevard, leading into the 60-inch culvert in Cherokee Heights Ravine, is the closest option for stormwater detention it was selected for modeling. Given that the pond will not likely be designed to hold water for long periods of time, it was conservatively assumed that the water surface was near the pond bottom (unless associated with a storm event).

4.3.2.7 Saturation and Loss of Stability from Ponding

Loss of suction due to higher groundwater table can also result from ponding upstream of the bluffs. This ponding may reduce the strength of the soil due to increases in moisture content from infiltration of the pond water. The degree of saturation and suction loss will depend on the duration of ponding. For stability modeling, it was assumed that groundwater was near the pond bottom at most times and the pond was full during rain events.

Results of the stability analysis with ponding are provided on Figures E-24 through E-28, E-33 through E-36, and summarized in Table 4-6.

Table 4-6 Summary of stability results for ponding upstream of Cherokee Heights Ravine

Analyzed Cross Section	Sunny Day		Infiltration of 3.5 Inches of Water in 24 Hours	
	Factors of Safety		Factors of Safety	
	No Suction	With Suction	No Suction	With Suction
Cherokee Heights Slope 1, ponding	0.53	0.62	0.45	0.50
Cherokee Heights Slope 2, ponding	1.48	2.30	1.48	2.01

4.4 Summary of Stability Analyses

4.4.1 Predicted Slope-Stability Factors of Safety

The modeling results for selected cases are summarized in Table 4-7. As illustrated, the natural soil slopes require suction forces to stand at their existing slope angles. Infiltration from rain events, infiltration from ponding upstream of the slopes, or a raised phreatic surface will all reduce the effects of suction and reduce slope stability.

Table 4-7 Predicted slope-stability factors of safety

Analyzed Cross Section	Sunny Day Factors of Safety[1] No Suction	Sunny Day Factors of Safety[1] With Suction	Infiltration of 3.5 Inches of Water in 24 hours Factors of Safety[1] No Suction	Infiltration of 3.5 Inches of Water in 24 hours Factors of Safety[1] With Suction	Water Table Elevation to Reduce FOS to 1.0[3] (elevation in feet)
North End	0.75	1.40	0.75	1.29	921.5
Waterfall Landslide Slope 1	0.66	1.18	0.59	0.78	855
Waterfall Landslide Slope 2	0.83	2.34	0.83	1.91	--
Cherokee Heights Slope 1	0.70	1.53	0.70	1.11	918
Cherokee Heights Slope 1, ponding	0.70	1.03	0.47	0.52	--
Cherokee Heights Slope 2	1.34	1.53	1.48	2.33	--
Cherokee Heights Slope 2, ponding	1.34	1.53	1.48	2.01	--
Middle Clay Pit	0.68	1.22	0.68	0.92	910.5
West Clay Pit[2]	0.58	1.11	0.58	0.73	901

1 Factors of safety (FOS) are based on limited boring/subsurface investigations (May and June 2014) and the assumption that the soil borings referenced in this Appendix are representative of the identified locations.

2 The boring in the area of the West Clay Pit was not obtained due to access issues; soil conditions in the West Clay Pit were assumed to be similar to the Middle Clay Pit.

3 The secondary slope (Slope 2) for the Waterfall and Cherokee Heights Ravine cross sections were not analyzed for high groundwater conditions. A high groundwater condition also was not evaluated as part of the "ponding" analysis for the Cherokee Heights Ravine section; see Table 4-6.

4.4.2 Role of Vegetation in Stability

There is diverse vegetation on the upper soil slopes of the study area and trees of various sizes—from saplings to mature 40-foot trees. There is also grass/weed vegetation that has formed carpet-like mats on many of the park's slopes (see photos 12, 13, and 24 in Attachment D).

In certain scenarios, vegetation can help increase slope stability by reinforcing soils and absorbing water that would otherwise increase moisture content. However, trees in the study area have not stabilized the larger slides, as evidenced by the trees caught in the large 2014 landslide (see photos 4 through 7 and 14 in Attachment D). Furthermore, trees that are overhanging or near the edge of slopes may help trigger landslides when undermined, unstable, or blown over—dragging the surrounding soils down slope.

The root mats formed from the grassy/weed vegetation is effective at stabilizing the surface of the slopes, to a depth of approximately one foot. However, as seen on many of the slopes in the West and Middle

Clay Pits, these mats of root-reinforced soils appear to reach a critical condition and result in slope failures. In fact, it appears that the soils on the slopes may actually store materials in the root mats, potentially making the volume of the slides slightly larger than if the soils were allowed to ravel on un-vegetated slopes. Therefore, caution should be exercised below steep, vegetated, natural slopes (i.e., against the steep slopes of the clay pits). And, because the failure surface extends well below the root zones that bind the soils, neither trees nor grass/weed vegetation should be considered to stabilize the upper soil slopes.

Ultimately, some form of surface vegetation should be placed on the park slopes. Otherwise, erosion will create large amounts of downstream sediment that is both costly and time-consuming to manage. If slopes are regraded or existing vegetation is removed, vegetation that is suitable to park conditions and able to minimize soil erosion is recommended. Removal of larger trees overhanging or near the edge of the soil slopes may also be beneficial, reducing these as a trigger mechanism for slides and/or reducing the volume of slide events.

4.5 Summary of Geotechnical Findings

Seepage and soil saturation (which results in a loss of suction) can reduce stability of the slopes. Geotechnical modeling results indicate that the infiltration of approximately 3.5 inches of water in a 24-hour period is enough to impact soil stability. Loss of suction can also be realized through elevation of the groundwater table following periods of heavy precipitation either at the site or upstream within the watershed. Modeling results also indicate that a rise in the groundwater table caused by seepage (an increase of a few to several feet) can also impact slope stability.

These results and the observations made by Barr during the May and July 2014 site visits have been used to define risk categories and evaluate potential remediation options discussed in the Main Report.

5.0 Additional Testing and Analysis

This study was performed to evaluate general slope stability in the Brickyard Area of Lilydale Regional Park. To perform detailed design of stabilization methods such as soldier piles, soil nails, or retaining walls, additional investigations, testing, and analysis are required. To gain a better understanding of fluctuations in groundwater and evaluate potential changes in soil moisture content/saturation and subsequent changes in stability, we recommend that piezometers be installed and monitored.

More detailed descriptions of additional monitoring and testing options are provided in the following sections.

5.1 Additional Information, Testing, and Analysis

5.1.1 Groundwater

The only groundwater information available at the time of this report was from the saturated zones of soils found in the soil borings. There were several layers at depths much shallower than the soil/bedrock transition, which appeared to be saturated or nearly saturated during drilling. This was particularly true in the soil borings for the Cherokee Heights Ravine (STP B-1 and B-2). However, this does not agree with the observations of seepage primarily near the top of the shale at the face of the bluff. Thus, there appears to be some perched groundwater flow. This flow is influenced by the different permeabilities of the interlayered sand and clay soils but, eventually, combines to flow near the top of the bedrock.

In addition, a significant concentrated seep was observed flowing from the fresh scarp of the 2014 slide during the July site visit. The source of this groundwater may be infiltration flow from the second ravine or groundwater flow from another source.

If steep-slope mechanical stabilization is pursued, piezometer installation should be considered during final design to increase understanding of the groundwater depths and flow. Several piezometers installed along the cross sections, particularly the water fall and Cherokee Heights Ravine, would better identify groundwater flow and potential sources of seepage. An understanding of groundwater levels correlated to storm events may also be beneficial. Vibrating wire piezometers with data loggers could be used to evaluate the change in groundwater levels over time. For borings/areas where multiple potential zones of saturation were observed, nested piezometers at different depths should be used to evaluate different zones for perched groundwater flow.

5.1.2 Soil Borings

The soil stratigraphy in the borings appears to alternate among clean sands, silty sands, clayey sands, and sandy clays over the bedrock. The soils do not appear to be regularly ordered. The suction forces of the materials, which provide strength for the slopes, are much lower in the cleaner fine sand soils. Understanding the locations of these clean sand layers would be beneficial for evaluating and designing potential stabilization alternatives. Therefore, it is recommended that any of the soil borings completed for piezometer installation be logged to evaluate soil conditions.

5.1.3 Laboratory Testing

Soils derived from the additional soil borings should be tested to identify additional parameters for final analysis and design. Understanding drained strength parameters for the weathered shale soils would be particularly beneficial. The failures predicted from the drained strengths reported by NTI do not appear to match the observed failures.

5.1.4 Instrumentation

Understanding the location of the potential failure planes would also be beneficial if further evaluation and final design of stabilization alternatives is pursued. To date, failure scarps (usually observed from a distance) provide the only indication of the type and shape of failure surfaces. Installation of inclinometers in areas of anticipated failure would better define the failure surfaces; this should be considered during final design if steep-slope mechanical stabilization is pursued. This would allow for better "back analysis" (analyzing a known failure to determine the soil and groundwater properties) and potentially determine whether block-style failure planes may be observed.

6.0 Limitations

6.1 Variations in Subsurface Conditions

6.1.1 Material Variability and Degree of Weathering

This evaluation, analyses, and recommendations were developed from the information provided and subsurface collected. It is not standard engineering practice to retrieve material samples from borings continuously with depth; therefore, strata boundaries and thicknesses must be inferred to some extent. Strata boundaries may also be gradual transitions and can be expected to vary in depth, elevation, and thickness away from the boring locations. Although strata boundaries can be determined with continuous sampling, the boundaries apparent at boring locations likely vary away from each boring. Specifically, due to concern over the stability of the Brickyard Trail, soil conditions at the Middle Clay Pit were assumed to extend to the West Clay Pit. The soil conditions at the West Clay Pit would need to be determined prior to the final evaluation and design of any soil stabilization methods.

Variations in subsurface conditions between borings may not be revealed until additional exploration work is completed or construction commences. Such variations could increase construction costs, and a contingency should be provided to accommodate such variations.

6.1.2 Groundwater Variability

Groundwater measurements were made under the conditions indicated in the boring logs and interpreted in the text of this Appendix. It should be noted that the observation periods were relatively short, and groundwater can be expected to fluctuate in response to rainfall, snowmelt, flooding, irrigation, seasonal freezing and thawing, surface drainage modifications, and other seasonal and annual factors.

6.2 Limitations of Analysis

This Appendix is for the exclusive use of the City of Saint Paul Parks and Recreation. Barr assumes no responsibility to other parties. Our evaluation, analyses, and recommendations may not be appropriate for other parties or projects.

No published national standards exist for data retrieval and geotechnical evaluations. Barr has used the methods and procedures described in this Appendix. In performing its services, Barr used the degree of care, skill, and generally accepted engineering methods and practices ordinarily exercised under similar circumstances and under similar budget and time constraints by reputable members of its profession practicing in the same locality. Reasonable effort was made to characterize the project site based on the site-specific field work; however, there is always the possibility that conditions may vary away from the locations where testing was performed. Qualified personnel should carefully verify soil conditions during construction. No warranty, expressed or implied, is made.

7.0 References

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Attachment A

Soil Boring Summary

Attachment A
Soil Boring Summary

Turbine ID/ Test ID	Turbine Coordinates, decimal degrees		Soil Boring & Lab Soil Testing
	Latitude	Longitude	
SB-2-14	148037.2	570885.8	X
SB-3-14	146215.4	569917.8	X
STP-B-1	147165.0	571159.7	X
STP-B-2	147248.1	570934.1	X

Attachment B

Soil Boring Logs

Previous Boring Logs

Northern Technologies, Inc.
1408 Northland Drive, Suite 107
Mendota Heights, MN 55120
651-389-4191

BORING NUMBER HA-1

CLIENT City of St. Paul
PROJECT NAME Lilydale Slide
PROJECT NUMBER 13.60260.800
PROJECT LOCATION Lilydale, MN
DATE STARTED 7/10/13 **COMPLETED** 7/10/13
GROUND ELEVATION 199.68 ft **HOLE SIZE** 3 inches
DRILLING CONTRACTOR NTI
GROUND WATER LEVELS:
DRILLING METHOD Hand Auger
AT TIME OF DRILLING --- No groundwater observed.
LOGGED BY RL **CHECKED BY** RMB
AT END OF DRILLING ---
NOTES N-Value estimated via Dynamic Cone Penotrometer (DCP)
AFTER DRILLING ---

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
0.0		2" TOPSOIL SILTY SAND - (SP), fine to medium grained, trace roots, trace gravel, brown, moist, loose to dense	HA 1		8							
			HA		7			4				
		NOTE: Trace shale below 1 foot	HA 2		8							
			HA		6			5				20
			HA 3		11							
2.5			HA		17			6				
		NOTE: Cobbles at 3 feet	HA 4		14							
			HA					6				
			HA 5									
			HA									
5.0		NOTE: Occasional shale fragments at 5 feet	HA 6					7				23
		SHALE - gray	HA 7									

Boring terminated at 6.0 feet.

Northern Technologies, Inc.
1408 Northland Drive, Suite 107
Mendota Heights, MN 55120
651-389-4191

BORING NUMBER SB-1

CLIENT City of St. Paul
PROJECT NAME Lilydale Slide
PROJECT NUMBER 13.60260.800
PROJECT LOCATION Lilydale, MN
DATE STARTED 6/8/13 **COMPLETED** 6/12/13
GROUND ELEVATION 264.45 ft **HOLE SIZE** 5" Casing inches
DRILLING CONTRACTOR STS Enterprises LLC
GROUND WATER LEVELS:
DRILLING METHOD 3 1/4 in. H.S.A.
AT TIME OF DRILLING ---
LOGGED BY RTM **CHECKED BY** RMB
AT END OF DRILLING 58.00 ft / Elev 206.45 ft Taken in morning.
NOTES See below for casing and sampling notes
AFTER DRILLING 57.50 ft / Elev 206.95 ft Taken in morning (6/12/13).

DEPTH (ft)	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	PLASTIC LIMIT	PLASTICITY INDEX	FINES CONTENT (%)
0	6" TOPSOIL										
	FILL: CLAY, trace roots, brown, moist, medium	SS 1	50	2-2-2-2 (4)							
		HS									
		SS 2	58	2-2-5-6 (7)							
5		HS									
	FILL: POORLY GRADED SAND WITH A LITTLE SILT - (SP-SM), fine to medium grained, trace gravel, brown, dry, medium dense to dense 5" Casing from 0 to 8 feet 4" Casing from 8 to 41 feet	SS 3	67	6-6-9-9 (15)							
		HS									
		SS 4	100	9-12-15 (27)							
10		HS									
	CLAYEY SAND - (SC), fine to medium grained, trace gravel, brown, moist, dense to very dense	SS 5	92	12-12-12-15 (24)							
		RW									
		SS 6	100	12-16-18 (34)							
15		RW									
		SS 7	100	9-11-9 (20)							
	POORLY GRADED SAND WITH A LITTLE SILT - (SP-SM), fine to medium grained, trace gravel, brown, moist, dense	RW									
		SS 8	63	5-7-9-11 (16)							
20		RW									
		SS 9	83	8-10-8 (18)							
		RW									
		SS 10	63	10-9-8-11 (17)							
25	CLAYEY SAND - (SC), fine to medium grained, trace gravel, brown, moist, medium dense	RW									
		SS 11	75	8-7-7-9 (14)							
		RW									
	SANDY CLAY - (CL), trace gravel, brown to gray, moist, stiff	SS 12	100	5-8-10-12 (18)							
30		RW									
	POORLY GRADED SAND WITH A LITTLE SILT - (SP-SM), fine to coarse grained, trace gravel, light brown, waterbearing, dense to very dense	SS 13	89	8-11-13 (24)							
		RW									
		SS 14	92	12-18-18-20 (36)							
35		RW									

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Northern Technologies, Inc.
1408 Northland Drive, Suite 107
Mendota Heights, MN 55120
651-389-4191

CLIENT City of St. Paul
PROJECT NAME Lilydale Slide
PROJECT NUMBER 13.60260.800
PROJECT LOCATION Lilydale, MN

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
35		POORLY GRADED SAND WITH A LITTLE SILT - (SP-SM), fine to coarse grained, trace gravel, light brown, waterbearing, dense to very dense *(continued)*	SS 15	89	12-14-16 (30)							
			RW									
			SS 16	83	20-50/0"							
40		NOTE: Granite boulder from 39.5 to 43 feet.	RW									
		5 1/8" diameter rock bit from 0 to 41 feet 3 7/8" diameter rock bit from 41 to 41.5 feet Reamed boulder with 3 7/8" diameter core barrel	RC									
45		SANDY CLAY - (CL), trace gravel, brown to gray, moist, very stiff	SS 17	100	20-21-23-41 (44)							
			SS 18	100	15-30-33 (63)							
			RW									
			SS 19	75	15-25-40-60 (65)							
50			RW									
			SS 20	100	15-30-50 (80)							
		POORLY GRADED SAND - (SP), very fine grained, brown, waterbearing, very dense	RW									
			SS 21	88	25-35-30-35 (65)							
55			RW									
			SS 22	100	15-30-40 (70)							
		POORLY GRADED SAND - (SP), fine to medium grained, trace gravel, brown, waterbearing, very dense	RW									
			SS 23	92	30-35-38-50 (73)							
60			RW									
		WEATHERED SHALE OCCASIONALLY INTERBEDDED WITH LIMESTONE 30% water loss while coring	SS 24	50	50/4"							
			RW									
			RB									
65		NX Casing was set from 0 to 61 feet and cleaned out with 2 15/16" rock bit NX 2 15/16" core barrel sampling from 61 to 71, and 73 to 100 feet After sitting overnight with broken diamond bit at 71 feet, hole was cleaned out on 6-11-13 with rock bit from 71 to 73 feet. 100% water loss and 1 broken diamond bit while coring from 66 to 71 feet	RC 25	90								
70			RC 26	80								
			RB 27					16	43	16	27	
75		0.5 hrs to core from 73 to 78 feet.	RC									

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Northern Technologies, Inc.
1408 Northland Drive, Suite 107
Mendota Heights, MN 55120
651-389-4191

BORING NUMBER SB-1

CLIENT City of St. Paul **PROJECT NAME** Lilydale Slide

PROJECT NUMBER 13.60260.800 **PROJECT LOCATION** Lilydale, MN

DEPTH (ft)	GRAPHIC LOG	MATERIAL DESCRIPTION	SAMPLE TYPE NUMBER	RECOVERY % (RQD)	BLOW COUNTS (N VALUE)	POCKET PEN. (tsf)	DRY UNIT WT. (pcf)	MOISTURE CONTENT (%)	ATTERBERG LIMITS: LIQUID LIMIT	ATTERBERG LIMITS: PLASTIC LIMIT	ATTERBERG LIMITS: PLASTICITY INDEX	FINES CONTENT (%)
75		WEATHERED SHALE OCCASIONALLY INTERBEDDED WITH LIMESTONE *(continued)* 700 gallons of water used from 71 to 85 feet 50% water loss while coring 0.5 hrs to core from 78 to 79.5 feet.	RC 28	81								
80		1.2 hrs to core from 79.5 to 84.5 feet.	RC 29	97				14	52	19	33	
85		60 gallons of water loss from 84.5 to 92 feet	RC 30	73								
90–100		50 gallons of water loss from 92 to 100 feet	RC 31	100								

All shale and limestone drilled hard.
Voids or soft layers were not sensed with drill.
Very slow drilling with low downward pressure in shale.
Borehole backfilled with neat cement grout.
Boring terminated at 100.0 feet.

Core/Profile: Lilydale Core #1
Location: Northing 147504.8050 – Easting 570917.7170
Legal description: SW¼ SE¼ SE¼ Section 12 T28N R23W
County: Ramsey
Parent material: Glaciofluvial
Vegetation: Unknown
Slope: Unknown
Elevation: 958.71 feet (292.2 meters) NAVD 88 Datum
Remarks: Hollow-stem auger with discontinuous split-spoon sampling. Drillers reported drilling through a granite boulder at 39.5-43.0 feet depth. All samples were moist unless noted otherwise. Core described by Curtis M. Hudak on June 27, 2013.

Depth (feet)	Horizon or Zone	Description
1.6-1.8	C	very dark grayish brown (10YR3/2) silt loam to loam; few medium distinct strong brown (7.5YR4/6) mottles; massive to very weak thin platy structure; friable; non-effervescent; abrupt lower boundary; faint bedding may be indicative of sheetwash, alluvial/colluvial. NTI Sample #1.
1.8-2.0	C	alternating brown to dark brown (7.5YR4/4) and dark brown (7.5YR3/2) coarse silt loams; weak thin laminar bedding; friable; non-effervescent; unknown lower boundary; laminar beds are of the same textures but different colors and suggest transport of materials from nearby upslope sources, alluvial/colluvial. NTI Sample #1.
4.1-4.5	C	yellowish brown (10YR5/4-5/6) silt loam; few fine distinct strong brown (7.5YR4/6) mottles; very weak traces of laminar bedding; friable; non-effervescent; unknown lower boundary; common fine rootlets; one subangular metamorphic pebble lower boundary, alluvial/colluvial. NTI Sample #2.
6.6-7.0	C	pink (7.5YR7/4 dry; brown to dark brown 7.5YR4/4 when moistened) fine sand with few fine pebbles; single grain; loose; slight effervescence; unknown lower boundary; one coarse angular possibly fossiliferous pebble, fluvial. NTI Sample #3.
9.1-9.5	C	brown (7.5YR5/4) fine loamy sand with pebbles; single grain; weak thin bedding; very friable to loose; strong effervescence; unknown lower boundary; coarse pebbles are angular sandstones; fine pebbles are subrounded metamorphics. NTI Sample #4.
11.6-12.0	C	alternating brown (7.5YR5/4; saturated) fine sand thin bedding and dark brown to brown (7.5YR4/4; saturated) sandy loam medium beds; sandy loam medium beds part to thin beds; fines sands are loose; sandy loams are very friable; strong effervescence; unknown lower boundary; single subrounded 1.75”x1.25”x1.0” red granite pebble, fluvial. NTI Sample #5.
14.1-14.5	C	dark brown to brown (7.5YR4/2-4/4; moist) loamy sand to sandy loam with few pebbles; weak medium bedding; very friable; strong effervescence; unknown lower boundary; subangular 1.0”x1.25”x1.0” black basalt pebble, fluvial. NTI Sample #6.
16.6-17.0	C	dark yellowish brown to brown to dark brown (10YR-7.5YR4/4) loamy sand with few pebbles; very weak thin to medium bedding; very friable; strong effervescence; unknown lower boundary; subangular 0.75”x1.0”x0.5” white chert pebble; subangular 0.75”x1.0”x0.5” black basalt pebble, fluvial. NTI Sample #7.
19.1-19.5	C	brown to dark brown (7.5YR4/4) fine loamy sand with fine to medium pebbles; very weak medium bedding to massive; very friable to loose; slight effervescence; unknown lower boundary; single thin medium sand lens, fluvial. NTI Sample #8.
21.6-22.0	C	brown to dark brown (7.5YR4/4; saturated) fine loamy sand with medium pebbles; very weak medium bedding to massive; very friable to loose;

Depth (feet)	Horizon or Zone	Description
		slight effervescence; unknown lower boundary; triangular shaped subangular 1.25”x1.0”x0.5” black basalt pebble, fluvial. NTI Sample #9.
24.1-24.5	C	dark yellowish brown to brown to dark brown (10YR-7.5YR4/4) alternating fine sandy loam with pebbles and very fine to fine sand; very weak bedding to massive (sandy loam) and single grain (fine sands); very friable (loams) and loose (sands); slight effervescence; unknown lower boundary; abrupt boundaries between intra-sample beds, fluvial. NTI Sample #10.
26.6-27.0	C	brown (7.5YR5/4; saturated) silty clay loam to sandy clay loam with medium pebbles; massive; firm; slight effervescence; unknown lower boundary; chert and metamorphic pebbles are subrounded; sedimentary pebbles are subangular, fluvial/alluvial. NTI Sample #11.
29.1-29.5	C	brown (7.5YR5/4; saturated) sandy clay loam diamicton; few very coarse prominent gray to grayish brown (2.5Y5/0-5/2) mottles; massive; very firm; slight effervescence; unknown lower boundary; subrounded fine to medium pebbles with long axis dipping 45-50 degrees (fabric orientation could not be determined from uncontrolled split-spoon sampler), till. NTI Sample #12.
31.6-32.0	C	uppermost 0.25 inches are same as above except for abrupt gravelly lag deposit to 31.7 feet at lower boundary; very thin iron oxidized sand bed under lag deposit; 31.7-32.0 feet is strong brown to reddish yellow (7.5YR5/4-6/8) coarse to very coarse sand with crumbling pebbles; single grain; loose; slight effervescence; unknown lower boundary, till over lag over fluvial. NTI Sample #13.
34.1-34.5	C	brownish yellow (10YR6/8) medium to coarse sand with common pebbles; single grain; loose; slight effervescence; unknown lower boundary; pebbles and coarse sands are well rounded to subangular, fluvial. NTI Sample #14.
36.6-37.0	C	brownish yellow (10YR6/8) fine to medium sand; single grain; loose; slight effervescence; unknown lower boundary; single fine flat crumbling black schist pebble (aerodynamic shape may explain this being the only pebble amongst the finer sand grains), fluvial. NTI Sample #15.
39.1-39.5	C	yellowish brown (10YR5/4; saturated) very coarse sand to loamy sand; common medium distinct very dark brown (10YR2/2) and reddish yellow (7.5YR6/8) mottles; single grain; very friable to loose; slightly sticky in localized spots; slight effervescence; unknown lower boundary; variety of mottles indicates that a textural/hydraulic boundary may be in close proximity, fluvial. NTI Sample #16.
39.5-43.0		drillers reported drilling through granite boulder, possible lag deposit.
44.7-45.0	C	brownish yellow (10YR6/8) sandy clay loam diamicton; many coarse prominent yellowish red (5YR4/6 & 5/8) and very dark gray (10YR3/1) mottles (darker mottles are MnOx staining); alternating wavy and irregular bedding; firm; strong effervescence; unknown lower boundary; subrounded 1.0”x1.0”x0.5” black metamorphic pebble; mottle banding within texturally distinct bedding, till. NTI Sample #17.
46.6-47.0	C	brown to light yellowish brown (10YR5/3-6/4) coarse silt loam; common medium distinct reddish yellow (7.5YR6/8) and light gray (2.5Y7/0) mottles; massive; friable; slight effervescence; unknown lower boundary; possible loess or alluvially/colluvially reworked loess. NTI Sample #18.
49.1-49.5	C	very dark grayish brown to dark grayish brown (2.5Y3/2-4/2) clay loam diamicton; massive; extremely firm; slight effervescence; unknown lower boundary, till. NTI Sample #19.
50.5-50.9	C	strong brown (7.5YR5/6) sandy clay loam diamicton; common fine prominent black (10YR2/1) mottles (MnOx staining along joints); massive with traces of fabric; very firm; strong effervescence; unknown lower

Depth (feet)	Horizon or Zone	Description
		boundary. Drillers reported lithologic change at 51.7 ft., till. NTI Sample #20A
51.8-52.0	C	grayish brown (2.5Y5/2) fine sand; single grain; loose; noneffervescent; abrupt lower boundary, alluvium. NTI Sample #20B
54.1-54.5	C	light brownish gray (2.5Y6/2-6/4) silt loam; many medium distinct strong brown (7.5YR5/8) mottles; weak thin bedding; friable; strong effervescence; unknown lower boundary, alluvium/colluvium. NTI Sample #21.
56.6-57.0	C	uppermost 0.04 feet is a light brownish gray (10YR-2.5Y6/2) fine silt loam; few fine prominent reddish yellow (7.5YR6/8) mottles; massive; friable to firm; slight effervescence; abrupt lower boundary; lowermost 0.3 feet is a light brownish gray (10YR-2.5Y6/2) very fine sand; few medium faint brownish yellow (10YR6/6) mottles; very weak bedding to massive; very friable; spotty effervescence; unknown lower boundary, alluvial. NTI Sample #22.
59.1-59.5	C	olive brown (2.5Y4/4; saturated) fine to coarse sand; few fine distinct strong brown (7.5YR5/6) mottles; single grain; loose; slight effervescence; poorly sorted sands indicates probable flood deposit, fluvial. NTI Sample #23.
60.2-60.5	CR	multicolored and alternating silt loams (2.5Y6/0-6/2; possibly weathered shale), silty clay loams (10YR5/4), and sandy clay loams (7.5YR6/8); common prominent black (10YR2/1) MnOx stains; thin bedding; silt loams are hard or weakly cemented and have slight effervescence; silty clay loams are very firm and have strong effervescence; sandy clay loams are firm and have strong effervescence; boundaries within sample are irregular; unknown lower boundary; subrounded 1.75”x1.0”x0.75” pebble at lower boundary, fluvially reworked bedrock. NTI Sample #24.
60.5-61.0	RC & R	brown (10YR5/3) very coarse sands; single grain; loose; violent effervescence; unknown lower boundary; very poor recovery; sand grains are angular and probably represent locally reworked sedimentary bedrock lying on top of shale bedrock; bedrock shale beds reported by drillers at 60.5 feet. NTI Sample #25.
End of Split-Spoon Boring @ 61.0		top of bedrock elevation is 897.71 ft.

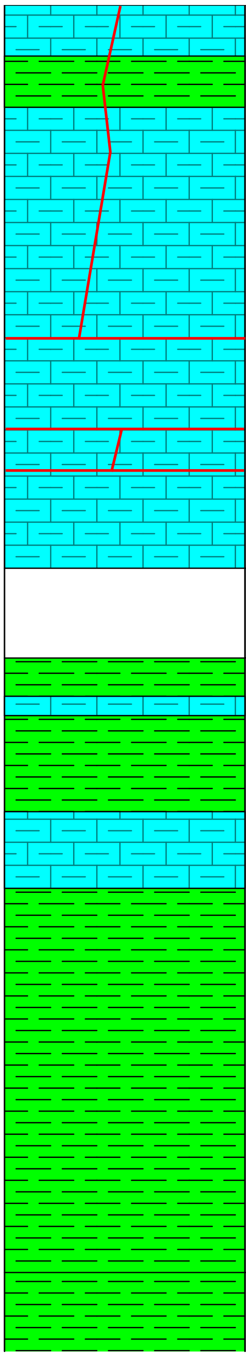
Summit Envirosolutions

Summit Envirosolutions, Inc.
1217 Bandana Boulevard North
St. Paul, MN 55180-5114

Project Name : Lillydale Slide
Summit Project No. : 2198-0001
Project Location : Lillydale, MN
County : Ramsey
Description Performed by: Brian Gulbranson
Surface grade elelvation: N/A

LOG OF BORING 13-60260-800

Date : 7/2/13
Company/Method : Northern Technologies Inc.
Sample Method : Wire line Core
Field Observer(s) : Ryan Benson
Weather :

Depth in feet	GRAPHIC LOG	MAJOR LITHOLOGY DESCRIPTIONS	MINOR LITHOLOGY DESCRIPTIONS
		Decorah limestone, gray green, argillaceous, fossiliferous (bryozoans, brachiopods, ostracods, crinoids), extensively bioturbated (flattened burrows), yellow brown ooids, trace FeS fossil replacement, trace black phosphatic grains, rare gypsum nodules along bedding planes, thin bryozoan coquina beds	Calcareous shale, green gray, thin, slightly wavy partings Subvertical fracture, 61.1 - 63.75 Subvertical fracture, 64.4 - 64.75
65		No sample	
		Calcareous Decorah shale, gray green, thinly bedded, clay particles parallel bedding, rare fossils	Argillaceous Limestone Argillaceous Limestone, 67.4 - 68
70		Calcareous Decorah shale, gray green, massive, rare fossils	

End of Boring at 100 feet.

Summit Envirosolutions

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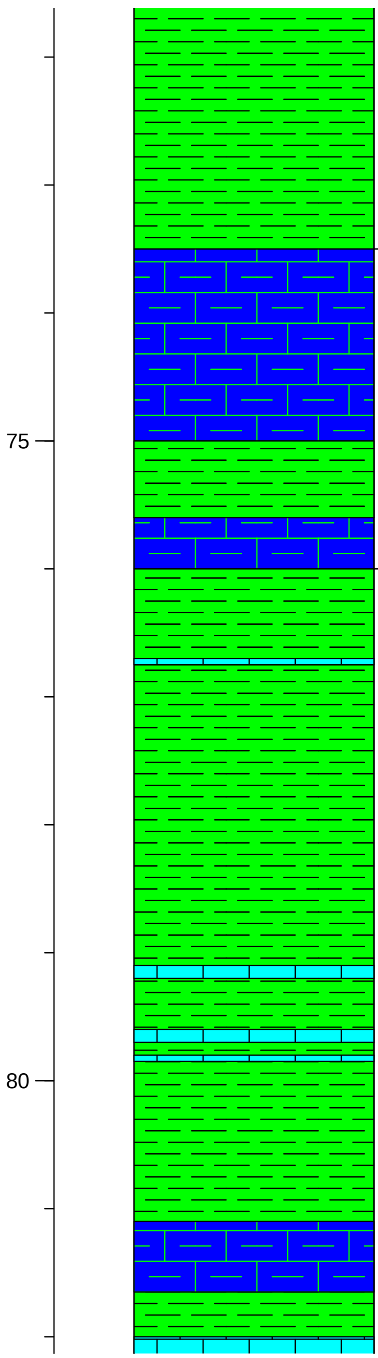
1217 Bandana Boulevard North
St. Paul, MN 55180-5114

Project Name : Lillydale Slide
Summit Project No. : 2198-0001
Project Location : Lillydale, MN
County : Ramsey
Description Performed by: Brian Gulbranson
Surface grade elelvation: N/A

LOG OF BORING 13-60260-800

Date : 7/2/13
Company/Method : Northern Technologies Inc.
Sample Method : Wire line Core
Field Observer(s) : Ryan Benson
Weather :

Depth in feet	GRAPHIC LOG	MAJOR LITHOLOGY DESCRIPTIONS	MINOR LITHOLOGY DESCRIPTIONS
		Decorah limestone as above with numerous shale laminae	
75			Shale, 75 - 75.6
		Calcareous Decorah shale, gray green, thinly bedded, clay particles parallel bedding, rare fossils	Limestone, 76.7 - 76.75
			Limestone, 79.1 - 79.2
			Limestone, 79.6 - 79.7
			Limestone, 79.8 - 79.85
80			
			Shaly Limestone, 81.1 - 81.65
			Limestone, 82 - 82.2



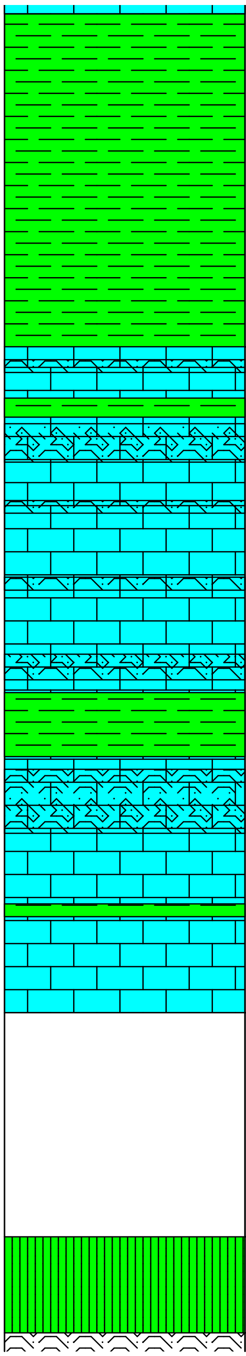
End of Boring at 100 feet.

Summit Envirosolutions, Inc.
1217 Bandana Boulevard North
St. Paul, MN 55180-5114

Project Name : Lillydale Slide
Summit Project No. : 2198-0001
Project Location : Lillydale, MN
County : Ramsey
Description Performed by: Brian Gulbranson
Surface grade elevation: N/A

LOG OF BORING 13-60260-800

Date : 7/2/13
Company/Method : Northern Technologies Inc.
Sample Method : Wire line Core
Field Observer(s) : Ryan Benson
Weather :

Depth in feet	GRAPHIC LOG	MAJOR LITHOLOGY DESCRIPTIONS	MINOR LITHOLOGY DESCRIPTIONS
85		Decorah limestone, blue gray, coarsely crystalline, massive, fossiliferous, trace black phosphatic grains, rare gypsum nodules	Coquina, 84.9 - 85 Shale, 85.2 - 85.35 Coquina, 85.4 - 85.7 Coquina, 86 - 86.1 Coquina, 86.6 - 86.7 Coquina, 87.2 - 87.4 Shale, 87.5 - 88 Coquina, 88.1 - 88.6 Shale, 89.15 - 89.25
90		No sample	
		K - Bentonite	

End of Boring at 100 feet.

Summit Envirosolutions, Inc.
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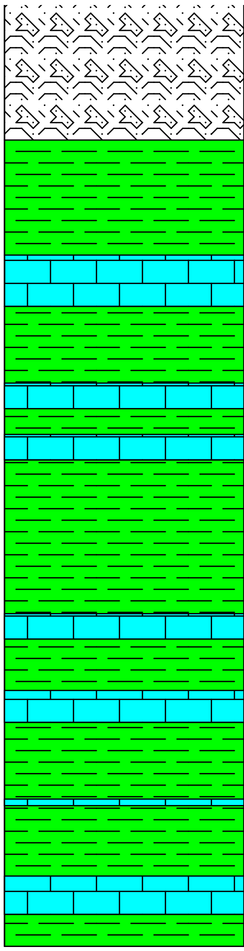
St. Paul, MN 55180-5114

Project Name : Lillydale Slide
Summit Project No. : 2198-0001
Project Location : Lillydale, MN
County : Ramsey
Description Performed by: Brian Gulbranson
Surface grade elevation: N/A

LOG OF BORING 13-60260-800

Date : 7/2/13
Company/Method : Northern Technologies Inc.
Sample Method : Wire line Core
Field Observer(s) : Ryan Benson
Weather :

Depth in feet	GRAPHIC LOG	MAJOR LITHOLOGY DESCRIPTIONS	MINOR LITHOLOGY DESCRIPTIONS
		Coquina: calcitic, fossiliferous hash of bryozoans, brachiopods, ostracods and crinoids, includes shaley matrix	
		Calcareous Decorah shale, gray green, thinly bedded, clay particles parallel bedding, rare fossils, some detrital fragments	
		Decorah limestone, blue gray, coarsely crystalline, massive, fossiliferous, trace black phosphatic grains, rare gypsum nodules	
95		Calcareous Decorah shale, gray green, massive, rare fossils	Limestone, 95.6 - 95.8 Limestone, 96 - 96.2 Limestone, 97.4 - 97.6 Limestone, 98 - 98.25 Limestone, 98.85 - 98.9 Limestone, 99.45 - 99.75
100			

End of Boring at 100 feet.

Current Boring Logs

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-2-14

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Surface Elev.: 966.6 ft

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description
965.1	1.5	TOPSOIL | FILL (SM): fine to medium grained; black; moist; medium dense; trace to few coarse grained sand to fine grained gravel; subrounded to rounded; with organics.
954.1	12.5	LEAN CLAY | FILL (CL): orangish to reddish brown with dark brown; dry to moist; medium stiff to stiff; with silt; few to some fine grained sand; trace coarse grained sand to fine grained gravel; subrounded to rounded. 7.0 ft: Layer (up to 12" thick) of poorly graded sand with clay (SP-SC); fine to medium grained; reddish brown; dry to moist; medium dense; few coarse grained sand.
948.6	18.0	POORLY GRADED SAND WITH CLAY (SP-SC): fine to medium grained; light brown to brown; dry to moist; dense to very dense; some coarse grained sand; few to some fine grained gravel; trace coarse grained gravel; subrounded; some apparent cohesion due to clay content.
942.1	24.5	SANDY LEAN CLAY (CL): light brown to brown; dry to moist; very stiff to hard; some fine to coarse grained sand; few to some fine grained gravel; trace coarse grained gravel; subrounded.
937.6	29.0	POORLY GRADED SAND WITH CLAY (SP-SC): fine to medium grained; light brown to light reddish brown; moist; medium dense; few coarse grained sand to fine grained gravel; subrounded; occasional thin layer of moist, clean, very fine to fine grained sand.

Elevation scale: 965, 960, 955, 950, 945, 940. Depth scale: 0, 5, 10, 15, 20, 25, 30.

Test Data

Graphic Log | Sample Type & Rec. | STANDARD PENETRATION TEST DATA (N in blows/ft: 10, 20, 30, 40) | WATER CONTENT % (PL, LL: 20, 40, 60) | SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES: 20, 40, 60, 80) | Physical Properties

N (blows/ft)	Sieve Analysis	WC %	γ pcf	ϕ °	Qu tsf	Qp tsf	Gs	RQD %
20								
7		19.6	102.8			1.75		
14						1.75		
25		5.2						
39						4.5		
35		9.1	127.4			4.5		
48								
48	11, 68	6.3						
>>67								
43		7.8						
31								
27						4.5		
25		7.2						
19								
17	85	5.2						

Continued Next Page

Completion Depth:	104.0
Date Boring Started:	6/18/14
Date Boring Completed:	6/25/14
Logged By:	JWH
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	966.6
Coordinates:	N 148,037.2 ft E 570,885.8 ft
Datum:	NAD83 Survey Feet

Remarks: Coring time per foot continually increased with depth

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft): At Time of Drilling 65.0

LEGEND

MC Moisture Content; γ Dry Unit Weight; ϕ Friction Angle; Q_u Unconfined Compression; Q_p Hand Penetrometer UC; Gs Specific Gravity; RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

M:\GINTPROJECTS\23621151 LILYDALE PARK.GPJ BARRLIBRARY.GLB HORIZONTAL LOG REPORT BARR GEOTECH TEMPLATE.GDT

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-2-14

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)
	30	POORLY GRADED SAND (SP): fine to medium grained; orangish tan to light brown; moist to wet; medium dense; trace coarse grained sand; trace silt; occasional thin layer of high silt content. *(Continued)*
934.1	32.5	SANDY LEAN CLAY (CL): tan to light brown; moist to wet; very stiff; with fine to coarse grained sand; few fine grained gravel; occasional thin layer of moist, clean, medium to coarse grained sand.
927.6	39.0	POORLY GRADED SAND (SP): fine to medium grained; reddish tan to orangish red; moist; dense; few coarse grained sand; trace fine to coarse grained gravel; occasional thin layer of sandy lean clay. 42.0 ft: Layer (up to 12" thick) of lean clay with silt (CL); gray with orange to red oxidation; moist.
922.6	44.0	POORLY GRADED SAND (SP): very fine to fine grained; orange with red layering; moist to wet; dense; trace to few medium to coarse grained sand; trace to few fine grained gravel at depth; layer of fine to coarse grained gravel at lower contact.
913.6	53.0	SANDY LEAN CLAY (CL): reddish brown to brownish dark gray; moist; very stiff to hard; some fine to medium grained sand; few coarse grained sand to fine grained gravel; rounded; low toughness.
907.6	59.0	

Continued Next Page

STANDARD PENETRATION TEST DATA (N in blows/ft); WATER CONTENT % (PL, LL); SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES); Physical Properties

Approx. Depth, feet	N (blows/ft)	PL	LL	Sieve	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
31	14				7.9						
33	26										
35	18				12.9						
37	30			21, 67, 91	11.7				1.5		
41	30										
42.5	31	19.9	33		24	101.9			1.5		
45	36										
47	49			4, 88	6.6						
49	39										
51	34										
52.5	16										
54									1.5		
55	25				16.7				1		
57	>>50/2"										
58.5	>>84								1		

Completion Depth:	104.0
Date Boring Started:	6/18/14
Date Boring Completed:	6/25/14
Logged By:	JWH
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	966.6
Coordinates:	N 148,037.2 ft E 570,885.8 ft
Datum:	NAD83 Survey Feet

Remarks: Coring time per foot continually increased with depth

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft): At Time of Drilling 65.0

LEGEND: MC Moisture Content; γ Dry Unit Weight; ϕ Friction Angle; Q_u Unconfined Compression; Q_p Hand Penetrometer UC; Gs Specific Gravity; RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

M:\GINTPROJECTS\23621151 LILYDALE PARK.GPJ BARRLIBRARY.GLB HORIZONTAL LOG REPORT BARR GEOTECH TEMPLATE.GDT

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-2-14

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description
	60	WELL GRADED SAND WITH CLAY (SW-SC): medium to coarse grained; orangish brown to brown; moist; very dense; some fine to coarse grained gravel; subangular to angular; occasional thin layer of very fine to fine grained sand; occasional thin layer of sandy lean clay with gravel. *(Continued)*
901.6	65.0	POORLY GRADED SAND WITH SILT (SP-SM): fine grained; tan to gray with orange; wet to saturated; very dense; trace to few medium grained sand.
898.6	68.0	LIMESTONE WITH CALCAREOUS SHALE; buff to light gray with blue-green gray shale; fresh; thinly bedded; horizontal; close to medium fracture spacing; 0° fracture dipping; some thinly bedded to laminated with calcareous shale as described below; rare thin calcareous shale zone weathered to clayey shale; horizontal fractures generally at or adjacent to calcareous shale zones; rare noncontinuous subvertical fracture with some oxidation; strong HCl reaction.
898.1	68.5	
896.6	70.0	
895.6	71.0	
894.6	72.0	
894.1	72.5	
892.6	74.0	
889.6	77.0	CALCAREOUS SHALE WITH LIMESTONE; blue-green gray to gray green; fresh; fine-grained; very thinly bedded; horizontal; close to medium fracture spacing; 0° fracture dipping; few thin to medium layers of interbedded limestone as described above; weak to moderate HCl reaction.
888.1	78.5	
887.1	79.5	
886.6	80.0	
885.6	81.0	
883.6	83.0	LIMESTONE WITH CALCAREOUS SHALE; light gray with blue-green gray shale; fresh; thinly bedded; horizontal; medium fracture spacing; 0° fracture dipping; trace to few thinly bedded to laminated with calcareous shale as described above; rare thin calcareous shale zone weathered to clayey shale; horizontal fractures generally at or adjacent to

Continued Next Page

Elevation scale: 905, 900, 895, 890, 885, 880. Depth scale: 60, 65, 70, 75, 80, 85, 90.

Test Data

STANDARD PENETRATION TEST DATA (N in blows/ft: 10, 20, 30, 40); WATER CONTENT % (PL — LL: 20, 40, 60); SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES: 20, 40, 60, 80)

Approx. Depth, feet	SPT N (blows/ft)	PL	LL	Sieve Analysis	WC %	γ pcf	φ °	Qu tsf	Qp tsf	Gs	RQD %
61	>>62			40, 78	9.1						
62.5	>>116										
65	>>50/3"										
67	>>64										
68	>>50/1"										
69.5					14.4						33
72.5											37
75.5					13.7	119		4.9			62
78					2.1	156.8		210.6			69
82.5											20
87.5		21.8	54		18.8						60

Completion Depth:	104.0
Date Boring Started:	6/18/14
Date Boring Completed:	6/25/14
Logged By:	JWH
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	966.6
Coordinates:	N 148,037.2 ft E 570,885.8 ft
Datum:	NAD83 Survey Feet

Remarks: Coring time per foot continually increased with depth

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft): At Time of Drilling 65.0

LEGEND

MC	Moisture Content	Q_u	Unconfined Compression
γ	Dry Unit Weight	Q_p	Hand Penetrometer UC
ϕ	Friction Angle	Gs	Specific Gravity
		RQD	Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-2-14

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Sample depth	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
	90	calcareous shale zones; strong HCl reaction.		17.3	114.9		8.4			75
874.1		85.0 ft: Layer (up to 12" thick) of highly mechanically disturbed calcareous shale due to swelling within core barrel..								74
872.6		CALCAREOUS SHALE WITH LIMESTONE; blue-green gray to gray green; fresh; fine-grained; very thinly bedded; horizontal; medium to wide fracture spacing; 0° fracture dipping; few thin to medium layers of interbedded limestone as described above; weak to moderate HCl reaction. *(Continued)*	92.5							
869.1		94.0 ft: Layer (up to 42" thick) of alternating thin beds of calcareous shale and limestone as described above.	94.0							100
867.6		97.5 ft: Horizontal fracture with clayey sand to sandy clay infill or weathered material; tan to orange tan; moist.	97.5							
862.6		99.0 ft: Core sample recovered largely intact.	99.0	13	123.4		6.2			
				6.4	140.4		21.5			
		Bottom of Boring at 104.0 feet Terminated within Bedrock at Target Depth.	104.0							

Elevation scale: 875, 870, 865. Depth scale: 90, 95, 100, 105, 110, 115, 120.

STANDARD PENETRATION TEST DATA — N in blows/ft: 10, 20, 30, 40

WATER CONTENT % — PL, LL: 20, 40, 60

SIEVE ANALYSIS — GRAVEL, SAND, SILT, CLAY, FINES: 20, 40, 60, 80

Physical Properties

Completion Depth:	104.0
Date Boring Started:	6/18/14
Date Boring Completed:	6/25/14
Logged By:	JWH
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	966.6
Coordinates:	N 148,037.2 ft E 570,885.8 ft
Datum:	NAD83 Survey Feet

Remarks: Coring time per foot continually increased with depth

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft): At Time of Drilling 65.0

LEGEND:
MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-3-14

Project: Lilydale Regional Park	Location: St. Paul, MN	Client: City of St. Paul

Barr Project Number: 23621151.00

Surface Elev.: 972.6 ft

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description
972.6–968.1	0–4.5	LEAN CLAY (CL): orangish brown; dry to wet; medium stiff to stiff; with silt; few fine grained sand; trace medium grained sand to fine grained gravel; subangular to angular.
968.1–966.6	4.5–6.0	CLAYEY SAND (SC): fine to medium grained; reddish brown; moist to wet; medium dense; few to some coarse grained sand to coarse grained gravel; subangular to angular.
966.6–958.6	6.0–14.0	SANDY LEAN CLAY (CL): light brown; moist to wet; stiff to very stiff; some fine to medium grained sand; trace coarse grained sand to coarse grained gravel; subangular to angular; occasional thin layer of wet, fine grained sand.
958.6–956.6	14.0–16.0	CLAYEY SAND (SC): fine to medium grained; brown with orange to red oxidation; moist to wet; dense; few to some coarse grained sand; trace to few fine to coarse grained gravel; subangular to angular.
956.6–948.1	16.0–24.5	SANDY LEAN CLAY (CL): brown; moist to wet; very stiff to hard; with fine to medium grained sand; few coarse grained sand; trace fine to coarse grained gravel; subangular to angular. 19.5 ft: Layer (up to 6" thick) of clayey gravel (GC); fine to coarse grained; greenish white; dry.
948.1–945.1	24.5–27.5	POORLY GRADED SAND WITH CLAY (SP-SC): fine to medium grained; tan to light brown; wet; medium dense; trace medium to coarse grained sand. 25.0 ft: Layer (up to 12" thick) of sandy lean clay (CL).

Continued Next Page

Test Data

Approx. Depth, ft	SPT N (blows/ft)	PL	LL	Water Content (X)	Sieve Analysis	WC %	γ pcf	φ °	Qu tsf	Qp tsf	Gs	RQD %
1	16									4.5		
3	5			X		25				0.5		
5	13											
7	14	12.9	24.3	X		9.2	126.6		2.22	2.75		
9	20			X		15.4				2.5		
11	21									2		
15	42											
17	30											
19	41			X	9, 69	7.7	126.4					
21	36											
23	30			X		8.4	128.8			2		
25	25											
27	14			X		15.5						

Completion Depth:	82.0
Date Boring Started:	6/26/14
Date Boring Completed:	7/10/14
Logged By:	JWH/KNA
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	972.6
Coordinates:	N 146,215.4 ft E 569,917.8 ft
Datum:	NAD83 Survey Feet

Remarks: Offset approximately 25 ft southeast due to landslide scarp near staked location.

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft)
- At Time of Drilling 44.0 — Saturated Layer from 44.0 to 45.0 ft.
- At Time of Drilling 50.5 — Saturated Layer from 50.5 to 53.0 ft.
- At Time of Drilling 70.0 — Saturated Layer from 70.0 to Bedrock Surface.

LEGEND
- MC Moisture Content
- γ Dry Unit Weight
- φ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

Barr Engineering Company
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LOG OF BORING SB-3-14

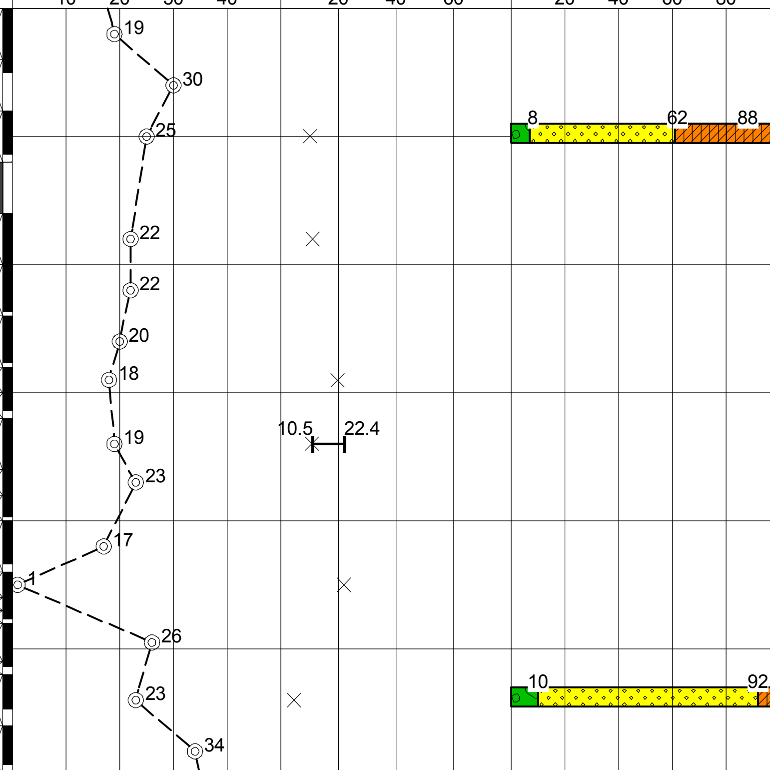
Project: Lilydale Regional Park	Location: St. Paul, MN	Client: City of St. Paul

Barr Project Number: 23621151.00

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description
	30	SANDY LEAN CLAY (CL): light brown to brown with red oxidation; moist to wet; very stiff; some fine to medium grained sand; trace to few coarse grained sand to coarse grained gravel; subangular to angular; occasional thin layer of moist, clean, fine grained sand. *(Continued)*
930.1	42.5	POORLY GRADED SAND (SP): fine grained; light tan to tan; wet to saturated; medium dense; trace to few silt; few medium grained sand. 44.0 ft: Layer (up to 12" thick) of sandy silt (ML); brownish tan; saturated; very loose to loose; with very fine grained sand.
926.6	46.0	SANDY LEAN CLAY (CL): grayish brown with red oxidation; moist to wet; very stiff; some fine to medium grained sand; trace to few coarse grained sand to coarse grained gravel; subangular to angular; occasional thin layer of moist, clean, fine grained sand.
923.6	49.0	
920.6	52.0	
919.1	53.5	POORLY GRADED SAND WITH CLAY (SP-SC): fine to medium grained; reddish tan to reddish brown; wet to saturated; medium dense; trace to few coare grained sand; subangular.
917.1	55.5	SANDY SILT (ML): light brown to light brownish red; wet to saturated; very soft; trace to few fine to

Continued Next Page



Depth (approx.), ft	N (blows/ft)	Sieve	PL / LL	WC %	γ pcf	φ °	Qu tsf	Qp tsf	Gs	RQD %
31	19							2.25		
33	30									
35	25	8, 62, 88		10.2						
39	22			11.1	120.4			2.25		
41	22							2.25		
43	20									
44.5	18			19.7						
47	19		10.5 / 22.4	10.7	125.6			1.5		
48.5	23							1.25		
51	17									
52	1			21.9				1		
54.5	26							2		
57	23	10, 92		4.6						
59	34									

Completion Depth:	82.0
Date Boring Started:	6/26/14
Date Boring Completed:	7/10/14
Logged By:	JWH/KNA
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	972.6
Coordinates:	N 146,215.4 ft E 569,917.8 ft
Datum:	NAD83 Survey Feet

Remarks: Offset approximately 25 ft southeast due to landslide scarp near staked location.

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft)
- At Time of Drilling 44.0 — Saturated Layer from 44.0 to 45.0 ft.
- At Time of Drilling 50.5 — Saturated Layer from 50.5 to 53.0 ft.
- At Time of Drilling 70.0 — Saturated Layer from 70.0 to Bedrock Surface.

LEGEND
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

M:\GINTPROJECTS\23621151 LILYDALE PARK.GPJ BARRLIBRARY.GLB HORIZONTAL LOG REPORT BARR GEOTECH TEMPLATE.GDT

Barr Engineering Company
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Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING SB-3-14

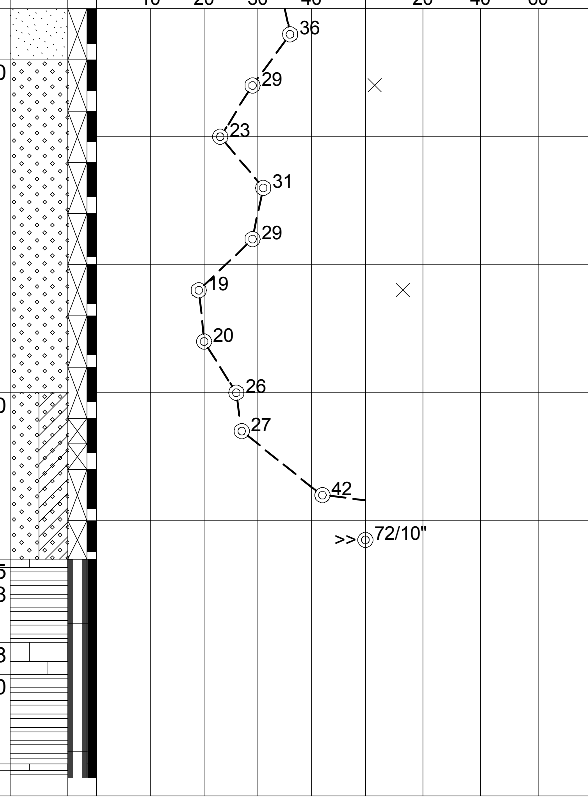
Project: Lilydale Regional Park	Location: St. Paul, MN	Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	
	60	medium grained sand; predominantly fine to medium grained sand with silt near upper contact.	
910.6		SANDY LEAN CLAY (CL): grayish brown with red oxidation; moist; very stiff; with fine to coarse grained sand; trace to few fine to coarse grained gravel; rounded to angular.	62.0
910	65	POORLY GRADED SAND (SP): fine to medium grained; orangish tan; moist to wet; medium dense to dense; trace to few silt to clay; few coarse grained sand to fine grained gravel; occasional thin layer of sandy gravel. *(Continued)*	
905	70	WELL GRADED SAND (SW): medium grained; orangish tan; wet to saturated; medium dense to dense; with fine to coarse grained sand; trace to few fine grained gravel; trace silt to clay.	
900			
897.6	75	WELL GRADED SAND WITH CLAY (SW-SC): medium to coarse grained; orange tan with dark gray grains; wet to saturated; medium dense; few fine grained sand to fine grained gravel; subrounded to subangular. 77.0 ft: Layer (up to 24" thick) of clayey gravel (GC); fine to coarse grained gravel; orange tan with dark gray grains; wet to saturated; some medium to coarse grained sand; few fine grained sand; includes rip-up clasts of greenish gray weathered shale.	75.0
895	80		
891.1			81.5
890.8			81.8
887.9	85	LIMESTONE WITH CALCAREOUS SHALE; buff to light gray with blue-green gray shale; fresh; thinly bedded; horizontal; medium fracture spacing; 0° fracture dipping; some thinly bedded to laminated with calcareous shale as described below; rare thin calcareous shale zone weathered to clayey shale;	84.8
886.6			86.0
883.1	90		

Continued Next Page

Graphic Log | Sample Type & Rec. | STANDARD PENETRATION TEST DATA (N in blows/ft; 10 20 30 40) | WATER CONTENT % (PL, LL; 20 40 60) | SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES; 20 40 60 80)



Physical Properties

WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
3.3						
13.1						
						83
						100

Completion Depth:	82.0
Date Boring Started:	6/26/14
Date Boring Completed:	7/10/14
Logged By:	JWH/KNA
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	972.6
Coordinates:	N 146,215.4 ft E 569,917.8 ft
Datum:	NAD83 Survey Feet

Remarks: Offset approximately 25 ft southeast due to landslide scarp near staked location.

SAMPLE TYPES

☒ Split Spoon ■ 3-inch Shelby Tube ▯ Rock Core

WATER LEVELS (ft)

At Time of Drilling 44.0
Saturated Layer from 44.0 to 45.0 ft.
At Time of Drilling 50.5
Saturated Layer from 50.5 to 53.0 ft.
At Time of Drilling 70.0
Saturated Layer from 70.0 to Bedrock Surface.

LEGEND

MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING SB-3-14

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Graphic Log	Sample Type & Rec.	RQD %
882.9	89.5	horizontal fractures generally at or adjacent to calcareous shale zones; rare noncontinuous subvertical fracture with some.			
880.6	89.8				73
880.2	92.0	CALCAREOUS SHALE WITH LIMESTONE; blue-green gray to gray green; fresh; fine-grained; very thinly laminated; horizontal; close to wide fracture spacing; 0° fracture dipping; few thin to medium layers of interbedded limestone as described above; weak to moderate HCl reaction; recover was greater than 100% indicating the shale was swelling.			
880.1	92.4				
877.9	92.5				
877.6	94.8				
877.4	95.0				85
876.1	95.3				
875.6	96.5				
874.6	97.0				
874.4	98.0	Layer of limestone with alternating thin beds of calcareous shale as described above.			100
873.6	98.3	Vertical fracture from 97.5 to 98 feet with yellow sediment infilling.			
872.6	99.0	Layer of calcareous shale with alternating thin beds of limestone as described above.			
	100.0				

Bottom of Boring at 82.0 feet
Terminated within Bedrock at Target Depth.

Chart columns: STANDARD PENETRATION TEST DATA (N in blows/ft; 10, 20, 30, 40); WATER CONTENT % (PL, LL; 20, 40, 60); SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES; 20, 40, 60, 80); Physical Properties: WC %, γ pcf, ϕ °, Q_u tsf, Q_p tsf, Gs, RQD %

Depth scale: 90, 95, 100, 105, 110, 115, 120

Completion Depth:	82.0
Date Boring Started:	6/26/14
Date Boring Completed:	7/10/14
Logged By:	JWH/KNA
Drilling Contractor:	Glacial Ridge
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	972.6
Coordinates:	N 146,215.4 ft E 569,917.8 ft
Datum:	NAD83 Survey Feet

Remarks: Offset approximately 25 ft southeast due to landslide scarp near staked location.

SAMPLE TYPES
Split Spoon; 3-inch Shelby Tube; Rock Core

WATER LEVELS (ft)
At Time of Drilling 44.0
Saturated Layer from 44.0 to 45.0 ft.
At Time of Drilling 50.5
Saturated Layer from 50.5 to 53.0 ft.
At Time of Drilling 70.0
Saturated Layer from 70.0 to Bedrock Surface.

LEGEND
MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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LOG OF BORING STP-B-1

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Surface Elev.: 964.4 ft

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)
964.1	0.3	TOPSOIL (OL): dark brown; moist; grass roots; some sand and gravel.
960.4	4.0	LEAN CLAY (CL): reddish brown; moist; soft to medium stiff; some small gravel and fine to medium sand; little silt; medium plasticity.
957.9	6.5	SILTY SAND (SM): reddish brown; moist; loose; some small gravel; 10% clay; round; slightly cohesive.
953.9	10.5	SILT WITH CLAY (ML): tan; moist; very stiff; little sand and gravel.
944.4	20.0	POORLY GRADED SAND WITH SILT (SP-SM): tan; moist; medium dense; angular to sub angular. 6 inch oxidation staining at 15 feet.
942.4	22.0	SILT WITH CLAY (ML): tan; wet; stiff; some sand; 4 inch sand layer containing water at 21 feet.
936.4	28.0	SILTY SAND WITH CLAY (SM): fine to coarse grained; dark red to brown; wet; medium dense; some gravel. 4 inch sand seam at 22.3 feet. 3 inch sand seam at 23 feet. 3 inch sand seam at 24 feet. 9 inch sand and gravel seam at 25.5 feet. 2 inch sand seam at 27.5 feet.

Continued Next Page

Graphic Log | Sample Type & Rec.

STANDARD PENETRATION TEST DATA (N in blows/ft): 4, 8, 10, 25, 14, 14, 13, 14, 13, 10, 13, 15, 13, 17

WATER CONTENT %: PL — LL; 17.2, 21.8

SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES): 8, 69, 96; 97

Physical Properties:

WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
22.2						
8.5						
13.7	104.7					
1.8						
1.3						
20.4						
13.5						
9.9	130.2					

Completion Depth:	71.0
Date Boring Started:	6/25/14
Date Boring Completed:	6/25/14
Logged By:	KNA
Drilling Contractor:	AET
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	964.4
Coordinates:	N 147,165.0 ft E 571,159.7 ft
Datum:	NAD83 Survey Feet

Remarks: Mud rotary started at 32 feet

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube

WATER LEVELS (ft):
- Wet Cave-in Depth 23.0
- At Time of Drilling 21.5 — Saturated layer from 21.5 to 38 ft.
- At Time of Drilling 63.5 — Saturated layer from 63.5 to 67 ft.

LEGEND:
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Barr Engineering Company
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Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING STP-B-1

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Bottom depth
	30	4 inch clay with silt and gravel seam at 27.75 feet. 2 inch sand seam at 29 feet. SILTY SAND (SM): fine to coarse grained; dark red; wet; medium dense; with clay and small to large gravel; increasing clay content with depth. *(Continued)* High clay content at 30 feet. 3 inch sand seam at 30.5 feet. 9 inch sand seam at 31.25 feet. 4 inch clay seam at 33.5 feet. 1 inch sand seam at 36.5 feet. 1 inch sand seam at 37.5 feet.	
926.4		LEAN CLAY (CL): gray; moist; very stiff; with fine to coarse sand; with small to large gravel. 4 inch silty sand seam at 41 feet.	38.0
922.9		SILTY SAND (SM): fine to coarse grained; brown; moist to wet; dense; small to large gravel. Seam of oxidized clay at 42.5 feet.	41.5
920.9		SILTY GRAVEL (GM): fine to coarse grained; brown; moist to wet; dense to very dense; some sand; orange oxidation; green and maroon mudstone inclusions; gravel size increases with depth.	43.5
913.4		LEAN CLAY (CL): gray; moist; very stiff; with fine to coarse sand; with small gravel; [TILL?].	51.0
909.4		LEAN CLAY WITH SILT (CL): yellowish tan; moist; very dense; some gravel; blocky; orange and black oxidized zones.	55.0
907.4			57.0
905.9		SILTY SAND (SM): fine to medium grained; tan; moist; dense.	58.5

Elevation scale: 930, 925, 920, 915, 910, 905. Depth scale: 30, 35, 40, 45, 50, 55, 60.

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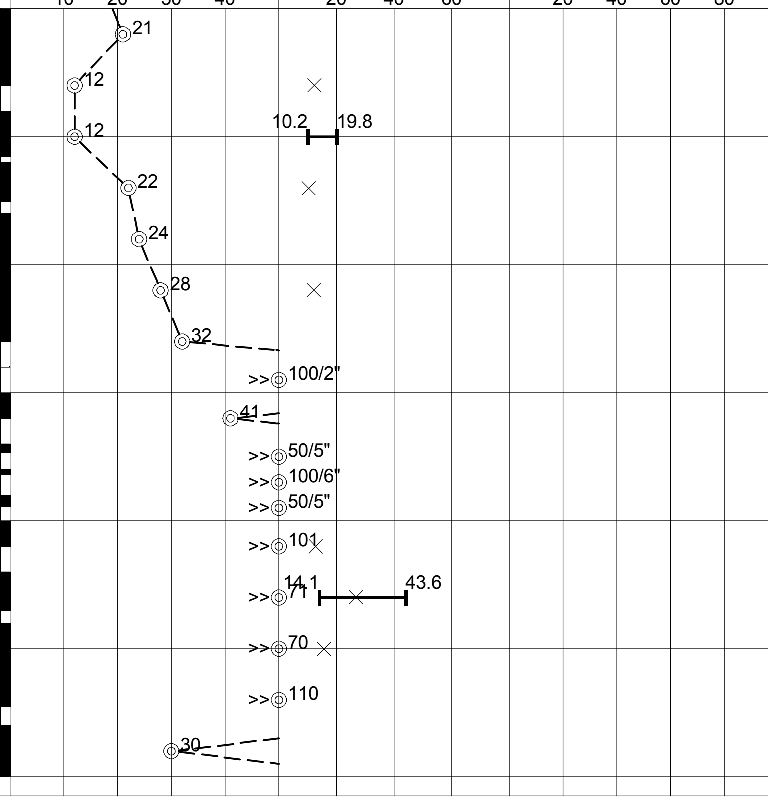
Graphic Log | Sample Type & Rec.



Physical Properties

WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
12.3						
10.3	127.8		1.32			
12.1	127.3					
12.7						
26.7						
15.7	112.8		5.33			

Completion Depth:	71.0
Date Boring Started:	6/25/14
Date Boring Completed:	6/25/14
Logged By:	KNA
Drilling Contractor:	AET
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	964.4
Coordinates:	N 147,165.0 ft E 571,159.7 ft
Datum:	NAD83 Survey Feet

Remarks: Mud rotary started at 32 feet

SAMPLE TYPES

Split Spoon
3-inch Shelby Tube

WATER LEVELS (ft)

Wet Cave-in Depth 23.0
At Time of Drilling 21.5
Saturated layer from 21.5 to 38 ft.
At Time of Drilling 63.5
Saturated layer from 63.5 to 67 ft.

LEGEND

MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Minneapolis, MN 55435
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LOG OF BORING STP-B-1

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Bottom depth	STANDARD PENETRATION TEST DATA (N in blows/ft)	WATER CONTENT %	SIEVE ANALYSIS	WC %
903.9		SILT WITH CLAY (ML): tan; moist; possibly varved; oxidation staining; occasional fine sand seams; slightly cohesive. *(Continued)*	60.5	>>110		83	16.6
899.4		SILTY SAND (SM): medium to coarse grained; tan, orange, and brown; moist to wet; very dense; little small gravel; trace clay. 4 inch silt with clay seam at 63 feet; oxidized.	65.0	>>82; >>100/5.5"			
897.4		SILTY GRAVEL (GM): tan; moist to wet; very dense; with clay and sand; oxidized and cemented; [weathered shale?].	67.0	>>100/3"; >>100/2"			
893.4		SHALE; gray; bedded in layers.	71.0	>>100/2"			
		Bottom of Boring at 71.0 feet					

Elevation scale: 900, 895. Depth scale: 60, 65, 70, 75, 80, 85, 90.

Graphic Log; Sample Type & Rec.

Water Content: PL, LL; 20, 40, 60. SPT: 10, 20, 30, 40. Sieve Analysis: GRAVEL, SAND, SILT, CLAY, FINES; 20, 40, 60, 80.

Physical Properties: WC %; γ pcf; ϕ °; Q_u tsf; Q_p tsf; Gs; RQD %

Completion Depth:	71.0
Date Boring Started:	6/25/14
Date Boring Completed:	6/25/14
Logged By:	KNA
Drilling Contractor:	AET
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	964.4
Coordinates:	N 147,165.0 ft E 571,159.7 ft
Datum:	NAD83 Survey Feet

Remarks: Mud rotary started at 32 feet

SAMPLE TYPES

Split Spoon; 3-inch Shelby Tube

WATER LEVELS (ft)

Wet Cave-in Depth 23.0
At Time of Drilling 21.5
Saturated layer from 21.5 to 38 ft.
At Time of Drilling 63.5
Saturated layer from 63.5 to 67 ft.

LEGEND

MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

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Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING STP-B-2

Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Surface Elev.: 962.5 ft

MATERIAL DESCRIPTION (ASTM D2488)

Elevation, feet	Depth, feet	Material Description
962.0	0.5	TOPSOIL (OL): dark brown; moist to wet; with silt, organics, and root inclusions.
958.5	4.0	LEAN CLAY (CL): reddish brown; moist; soft to medium stiff; trace fine sand; trace silt; organic inclusions; cohesive; medium plasticity.
953.5	9.0	LEAN CLAY WITH SILT (CL): tan and gray; moist to wet; very stiff; some large gravel; trace fine sand; root inclusions; low plasticity; rapid dilatency. 2 inch silty sand seam at 6.5 feet.
941.0	21.5	SILTY SAND (SM): fine to medium grained; dark reddish brown; moist; medium dense to very dense; some small to large gravel and clay; slightly cohesive; increasing sand and gravel content with depth. 6 inches of crushed rock from 11.5 to 12 feet. 2 inches of crushed rock at 13 feet. Saturated sand seam from 14.5 to 14.8 feet. Saturated sand seam from 16 to 16.5 feet. 2 inches of crushed rock at 17 feet.
940.5	22.0	LEAN CLAY WITH SILT (CL): brown; moist to wet; 1/2 inch sand seams throughout.
937.5	25.0	POORLY GRADED SAND WITH SILT (SP-SM): fine to medium grained; tan; moist; medium dense; 1/2" clay with silt seams throughout; some large gravel.
935.5	27.0	SILTY SAND (SM): fine to medium grained; reddish brown; moist; medium dense; with clay; 10% small to large gravel. Wet from 26 to 27 feet.

Continued Next Page

Test Data

STANDARD PENETRATION TEST DATA (N in blows/ft); WATER CONTENT % (PL, LL); SIEVE ANALYSIS (GRAVEL, SAND, SILT, CLAY, FINES); Physical Properties

Approx. Depth, feet	N (blows/ft)	PL	LL	Sieve	WC %	γ pcf	ϕ °	Qu tsf	Qp tsf	Gs	RQD %
1	3										
3	5										
5					25.6	98.1		0.7			
7	17				12.7						
9					9.3	122.2		1.09			
11	>>69	10.3	15.2								
13	>>63			9, 70, 95	8.2						
15	25										
17	>>51				8	130.5		2.57			
19	41				7.9	129.8		2.78			
21	38										
23	20			1, 92	7						
25	16										
29	17	9.9	22.7		11.4						

Completion Depth:	50.0
Date Boring Started:	6/24/14
Date Boring Completed:	6/24/14
Logged By:	KNA
Drilling Contractor:	AET
Drilling Method:	3 1/4" ID HSA
Ground Surface Elevation:	962.5
Coordinates:	N 147,248.1 ft E 570,934.1 ft
Datum:	NAD83 Survey Feet

Remarks: Offset 50 feet southeast of landslide scarp

SAMPLE TYPES
- Split Spoon
- 3-inch Shelby Tube

WATER LEVELS (ft)
- At Time of Drilling 15.5
- Saturated layer from 15.5 to 17 feet

LEGEND
- MC Moisture Content
- γ Dry Unit Weight
- ϕ Friction Angle
- Q_u Unconfined Compression
- Q_p Hand Penetrometer UC
- Gs Specific Gravity
- RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

Barr Engineering Company
4700 West 77th St. Suite 200
Minneapolis, MN 55435
Telephone: 952-832-2600

LOG OF BORING STP-B-2

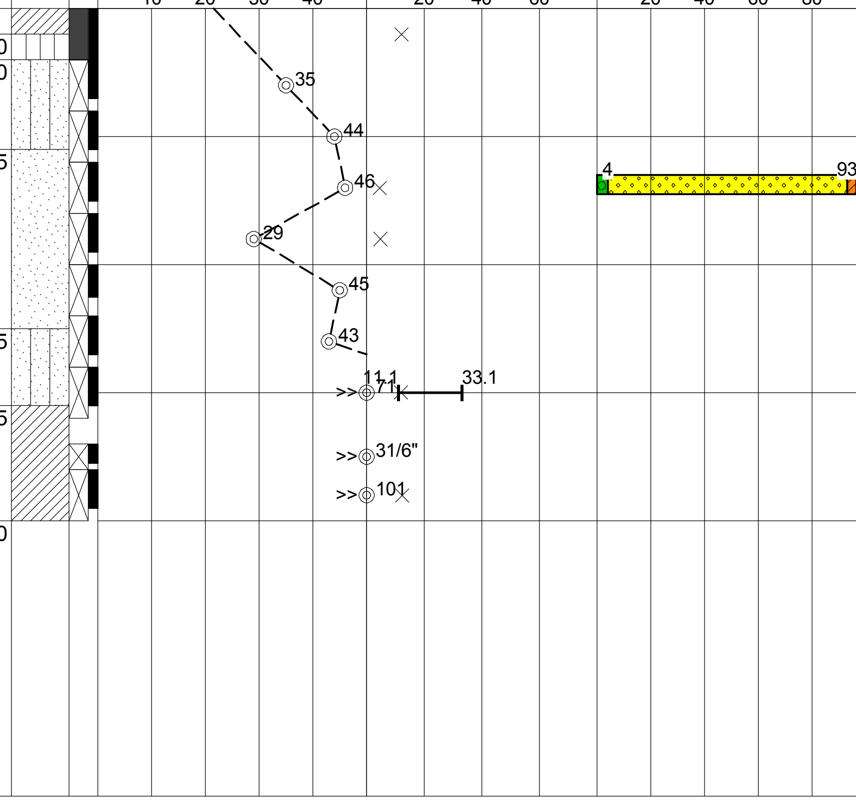
Project: Lilydale Regional Park | Location: St. Paul, MN | Client: City of St. Paul

Barr Project Number: 23621151.00

Elevation, feet	Depth, feet	MATERIAL DESCRIPTION (ASTM D2488)	Depth
931.5	30	LEAN CLAY (CL): brown and gray; moist to wet; very stiff; with medium to coarse sand and small to large gravel; very stiff; medium to high plasticity; oxidation staining. *(Continued)*	31.0
930.5		SILT (ML): orange; moist to wet; with sand and gravel; some clay; slightly cohesive.	32.0
927.0	35	SILTY SAND TO SILTY GRAVEL (SM): fine to medium grained; tan to brown; moist; dense to very dense; black-colored seams; oxidation staining.	35.5
920.0		POORLY GRADED SAND (SP): fine to coarse grained; tan and brown; moist; medium dense to dense; 20% small to large gravel; 10% silt; appears laminated. Orange stained sand from 40.5 to 41 feet due to oxidation. 3 inch wet gray claystone/shale at 41 feet. Wet from 42 to 42.5 feet.	42.5
917.0	45	SILTY SAND (SM): fine to coarse grained; brown; moist to wet; dense to very dense; with clay and gravel; black and orange staining. 2 inch wet gravel seam at 43.25 feet.	45.5
912.5	50	LEAN CLAY (CL): gray; moist; hard; 10% medium to coarse sand; blocky; medium plasticity.	50.0

Bottom of Boring at 50.0 feet

Elevation scale: 930, 925, 920, 915. Depth scale: 30, 35, 40, 45, 50, 55, 60.



Depth (ft)	WC %	γ pcf	ϕ °	Q_u tsf	Q_p tsf	Gs	RQD %
~31	12.2	126.6		1.5			
~37	4.6						
~39	4.8						
~45	11.8						
~48	12.4	123.8		16.11			

Completion Depth: 50.0
Date Boring Started: 6/24/14
Date Boring Completed: 6/24/14
Logged By: KNA
Drilling Contractor: AET
Drilling Method: 3 1/4" ID HSA
Ground Surface Elevation: 962.5
Coordinates: N 147,248.1 ft E 570,934.1 ft
Datum: NAD83 Survey Feet

Remarks: Offset 50 feet southeast of landslide scarp

SAMPLE TYPES: Split Spoon; 3-inch Shelby Tube

WATER LEVELS (ft): At Time of Drilling 15.5; Saturated layer from 15.5 to 17 feet

LEGEND:
MC Moisture Content
γ Dry Unit Weight
ϕ Friction Angle
Q_u Unconfined Compression
Q_p Hand Penetrometer UC
Gs Specific Gravity
RQD Rock Quality Designation

The stratification lines represent approximate boundaries. The transition may be gradual.

M:\GINT\PROJECTS\23621151 LILYDALE PARK.GPJ BARRLIBRARY.GLB HORIZONTAL LOG REPORT BARR GEOTECH TEMPLATE.GDT

Attachment C

Laboratory Physical Test Results

Previous Laboratory Physical Test Results

Moisture Contents and Atterberg Limits

Laboratory Test Summary

Project: Lilydale Slide — Job: 9014

Client: Northern Technologies, Inc. — Date: 7/31/2013

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)	71	80						
Type or BPF	Bag	Bag						
Material Classification	Lean Clay (CL)	Fat Clay (CH)						

Moisture Contents & Atterberg Limits

Moisture Content (%)	16.3	13.8						
Liquid Limit (%)	43.0	52.4						
Plastic Limit (%)	16.4	18.6						
Plasticity Index (%)	26.6	33.8						

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type or BPF								
Material Classification								

Moisture Contents & Atterberg Limits

Moisture Content (%)								
Liquid Limit (%)								
Plastic Limit (%)								
Plasticity Index (%)								

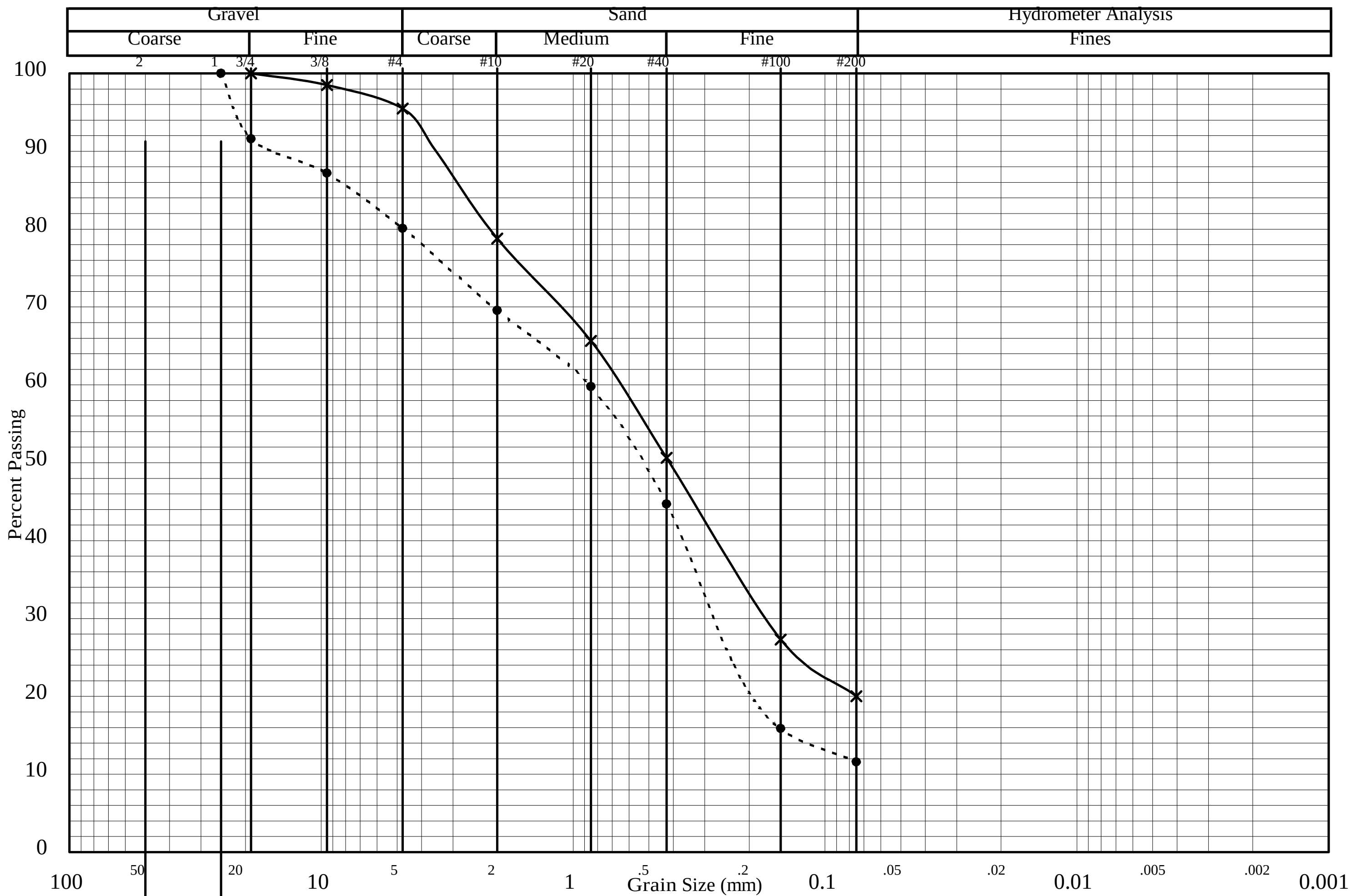
Grain Size

Grain Size Distribution ASTM D422

Job No. : **9014**

Project:	Lilydale Slide	Test Date:	7/10/13
Reported To:	Northern Technologies, Inc.	Report Date:	7/10/13

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	Side of Debris Pile			Bag	Silty Sand w/a little gravel (SM)
●	HA 1		4-5	Bag	Sand w/silt and gravel (SP-SM/SM)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	7.5	5.8	
Dry Density (pcf)			
Specific Gravity			
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	982.0	1039.9	
2"			
1.5"			
1"		100.0	
3/4"	100.0	91.6	
3/8"	98.5	87.2	
#4	95.5	80.1	
#10	78.8	69.6	
#20	65.6	59.8	
#40	50.6	44.7	
#100	27.3	15.9	
#200	20.0	11.6	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

2401 W 66th Street

SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Direct Shears

Direct Shear Test

ASTM: D3080

Job No.: 9014

Project/Client: **Lilydale Slide / Northern Technologies, Inc.**

Boring No.: **HA 1** Sample No. Depth: **4-5**

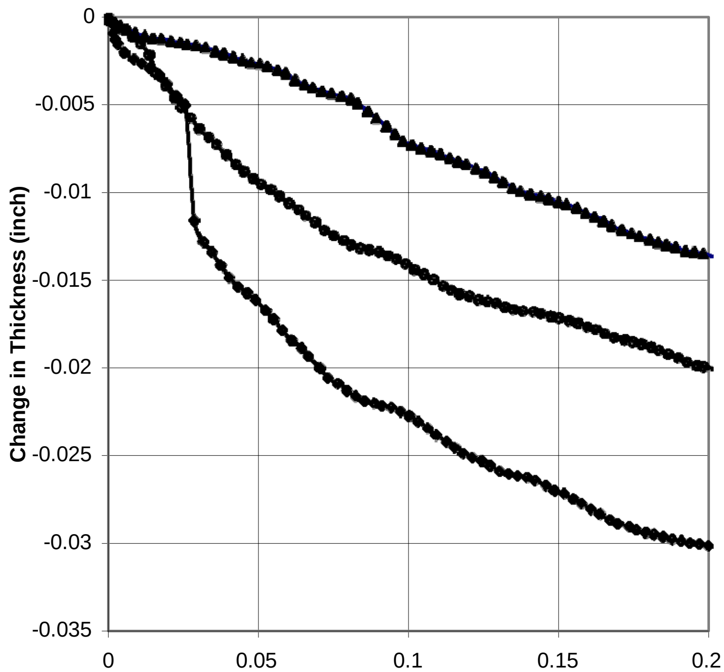
Location: Sample Type: **Bag**

Soil Type: **Sand with Silt and gravel, fine to medium grained (SP-SM/SM)**

Test Date:	**7/10/2013**
Date Reported:	**7/29/2013**
Shear Rate	**0.003** (in/min)
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.68**

Remarks: Specimens compacted to given densities, using -#10 material in loose condition; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.003 inches/minute.

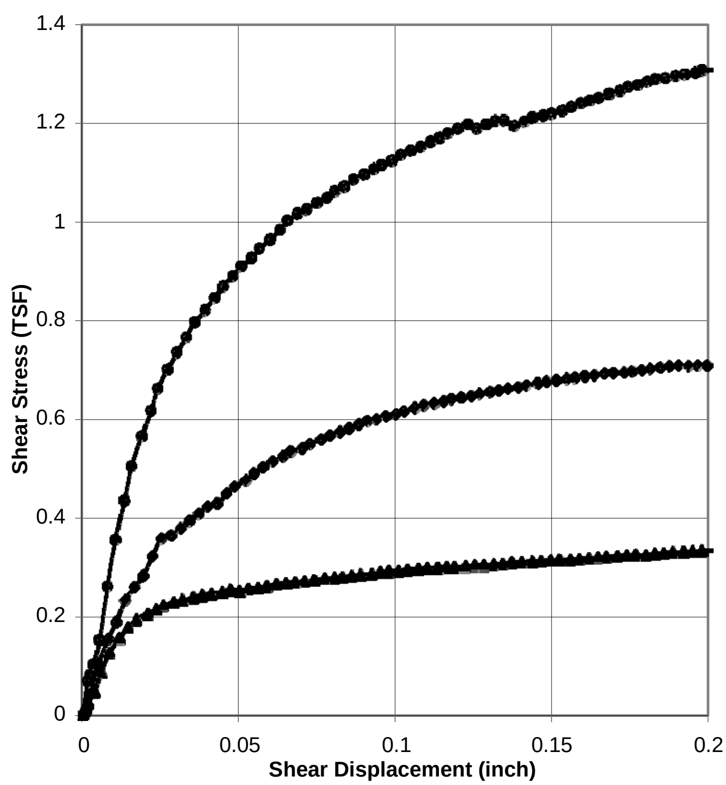
(*) = Assumed Specific Gravity

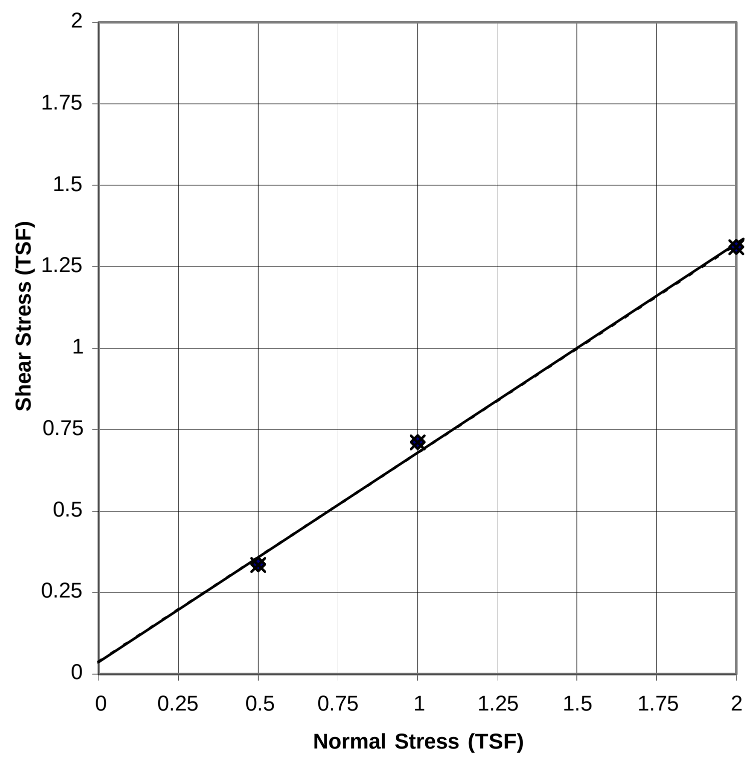


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.92	0.92	0.92	
Water Content (%)	5.7	5.7	5.7	
Dry Density (pcf)	107.9	107.9	107.9	
Before Shear				
Thickness (In.)	0.91	0.91	0.89	
Water Content (%)	20.2	19.6	18.8	
Dry Density (pcf)	108.6	109.7	111.3	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.34	0.71	1.31	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions			At Given Shear Disp. Of:		0.2
Friction Angle:	φ=	**32.7 deg.**	Friction Angle:	φ=	**32.7 deg.**
Apparent Cohesion		**0.037 TSF**	Apparent Cohesion		**0.036 TSF**





2401 W 66th Street

SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Direct Shear Test

ASTM: D3080

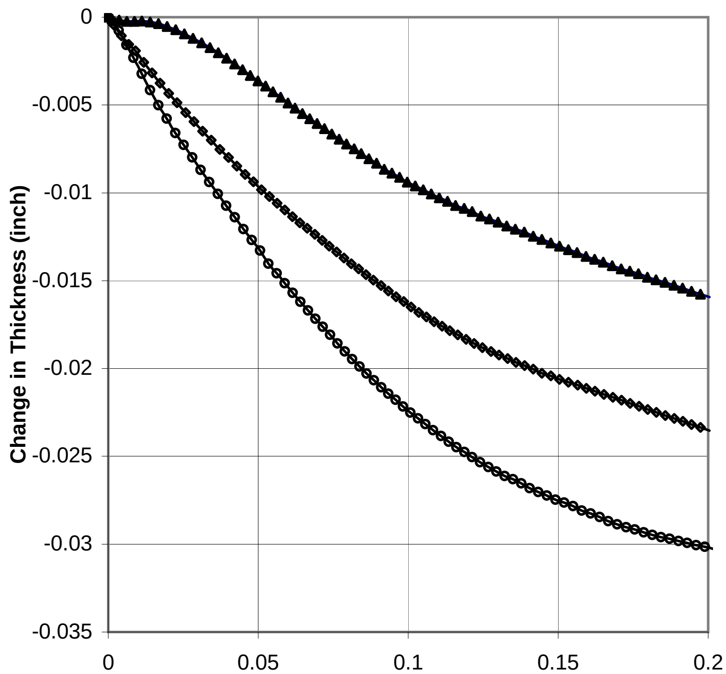
Job No.: 9014

Project/Client:	**Lilydale Slide / Northern Technologies, Inc.**		
Sample No.	**Slide Debris Pile**	Depth:	
Location:		Sample Type:	**Bag**
Soil Type:	**Silty Sand with a little gravel (SM)**		

Test Date:	**7/10/2013**
Date Reported:	**7/29/2013**
Shear Rate	**0.003** (in/min)
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.68**

Remarks: Specimens compacted to given densities, using -#10 material in loose condition; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.003 inches/minute.

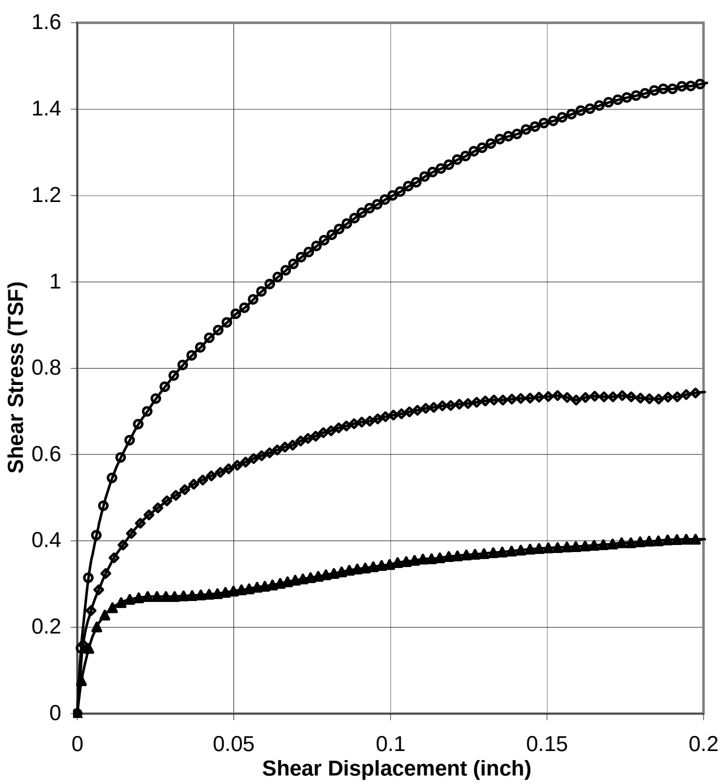
(*) = Assumed Specific Gravity

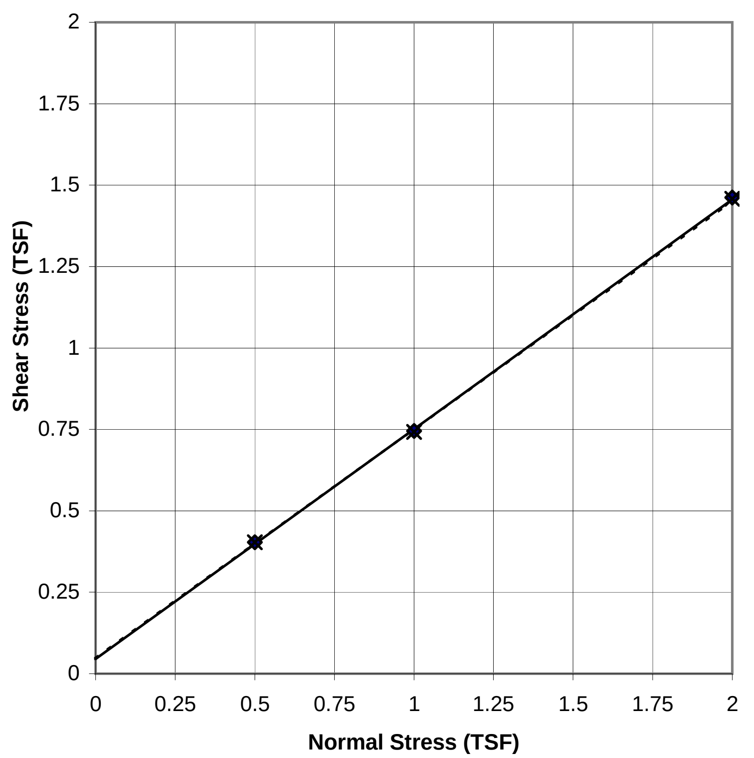


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.92	0.92	0.92	
Water Content (%)	7.5	7.5	7.5	
Dry Density (pcf)	108.3	108.3	108.3	
Before Shear				
Thickness (In.)	0.91	0.90	0.90	
Water Content (%)	19.6	19.3	18.9	
Dry Density (pcf)	109.8	110.3	111.0	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.40	0.74	1.46	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.2
Friction Angle:	= **35.2 deg.**	Friction Angle:	= **35.1 deg.**
Apparent Cohesion	**0.046 TSF**	Apparent Cohesion	**0.046 TSF**





Torsional Ring Shear Test

Torsional Ring Shear Test

ASTM D:6467-06a

Job #: **9014**

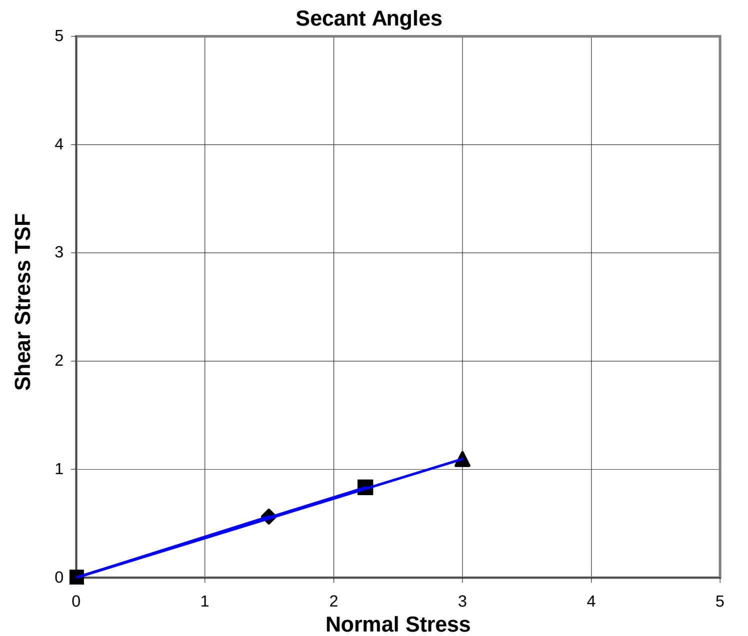
Project: **Lilydale Slide** Client: **Northern Technologies, Inc.** Date: **7/29/2013**

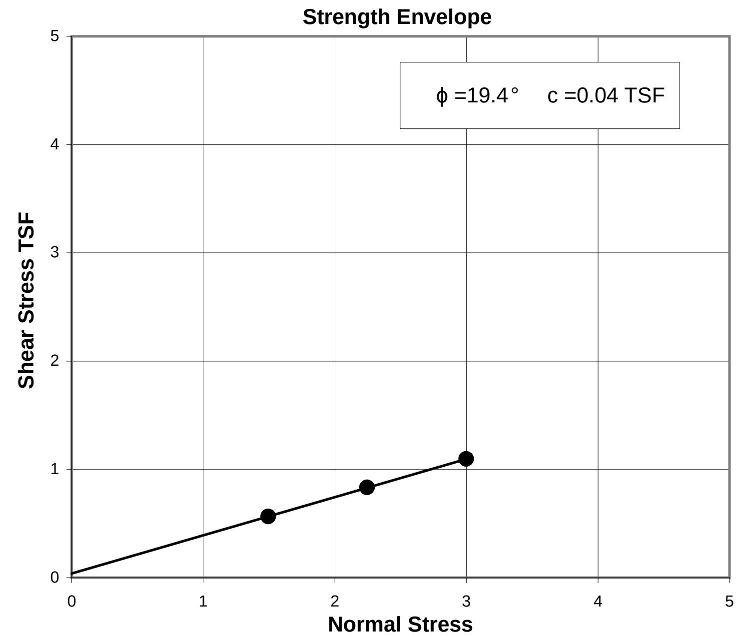
Boring:	Sample:	Depth:	**71**
Location:			
Soil Type:	**Lean Clay (CL)**		

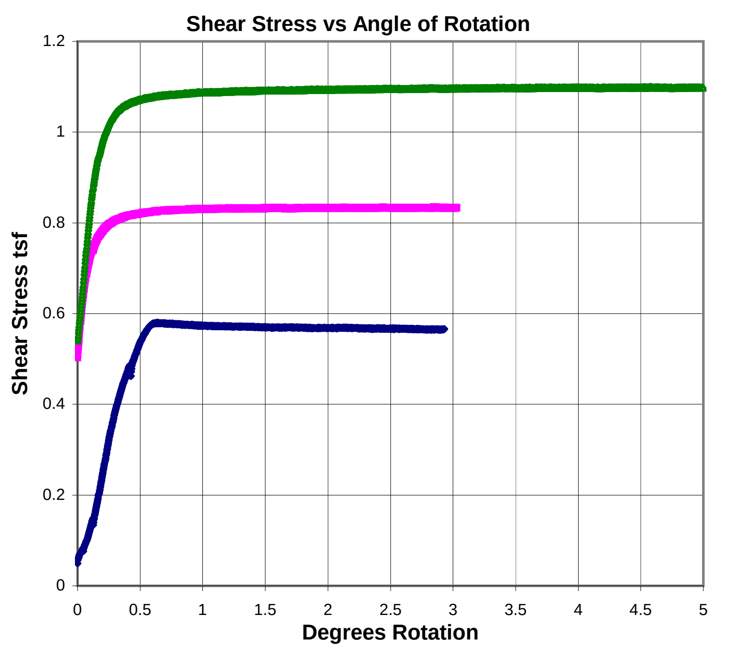
Remarks: Testing performed in general accordance with ASTM:D6467-06a. The testing chamber was modified to minimize sidewall friction.
The specimen was air dried and ground through a #200 sieve. The specimen was the rehydrated past the liquid limit and allowed to adjust for at least 10 days. The specimen was then placed into the testing chamber with a spatula. The sample was incrementally consolidated to 7.7 tsf and then unloaded to the initial testing pressure and presheared a minimum of 1 full rotation. The testing chamber was then removed from the apparatus and the wall height adjusted to specimen height minimizing sidewall friction. The testing chamber was then placed into the appatarus and sheared at the given rate until a constant load was measured. The specimen was then loaded to the next normal pressure and sheared again. This was repeated for a 3rd pressure before completing the test.

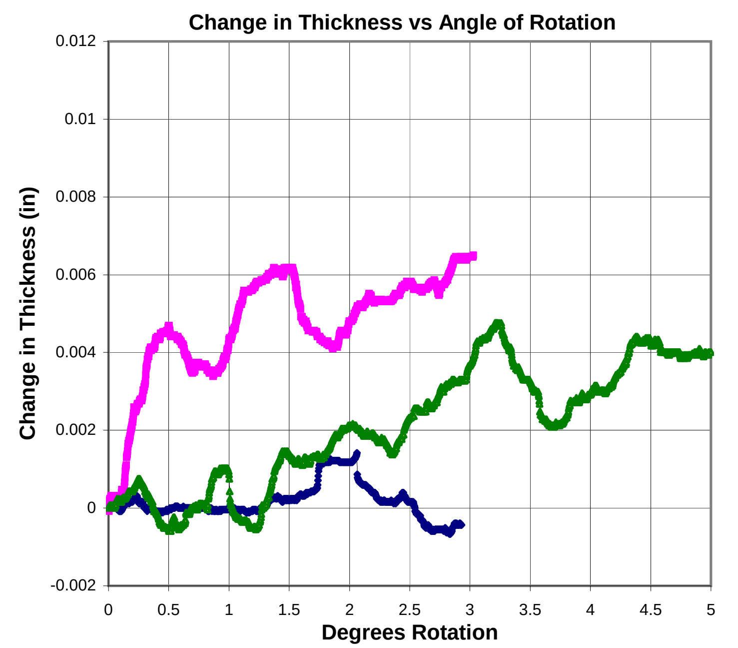
Shear Rate: **0.0270 °/min** Initial Ht: **0.197 in** Outer Dia.: **3.937 in** Inner Dia.: **2.756 in**

	Consolidated Specimen Info				Atterberg Limits	
Normal	**1.50 tsf**	**2.25 tsf**	**3.00 tsf**	**tsf**	LL:	**43.0**
Height	**in**	**in**	**in**	**in**	PL:	**16.4**
					PI:	**26.6**
Residual	**0.57 tsf**	**0.83 tsf**	**1.10 tsf**	**tsf**	Clay Fraction (%):	
Secant	**20.7 °**	**20.3 °**	**20.1 °**	**°**	Organic Content (%):	









Torsional Ring Shear Test

ASTM D:6467-06a

Job #: **9014**

Project: **Lilydale Slide** Client: **Northern Technologies, Inc.** Date: **7/24/2013**

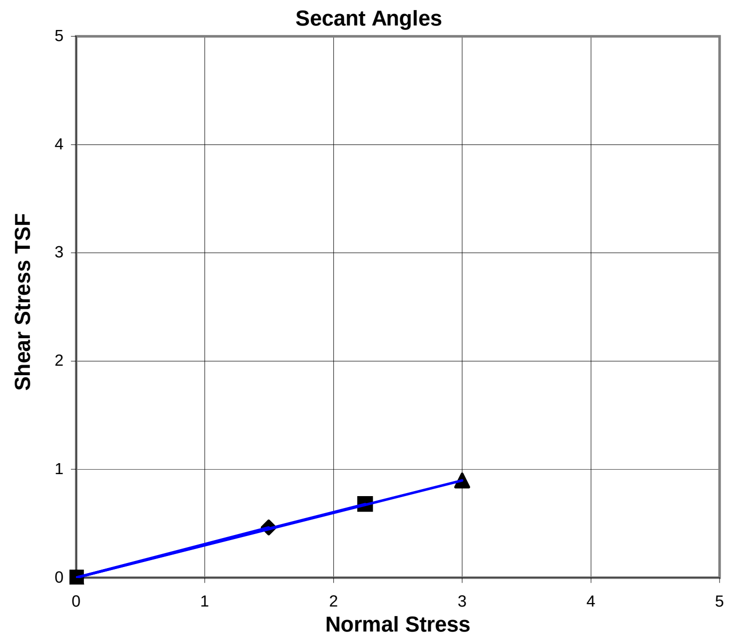
Boring:	Sample:	Depth:	**80**
Location:			
Soil Type:	**Fat Clay (CH)**		

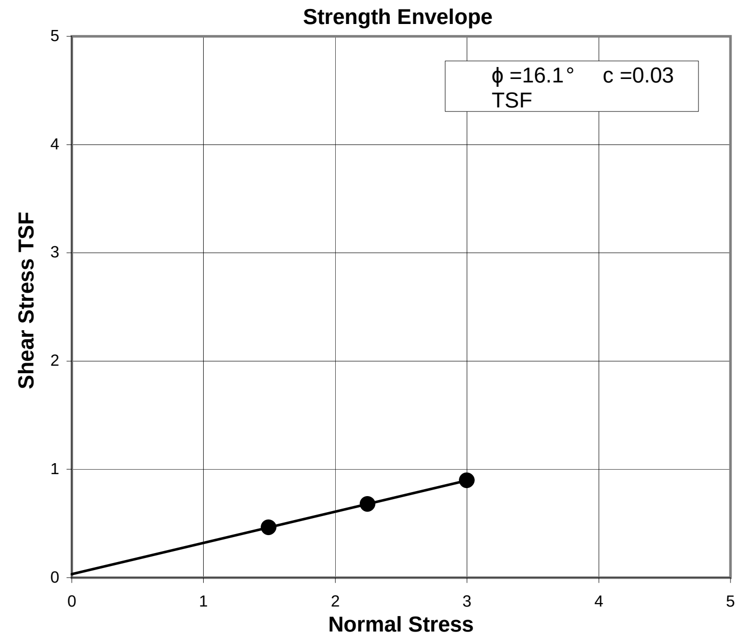
Remarks: Testing performed in general accordance with ASTM:D6467-06a. The testing chamber was modified to minimize sidewall friction.
The specimen was air dried and ground through a #200 sieve. The specimen was the rehydrated past the liquid limit and allowed to adjust for at least 10 days. The specimen was then placed into the testing chamber with a spatula. The sample was incrementally consolidated to 7.7 tsf and then unloaded to the initial testing pressure and presheared a minimum of 1 full rotation. The testing chamber was then removed from the apparatus and the wall height adjusted to specimen height minimizing sidewall friction. The testing chamber was then placed into the appatarus and sheared at the given rate until a constant load was measured. The specimen was then loaded to the next normal pressure and sheared again. This was repeated for a 3rd pressure before completing the test.

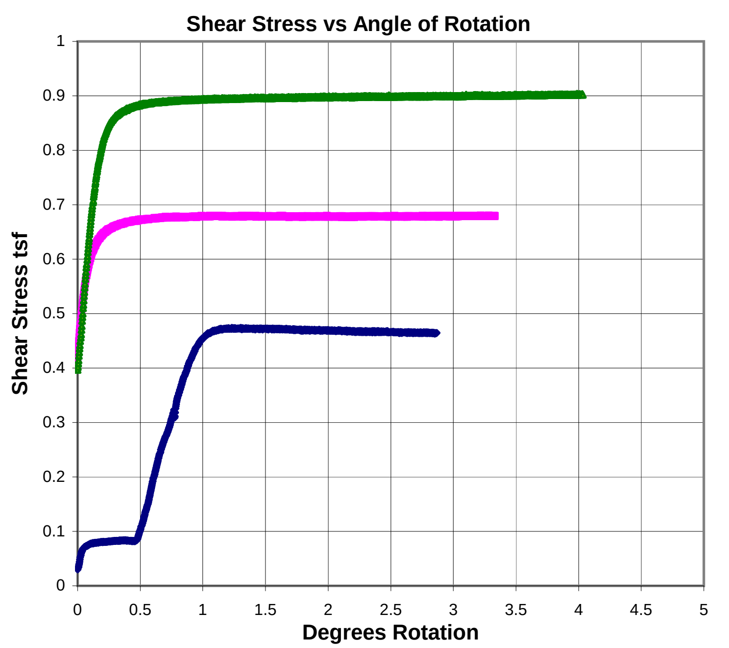
Shear Rate: **0.0270 °/min** Initial Ht: **0.197 in** Outer Dia.: **3.937 in** Inner Dia.: **2.756 in**

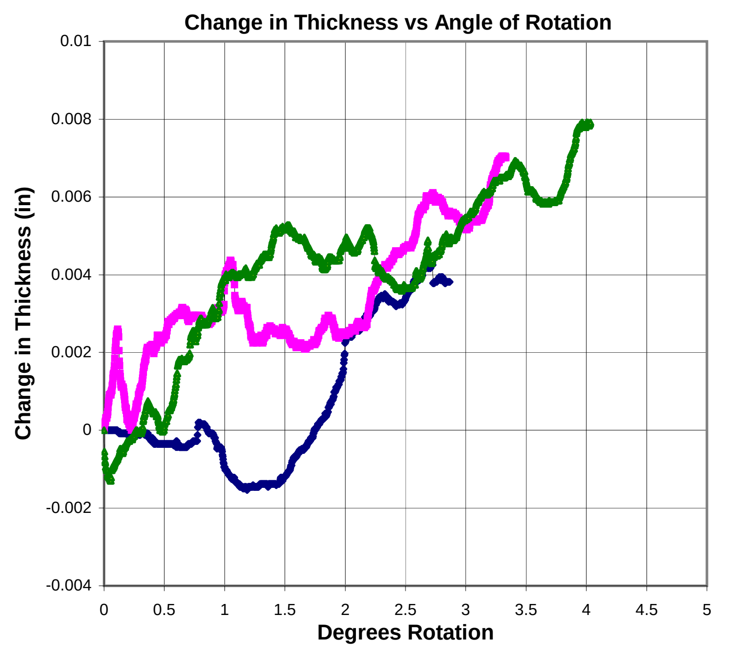
	Consolidated Specimen Info			
Normal	1.50 tsf	2.25 tsf	3.00 tsf	tsf
Height	in	in	in	in
Residual	0.46 tsf	0.68 tsf	0.90 tsf	tsf
Secant	17.3 °	16.8 °	16.7 °	°

Atterberg Limits	
LL:	52.4
PL:	18.6
PI:	33.8
Clay Fraction (%):	
Organic Content (%):	









Current Laboratory Physical Test Results

Table C-1
Lilydale Regional Park
Soil Testing Summary

Sample Location		Approx	Moisture	Dry	Calc.	Atterberg Limits			Unconfined	Direct Shear		Grain Size Distribution					Saturated
Boring No.	Depth (ft)	Soil Type (1)	Content (%)	Density (pcf)	Bulk Dens. (pcf)	Liq. Limit	Plast. Limit	Plast. Index	Compressive Strength (tsf)	Friction Angle (degrees)	Cohesion (psf)	gravel (%)	sand (%)	silt (%)	clay (%)	fines (%)	Permeability (cm/sec)
						(% moisture content)											
Slide Pile		SM	7.5	108.3	116.4					35.1	92	4.5	75.5			20	
HA-1	5	SM	5.7	107.9	114.1					32.7	74	19.9	68.5			11.6	
SB-1	71	CL	16.3			43	16.4	26.6									
	80	CH	13.8			52.4	18.6	33.8									
SB-2-14	3	CL	19.6	102.8	122.9												
	7	CL	5.2														
	11	CL	9.1	127.4	139.0												
	15	SC	6.3									10.8	57.2			32.0	
	19	SC	7.8							33.2	94						
	25	SM	7.2														
	29	SM	5.2									0.1	84.5			15.4	
	31	SM	7.9														
	35	SC	12.9														
	37	SC	11.7									21.1	46.4	23.5	9.0	32.5	
	42.5	CL	24.0	101.9	126.4	33.0	19.9	13.1									
	47	SP-SM	6.6									3.9	83.9			12.2	
	48	SP-SM	5.2	112.7	118.6					28.5	512						
	55	CL	16.7														
	61	SM	9.1									39.9	37.6			22.5	
	69	SM	14.4														
	75.5	Shale	13.7	119.0	135.3				4.9								
	78	Limestone	2.1	156.8	160.1				210.6								
	85.5	Shale	18.8			54.0	21.8	32.2									
	89.5	Shale	17.3	114.9	134.8				8.4								
	99.5	Shale	13.0	123.4	139.4				6.2								
	102.5	Shale	6.4	140.4	149.4				21.5								
SB-3-14	3	CL	25.0														
	7	CL	9.2	126.6	138.2	24.3	12.9	11.4	2.2								
	9	SC	15.4														
	18.5	SC	7.7	126.4	136.1							9.0	60.0			31.0	
	23	SC	8.4	128.8	139.6												
	27	MLS	15.5														
	28	SP	5.2	111.3	117.1					33.7	136						
	35	SC	10.2									7.6	53.9	26.3	12.2	38.5	
	39	SC	11.1	120.4	133.8												
	44.5	MLS	19.7														
	45.5	SP	3.2	100.8	104.0					28.7	106						
	47	SC	10.7	125.6	139.0	22.4	10.5	11.9									
	52.5	SM	21.9														
	55	SM	12.2	118.3	132.7					31.3	184						
	56	SM	6.0														
	57	SP-SM	4.6									10.2	82.3			7.5	
	63	SM	3.3														
	71	SM	13.1														
STP B-1	3	CL	22.2														
	5	SC	8.5									7.7	60.8	26.7	4.8	31.5	
	9	SC	13.7	104.7	119.0												1.60E-04
	11	SP	1.8									0	96.5			3.5	
	17	SP	1.3	101	102.3					29.8	80						
	21	CL-ML	20.4			21.8	17.2	4.6									
	25	SC	13.5														
	29	SC	9.9	130.2	143.1					33.4	180						
	33	SP	12.3														
	35	SC				19.8	10.2	9.6									
	37	SC	10.3	127.8	141.0				1.3								
	41	SC	12.1	127.3	142.7												
	51	SC	12.7														
	53	CL	26.7			43.6	14.1	29.5									
	55	CL	15.7	112.8	130.5				5.3								
	61	SM	16.6									0.1	83.4			16.5	
STP B-2	5	CL-ML	25.6	98.1	123.2				0.7								2.80E-07
	7	SM	12.7														
	9	SM	9.3	122.2	133.6				1.1								2.00E-08
	11	SM				15.2	10.3	4.9									
	13	SC	8.2									8.6	60.6	25.4	5.4	30.8	
	17	SC/SM	8.0	130.5	140.9				2.6								
	19	SC/SM	7.9	129.8	140.1				2.8								
	23	SM	7.0									0.9	90.9			8.2	
	29	CL	11.4			22.7	9.9	12.8									
	31	CL-ML	12.2	126.6	142.0				1.5								
	37	SP	4.6	97.8	102.3					30.00	110	4.4	89.0			6.6	
	39	SM	4.8														
	44.5	CL	11.8														
	46	CL				33.1	11.1	22.0									
	49	CL	12.4	123.8	139.2				16.1								
	Number of Tests		72	32	32	12	12	12	14	10	10	16	16	4	4	16	3
	Minimum Values		1.3	97.8	102.3	15.2	9.9	4.6	0.7	28.5	74.0	0.0	37.6	23.5	4.8	3.5	0.0
	Maximum Values		26.7	156.8	160.1	54.0	21.8	33.8	210.6	35.1	512.0	39.9	96.5	26.7	12.2	38.5	0.0
	Average Values		11.4	118.9	131.2	32.1	14.4	17.7	20.4	31.6	156.8	9.3	70.7	25.5	7.9	20.0	0.0
	Standard Deviations		5.9	13.4	13.7	13.2	4.2	10.6	55.1	2.3	130.6	10.3	17.4	1.4	3.4	11.3	0.0

Notes
(1) Approximate Soil Types - see boring logs for full description
(2) Samples may have been partially collapsed during the sampling process and results may not indicate full collapsibility

Moisture Contents

Laboratory Test Summary

Project: Lilydale Regional Park **Job:** 9428

Client: Barr Engineering Company **Date:** 7/8/14

Sample Information & Classification

Boring #	SB-2-14	SB-2-14	SB-2-14	SB-3-14	SB-3-14	SB-3-14	SB-3-14
Sample	2	6	21	47	49	57	62
Depth (ft)	2-4	10-12	42-43	18-19.5	20-22	38-40	46-48
Type or BPF	SB	SB	SB	SB	SB	SB	SB
Classification	Lean Clay with sand (CL)	Sandy Lean Clay (CL/SC)	Lean Clay (CL)	Clayey Sand with little gravel (SC)	Clayey Sand with a trace of gravel (SC)	Clayey Sand with a little gravel (SC)	Clayey Sand with a trace of gravel (SC)

Water Content, Dry Density

Water Content (%)	19.6	9.1	24.0	7.7	8.4	11.1	10.7
Dry Density (pcf)	102.8	127.4	101.9	126.4	128.8	120.4	125.6

Sample Information & Classification

Boring #							
Sample							
Depth (ft)							
Type or BPF							
Classification							

Water Content, Dry Density

Water Content (%)							
Dry Density (pcf)							

Sample Information & Classification

Boring #							
Sample							
Depth (ft)							
Type or BPF							
Classification							

Water Content, Dry Density

Water Content (%)							
Dry Density (pcf)							

Water Content Test Summary (ASTM:D2216)

Project:	Lilydale Regional Park	Job:	9428
Client	Barr Engineering Company	Date:	7/8/2014

Sample Information & Classification

Boring #	SB-2-14	SB-2-14	SB-2-14	SB-2-14	SB-2-14	SB-2-14	SB-2-14	SB-2-14
Sample #								
Depth (ft)	6-8	18-20	24-26	30-32	34-36	46-48	54-56	60-62
Type or BPF	SB	SB	SB	SB	SB	SB	SB	SB
Material Classification	Silty Sand (SM) with patches of Lean Clay (CL)	Clayey Sand with a trace of gravel (SC/SC-SM)	Silty Sand with a trace of gravel (SM)	Silty Sand (SM)	Clayey Sand (SC)	Silty Sand with a trace of gravel (SM/SP-SM)	Sandy Lean Clay with a little gravel (CL)	Silty Clayey Sand with gravel (SC-SM)
Water Content (%)	5.2	7.8	7.2	7.9	12.9	6.6	16.7	9.1

Sample Information & Classification

Boring #	SB-2-14	SB-2-14	SB-3-14	SB-3-14	SB-3-14	SB-3-14	SB-3-14	SB-3-14
Sample #	37	38	40	43	53	60	66	70
Depth (ft)	68-70	85-86	2-4	8-10	26-28	44-45	52-53	55.5-56
Type or BPF	SB	SB	SB	SB	SB	SB	SB	SB
Material Classification	Silty Clayey Sand (SC-SM)	Fat Clay (CH)	Lean Clay (CL)	Clayey Sand (SC)	Silt with sand (ML)	Silt with sand (ML)	Silty Sand (SM)	Silty Sand with gravel (SM)
Water Content (%)	14.4	18.8	25.0	15.4	15.5	19.7	21.9	6.0

Sample Information & Classification

Boring #	SB-3-14	SB-3-14						
Sample #	74	78						
Depth (ft)	62-64	70-72						
Type or BPF	SB	SB						
Material Classification	Silty Sand (SM)	Silty Sand (SM)						
Water Content (%)	3.3	13.1						

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type or BPF								
Material Classification								
Water Content (%)								

Laboratory Test Summary

Project: Cherokee Heights **Job:** 9444

Client: Barr Engineering Company **Date:** 7/15/14

Sample Information & Classification

Boring #	STP-B-1	STP-B-1					
Sample	K40	K46					
Depth (ft)	28-30	40-42					
Type or BPF	SB	SB					
Classification	Clayey Sand w/a little gravel (SC)	Clayey Sand w/a little gravel (SC)					

Water Content, Dry Density

Water Content (%)	9.9	12.1					
Dry Density (pcf)	130.2	127.3					

Sample Information & Classification

Boring #							
Sample							
Depth (ft)							
Type or BPF							
Classification							

Water Content, Dry Density

Water Content (%)							
Dry Density (pcf)							

Sample Information & Classification

Boring #							
Sample							
Depth (ft)							
Type or BPF							
Classification							

Water Content, Dry Density

Water Content (%)							
Dry Density (pcf)							

Water Content Test Summary (ASTM:D2216)

Project:	Cherokee Heights	Job:	9444
Client	Barr Engineering Company	Date:	7/16/2014

Sample Information & Classification

Boring #	STP-B-1	STP-B-1	STP-B-1	STP-B-1	STP-B-1	STP-B-1	STP-B-1	STP-B-1
Sample #	K27	K31	K34	K36	K38	K42	K53	K54
Depth (ft)	2-4	10-12	16-18	20-22	24-26	32-34	50-52	52-54
Type or BPF	SB	SB	SB	SB	SB	SB	SB	SB
Material Classification	Lean Clay (CL)	Sand, fine grained (SP)	Sand, fine grained (SP)	Silty Clayey Sand (SC-SM/SM)	Clayey Sand (SC)	Sand (SP)	Silty Sand (SM)	Lean Clay with sand (CL)
Water Content (%)	22.2	1.8	1.3	20.4	13.5	12.3	12.7	26.7

Sample Information & Classification

Boring #	STP-B-1	STP-B-2	STP-B-2	STP-B-2	STP-B-2			
Sample #	K58	K4	K15	K20	K23a			
Depth (ft)	60-62	6-8	28-30	38-40	44-45			
Type or BPF	SB	SB	SB	SB	SB			
Material Classification	Clayey Sand (SC)	Silty Sand (SM)	Sandy Lean Clay (CL)	Silty Sand (SM)	Sandy Lean Clay (CL)			
Water Content (%)	16.6	12.7	11.4	4.8	11.8			

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type or BPF								
Material Classification								
Water Content (%)								

Sample Information & Classification

Boring #								
Sample #								
Depth (ft)								
Type or BPF								
Material Classification								
Water Content (%)								

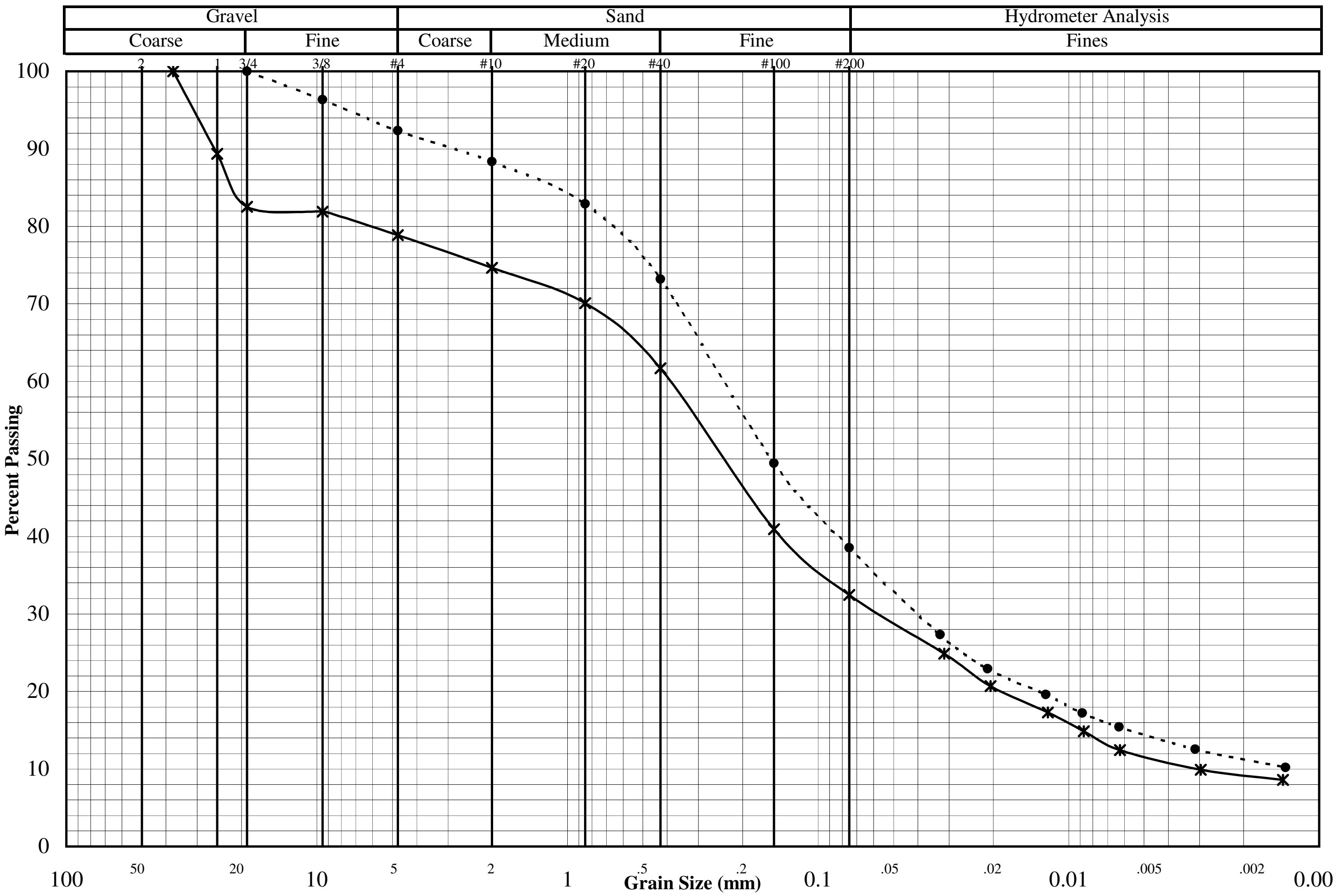
Grain Size

Grain Size Distribution ASTM D422

Job No. : **9428**

Project:	Lilydale Regional Park	Test Date:	6/26/14
Reported To:	Barr Engineering Company	Report Date:	7/8/14

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	SB-2-14		36-38	SB	Clayey Sand with gravel (SC)
●	SB-3-14	56	34-36	SB	Clayey Sand with a little gravel (SC)
◇					



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	11.7	10.2	
Dry Density (pcf)			
Specific Gravity	2.67*	2.67*	
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	350.1	249.1	
2"			
1.5"	100.0		
1"	89.4		
3/4"	82.5	100.0	
3/8"	81.9	96.4	
#4	78.9	92.4	
#10	74.7	88.4	
#20	70.1	82.9	
#40	61.7	73.2	
#100	40.9	49.4	
#200	32.5	38.5	

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

2401 W 66th Street

SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Grain Size Distribution ASTM D422

Job No. : **9428**

Project:	Lilydale Regional Park	Test Date:	6/26/14
Reported To:	Barr Engineering Company	Report Date:	7/8/14

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
Spec 1	SB-2-14		36-38	SB	Clayey Sand with gravel (SC)
Spec 2	SB-3-14	56	34-36	SB	Clayey Sand with a little gravel (SC)
Spec 3					

Sieve Data

Specimen 1		Specimen 2		Specimen 3	
Sieve	% Passing	Sieve	% Passing	Sieve	% Passing
2"		2"		2"	
1.5"	100.0	1.5"		1.5"	
1"	89.4	1"		1"	
3/4"	82.5	3/4"	100.0	3/4"	
3/8"	81.9	3/8"	96.4	3/8"	
#4	78.9	#4	92.4	#4	
#10	74.7	#10	88.4	#10	
#20	70.1	#20	82.9	#20	
#40	61.7	#40	73.2	#40	
#100	40.9	#100	49.4	#100	
#200	32.5	#200	38.5	#200	

Hydrometer Data

Specimen 1		Specimen 2		Specimen 3	
Diameter (mm)	% Passing	Diameter	% Passing	Diameter	% Passing
0.031	24.9	0.033	27.3		
0.020	20.7	0.021	22.9		
0.012	17.3	0.012	19.6		
0.009	14.9	0.009	17.2		
0.006	12.5	0.006	15.4		
0.003	9.9	0.003	12.6		
0.001	8.6	0.001	10.2		

Remarks

Specimen 1	Specimen 2	Specimen 3

2401 West 66th Street

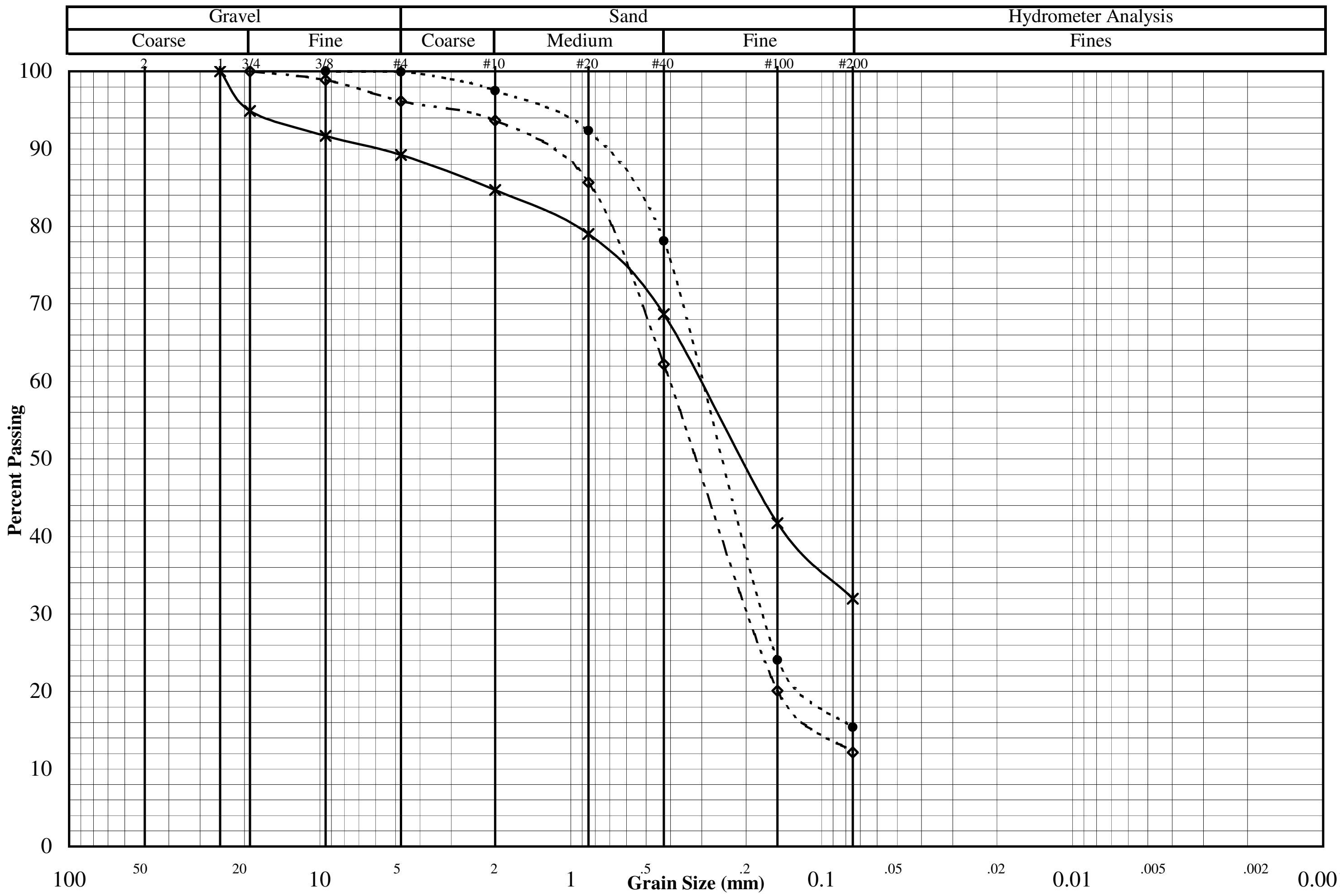
SOIL ENGINEERING TESTING, INC.

Richfield, MN 55423

Grain Size Distribution ASTM D422

Project:	Lilydale Regional Park	Job No. :	9428
		Test Date:	6/26/14
Reported To:	Barr Engineering Company	Report Date:	7/3/14

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	SB-2-14		14-16	Jar	Silty Sand with a little gravel (SM)
●	SB-2-14		28-30	Jar	Silty Sand (SM)
◇	SB-2-14		46-48	Jar	Silty Sand with a trace of gravel (SM/SP-SM)



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	6.3	5.2	6.6
Dry Density (pcf)			
Specific Gravity			
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	249.9	275.5	356.6
2"			
1.5"			
1"	100.0		
3/4"	94.9		100.0
3/8"	91.7	100.0	98.9
#4	89.2	99.9	96.1
#10	84.7	97.5	93.7
#20	79.0	92.3	85.7
#40	68.7	78.1	62.2
#100	41.7	24.1	20.1
#200	32.0	15.4	12.2

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

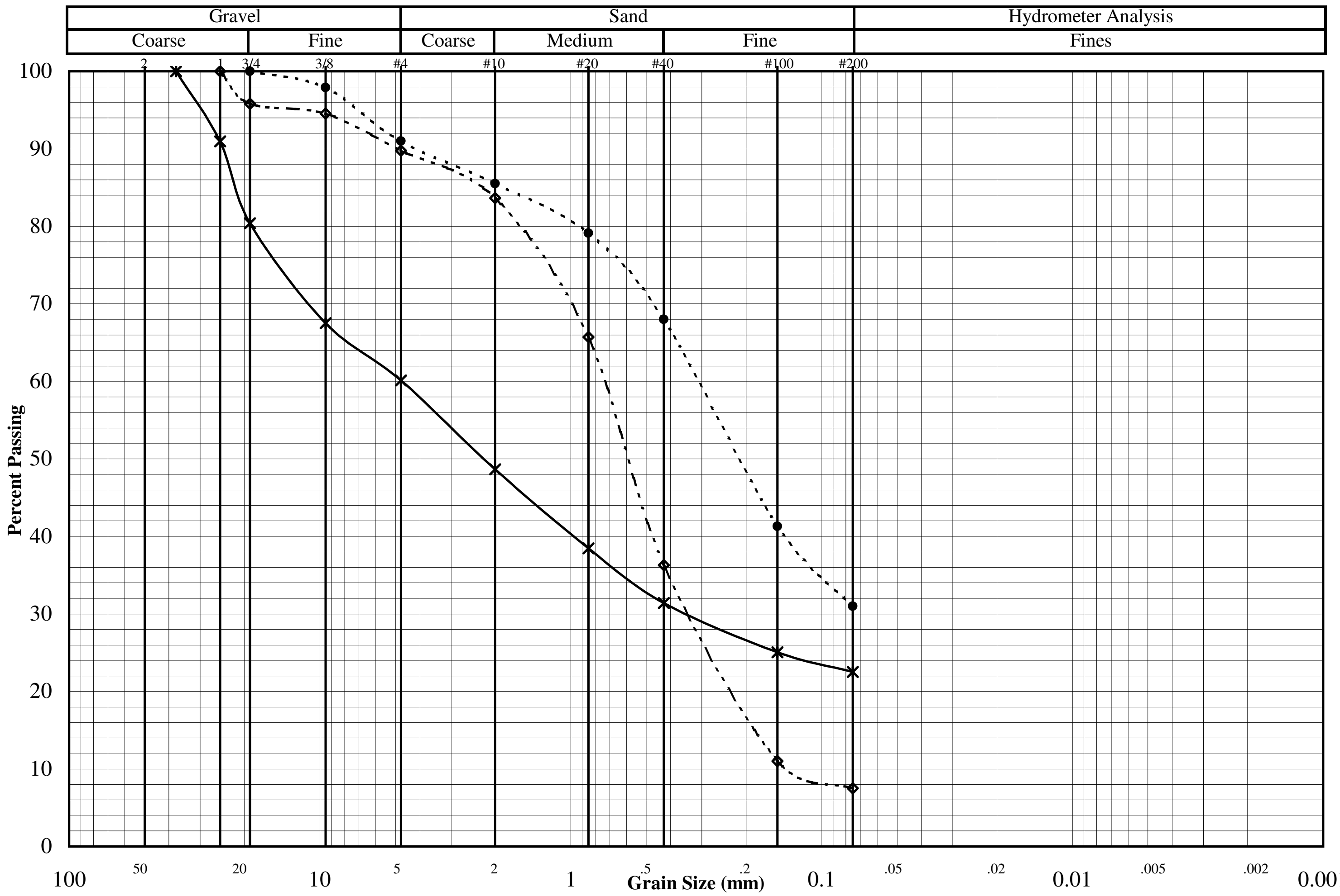
Remarks:

Grain Size Distribution ASTM D422

Job No. : **9428**

Project:	Lilydale Regional Park	Test Date:	6/26/14
Reported To:	Barr Engineering Company	Report Date:	7/8/14

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	SB-2-14		60-62	SB	Silty Clayey Sand with gravel (SC-SM)
●	SB-3-14	47	18-19.5	SB	Clayey Sand with a little gravel (SC)
◇	SB-3-14	71	56-58	SB	Sand with silt and a little gravel, medium to fine grained (SP-SM)



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	9.1	7.7	4.6
Dry Density (pcf)			
Specific Gravity			
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	263.9	291.1	341.9
2"			
1.5"	100.0		
1"	90.9		100.0
3/4"	80.4	100.0	95.8
3/8"	67.5	97.9	94.6
#4	60.1	91.0	89.8
#10	48.7	85.5	83.6
#20	38.5	79.1	65.7
#40	31.4	68.0	36.3
#100	25.1	41.3	11.0
#200	22.5	31.0	7.5

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

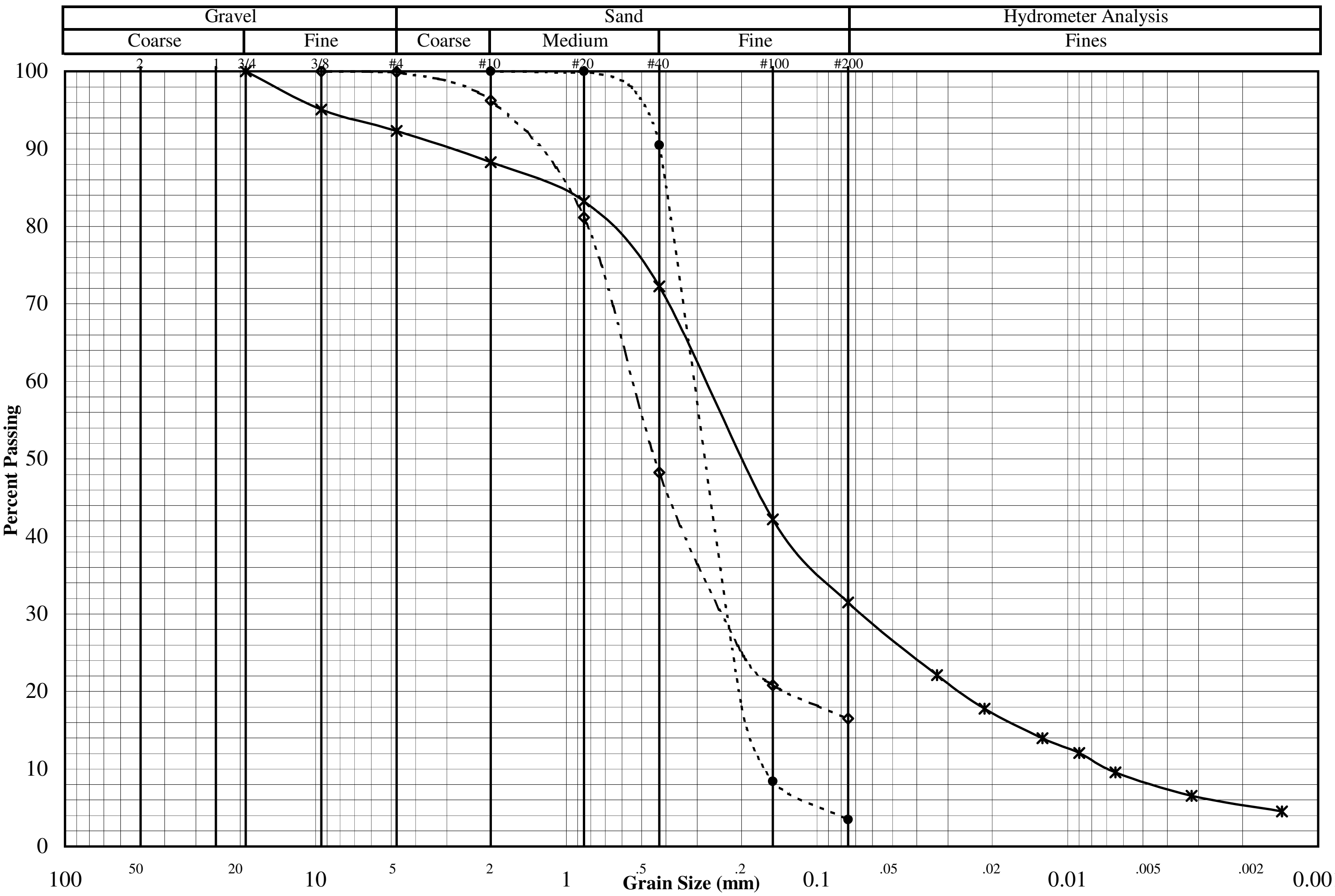
Remarks:

Grain Size Distribution ASTM D422

Job No. : **9444**

Project:	Cherokee Heights	Test Date:	
Reported To:	Barr Engineering Company	Report Date:	

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	STP-B-1	K28	4-6	SB	Clayey Sand with a little gravel (SC)
●	STP-B-1	K31	10-12	SB	Sand, fine grained (SP)
◇	STP-B-1	K58	60-62	SB	Clayey Sand (SC)



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	8.5	1.8	16.6
Dry Density (pcf)			
Specific Gravity	2.67*		
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	232.2	137.1	174.2
2"			
1.5"			
1"			
3/4"	100.0		
3/8"	95.1		100.0
#4	92.3		99.9
#10	88.3	100.0	96.2
#20	83.2	100.0	81.2
#40	72.3	90.5	48.2
#100	42.2	8.4	20.8
#200	31.5	3.5	16.5

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

2401 W 66th Street

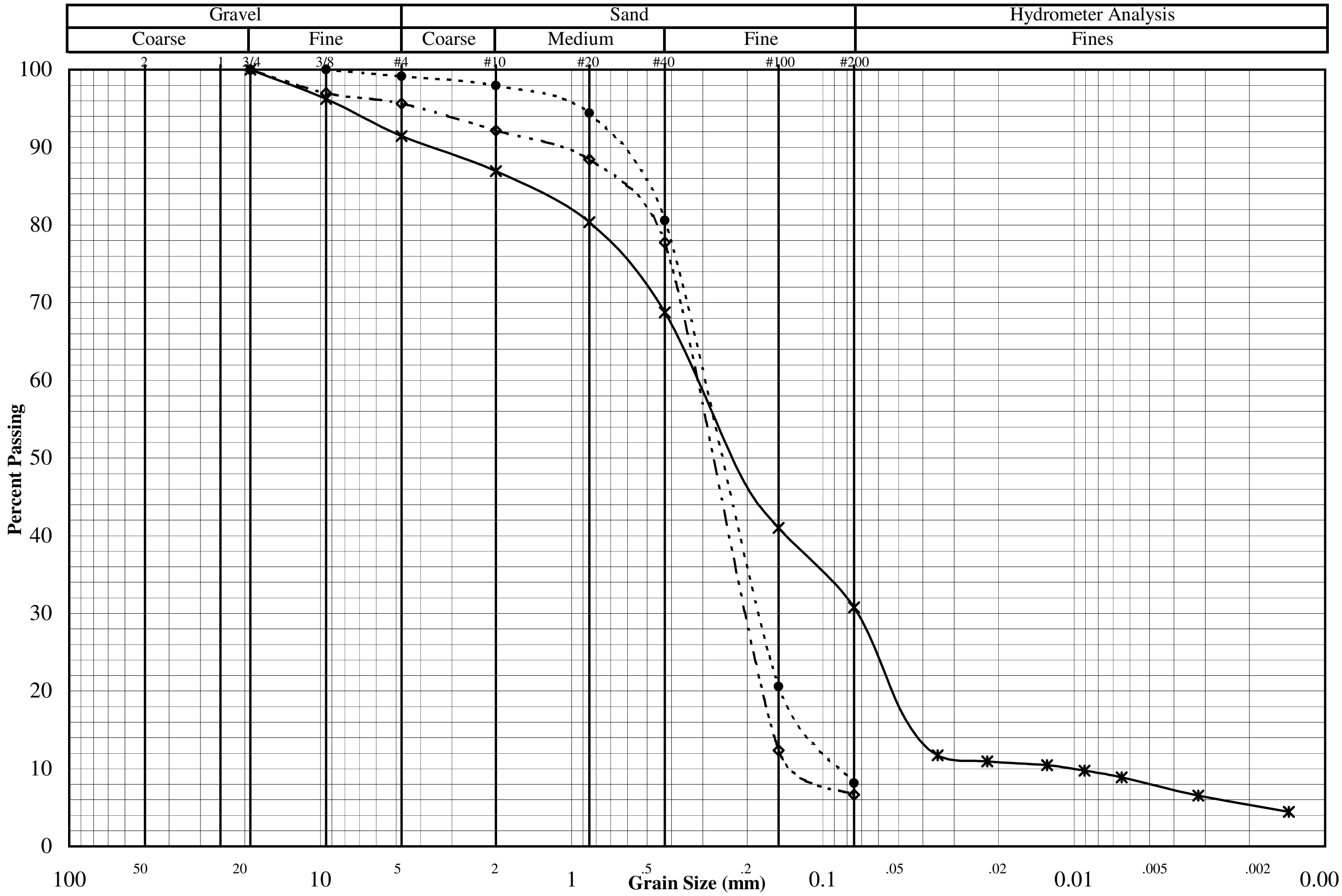
SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Grain Size Distribution ASTM D422

Job No. :	**9444**		
Project:	Cherokee Heights	Test Date:	7/2/14
Reported To:	Barr Engineering Company	Report Date:	7/8/14

	Location / Boring No.	Sample No.	Depth (ft)	Sample Type	Soil Classification
*	STP-B-2	K7	12-14	SB	Clayey Sand w/a little gravel (SC)
●	STP-B-2	K12	22-24	SB	Sand w/silt, fine grained (SP-SM)
◇	STP-B-2	K19	36-38	SB	Sand w/silt and a trace of gravel, fine graine (SP-SM)



Other Tests

	*	●	◇
Liquid Limit			
Plastic Limit			
Plasticity Index			
Water Content	8.2	7.0	4.6
Dry Density (pcf)			
Specific Gravity	2.67*		
Porosity			
Organic Content			
pH			
Shrinkage Limit			
Penetrometer			
Qu (psf)			

(* = assumed)

Percent Passing

	*	●	◇
Mass (g)	265.5	196.6	286.6
2"			
1.5"			
1"			
3/4"	100.0		100.0
3/8"	96.2	100.0	97.0
#4	91.4	99.1	95.6
#10	86.9	98.0	92.2
#20	80.4	94.4	88.4
#40	68.7	80.6	77.8
#100	41.0	20.6	12.3
#200	30.8	8.2	6.6

	*	●	◇
D_{60}			
D_{30}			
D_{10}			
C_U			
C_C			

Remarks:

2401 W 66th Street

SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Atterberg Limits

Laboratory Test Summary

Project: Lilydale Regional Park — Job: 9428

Client: Barr Engineering Company — Date: 7/8/2014

Sample Information & Classification

Boring #	SB-2-14	SB-2-14	SB-3-14	SB-3-14				
Sample #		38	43	62				
Depth (ft)	42-43	85-86	8-10	46-48				
Type or BPF	SB	SB	SB	SB				
Material Classification	Lean Clay (CL)	Fat Clay (CH)	Clayey Sand (SC)	Clayey Sand (SC)				

Atterberg Limits

Liquid Limit (%)	33.0	54.0	24.3	22.4				
Plastic Limit (%)	19.9	21.8	12.9	10.5				
Plasticity Index (%)	13.1	32.2	11.4	11.9				

Sample Information & Classification

Boring #								
Location								
Depth (ft)								
Type or BPF								
Material Classification								

Atterberg Limits

Liquid Limit (%)								
Plastic Limit (%)								
Plasticity Index (%)								

Laboratory Test Summary

Project:	Cherokee Heights	Job:	9444
Client:	Barr Engineering Company	Date:	7/8/2014

Sample Information & Classification

Boring #	STP-B-1	STP-B-1	STP-B-1	STP-B-2	STP-B-2	STP-B-2		
Sample #	K36	K43	K54	K6	K15	K23b		
Depth (ft)	20-22	34-36	52-54	10-12	28-30	45.5-46		
Type or BPF	SB	SB	SB	SB	SB	SB		
Material Classification	Silty Clayey Sand (SC-SM/SM)	Clayey Sand with a trace of gravel (SC)	Lean Clay with sand (CL)	Silty Clayey Sand (SC-SM/SM)	Sandy Lean Clay (CL)	Lean Clay with sand (CL)		

Atterberg Limits

Liquid Limit (%)	21.8	19.8	43.6	15.2	22.7	33.1		
Plastic Limit (%)	17.2	10.2	14.1	10.3	9.9	11.1		
Plasticity Index (%)	4.6	9.6	29.5	4.9	12.8	22.0		

Sample Information & Classification

Boring #								
Location								
Depth (ft)								
Type or BPF								
Material Classification								

Atterberg Limits

Liquid Limit (%)								
Plastic Limit (%)								
Plasticity Index (%)								

Direct Shears

Direct Shear Test

ASTM: D3080

Job No.: 9428

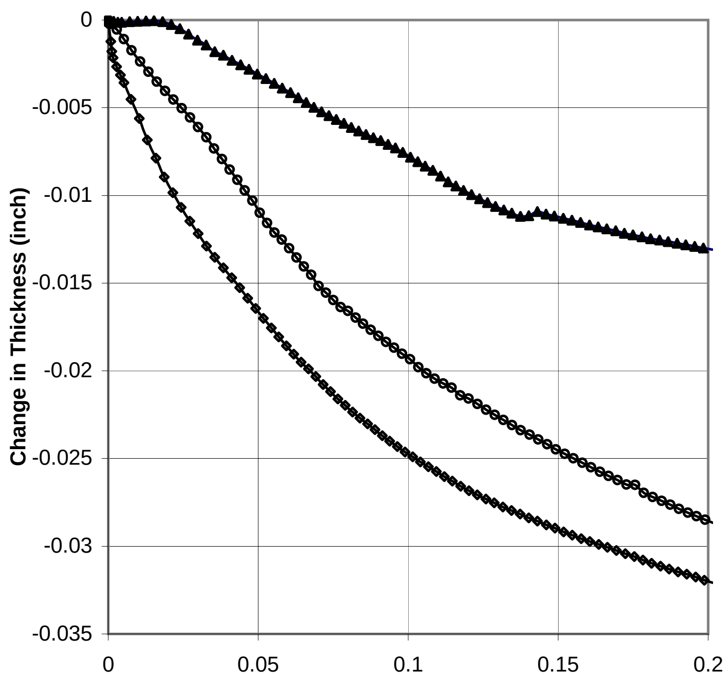
Project/Client: **Lilydale / Barr Engineering Company**
Boring No.: **SB-2-14** Sample No. Depth: **20-22**
Location: Sample Type: **SB**
Soil Type: **Silty Clayey Sand (SC-SM)**

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	
0.005 (in/min)	

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

(*) = Assumed Specific Gravity

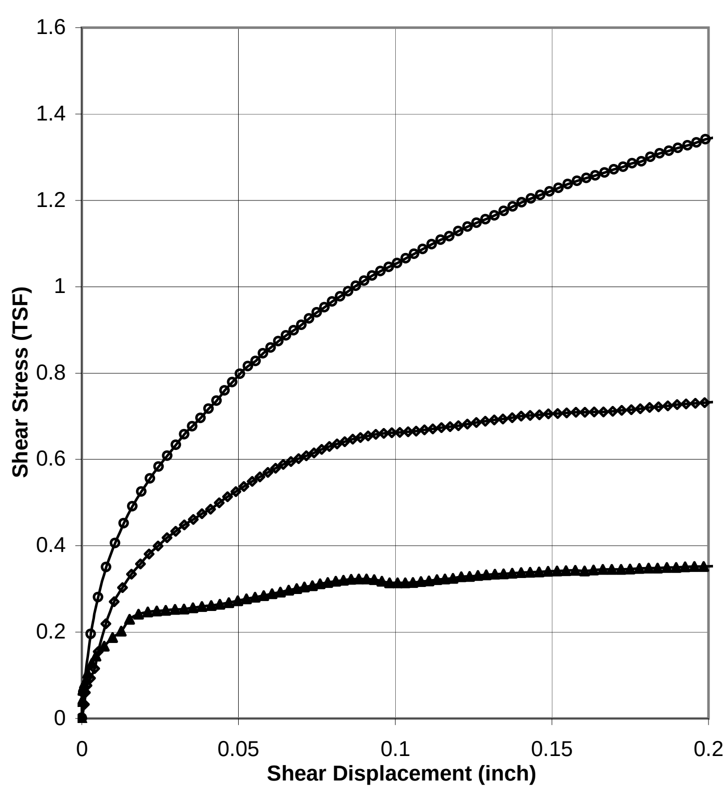
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.68**

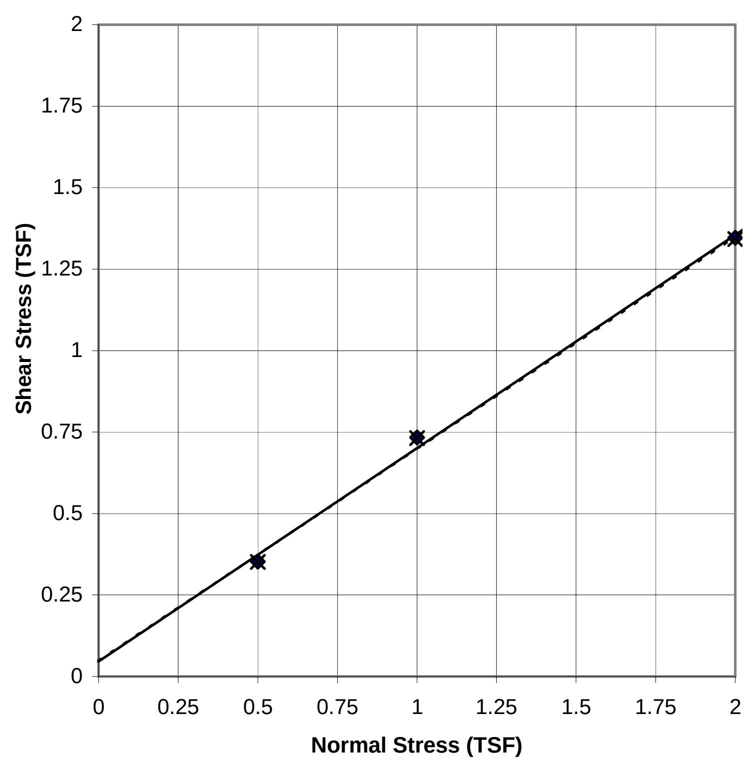


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	7.2	7.2	7.2	
Dry Density (pcf)	116.9	116.9	116.9	
Before Shear				
Thickness (In.)	0.90	0.87	0.85	
Water Content (%)	15.5	13.9	12.7	
Dry Density (pcf)	118.1	121.8	124.9	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.35	0.73	1.35	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.2
Friction Angle:	= **33.2 deg.**	Friction Angle:	= **33.1 deg.**
Apparent Cohesion	**0.047 TSF**	Apparent Cohesion	**0.047 TSF**





Direct Shear Test
ASTM: D3080

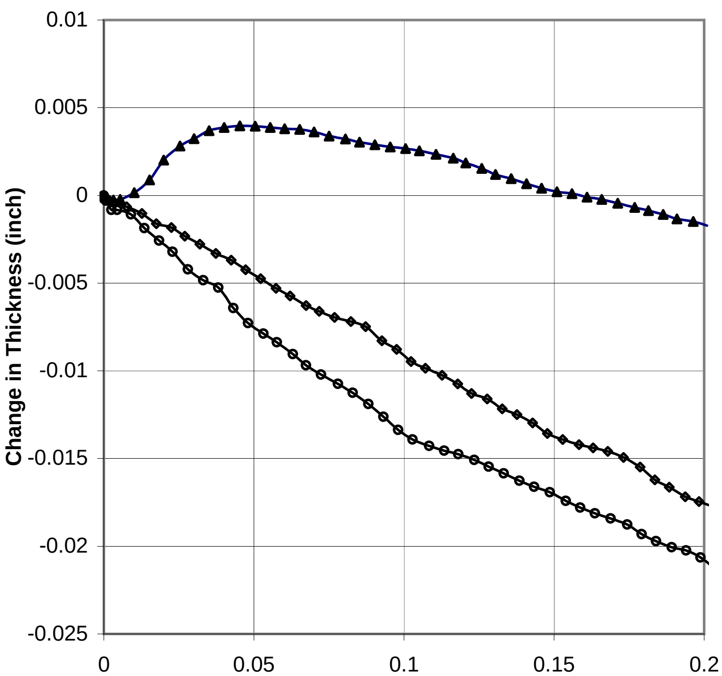
Job No.: 9428

Project/Client:	**Lilydale / Barr Engineering Company**		
Boring No.:	**SB-2-14**	Sample No.	Depth: **28-30**
Location:			Sample Type: **SB**
Soil Type:	**Sand (SP)**		

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	**0.005** (in/min)
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.67**

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

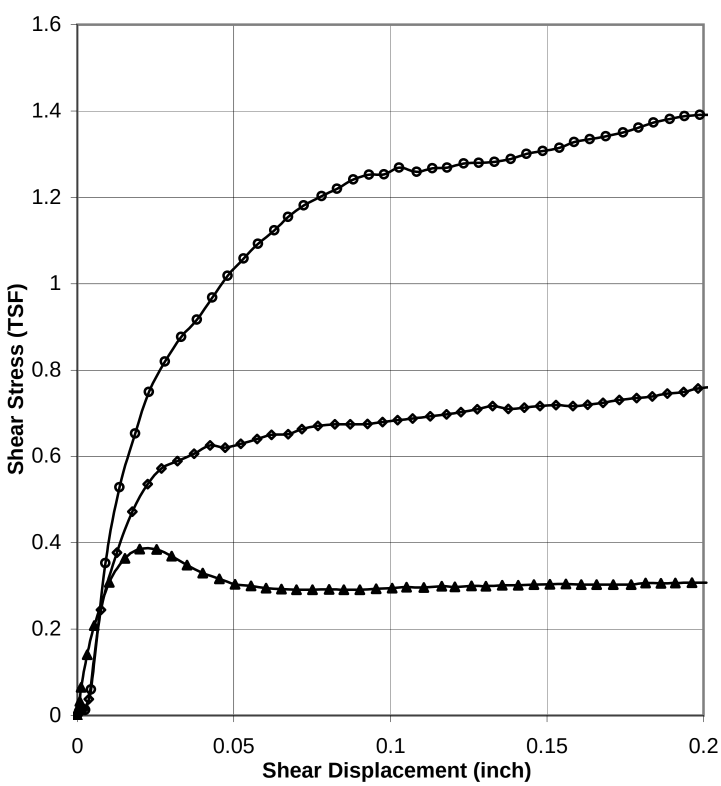
(*) = Assumed Specific Gravity

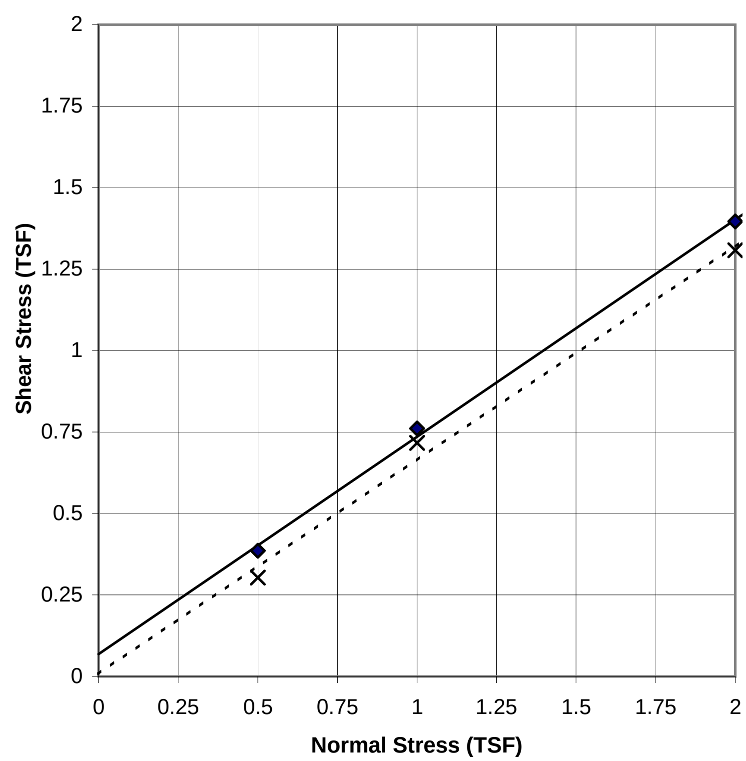


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	5.2	5.2	5.2	
Dry Density (pcf)	111.3	111.3	111.4	
Before Shear				
Thickness (In.)	0.90	0.88	0.90	
Water Content (%)	18.3	17.0	17.7	
Dry Density (pcf)	112.0	114.7	113.1	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.39	0.76	1.40	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.15
Friction Angle:	= **33.7 deg.**	Friction Angle:	= **33.3 deg.**
Apparent Cohesion	**0.068 TSF**	Apparent Cohesion	**0.008 TSF**





Direct Shear Test

ASTM: D3080

Job No.: 9428

Project/Client: **Lilydale / Barr Engineering Company**

Boring No.: **SB-2-14** Sample No. Depth: **48-50**

Location: Sample Type: **SB**

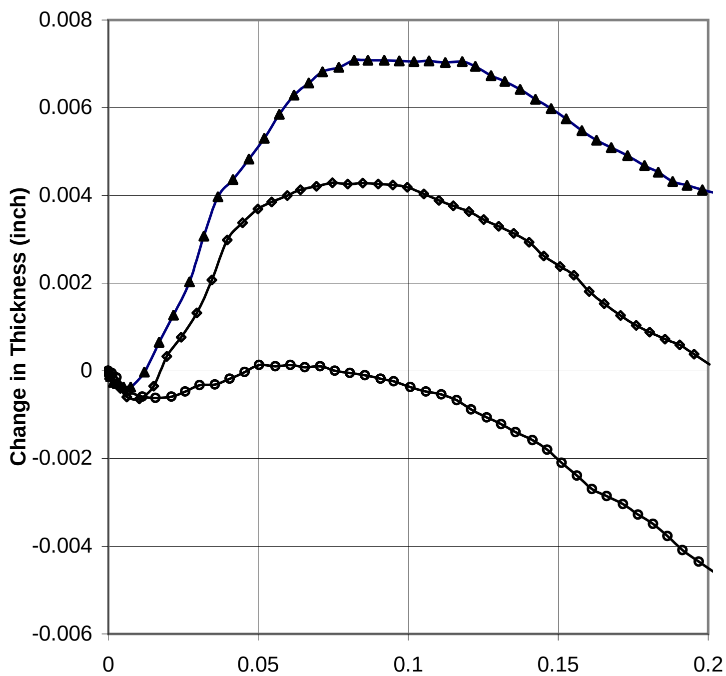
Soil Type: **Sand (SP/SP-SM)**

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	
0.005 (in/min)	

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

(*) = Assumed Specific Gravity

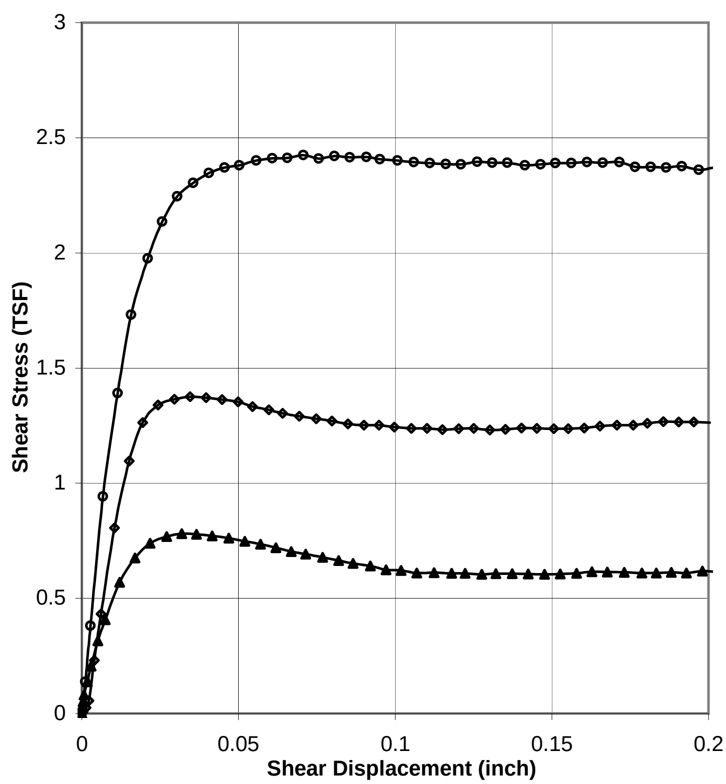
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.67**

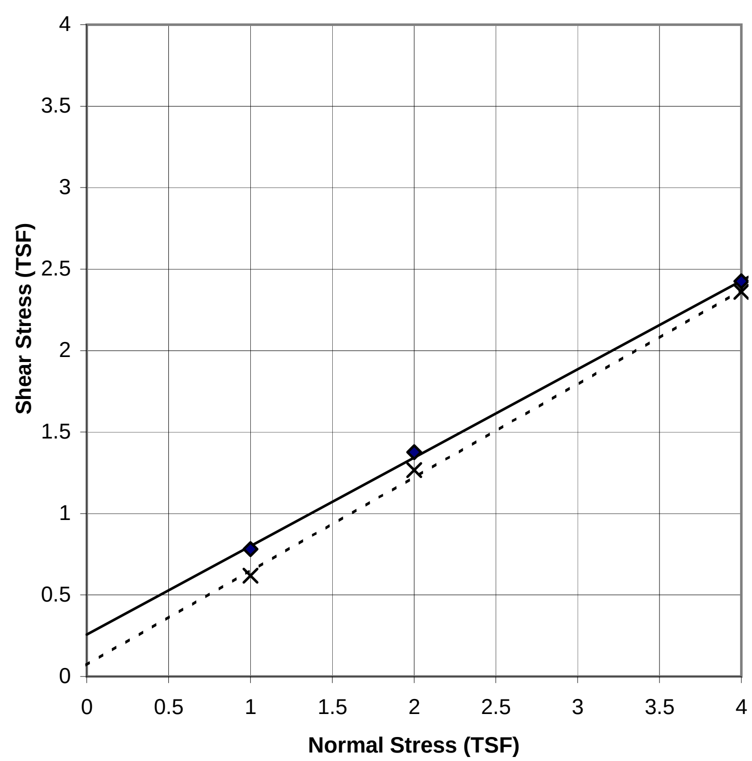


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	5.2	5.2	5.2	
Dry Density (pcf)	112.7	112.7	112.7	
Before Shear				
Thickness (In.)	0.90	0.90	0.88	
Water Content (%)	17.2	17.1	16.2	
Dry Density (pcf)	114.2	114.4	116.4	
Normal Stress	1.00	2.00	4.00	
Shear Stress	0.78	1.38	2.43	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.2
Friction Angle:	= **28.5 deg.**	Friction Angle:	= **29.9 deg.**
Apparent Cohesion	**0.256 TSF**	Apparent Cohesion	**0.072 TSF**





Direct Shear Test
ASTM: D3080

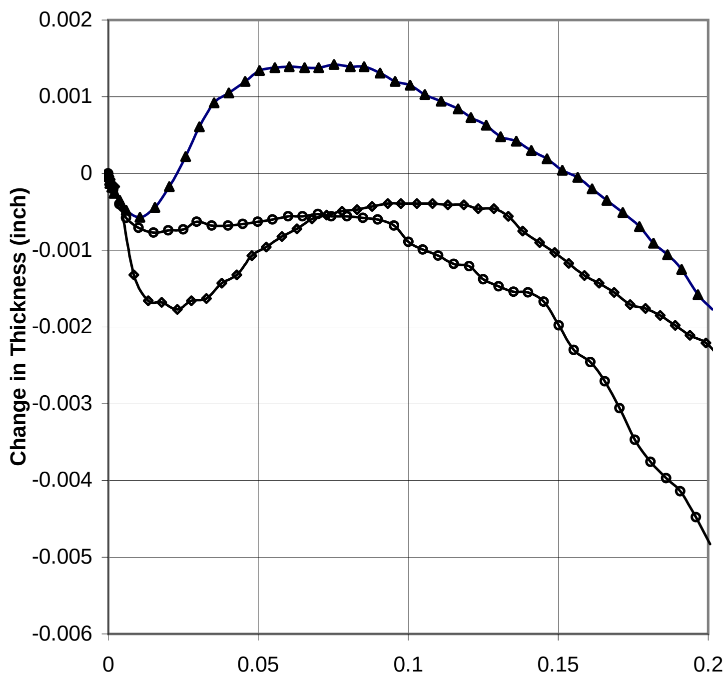
Job No.: 9428

Project/Client:	**Lilydale / Barr Engineering Company**				
Boring No.:	**SB-3-14**	Sample No. **61**	Depth: **45-46**	Test Date:	**7/8/2014**
Location:			Sample Type: **SB**	Date Reported:	**7/20/2014**
Soil Type:	**Sand (SP)**			Shear Rate	**0.005** (in/min)

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

(*) = Assumed Specific Gravity

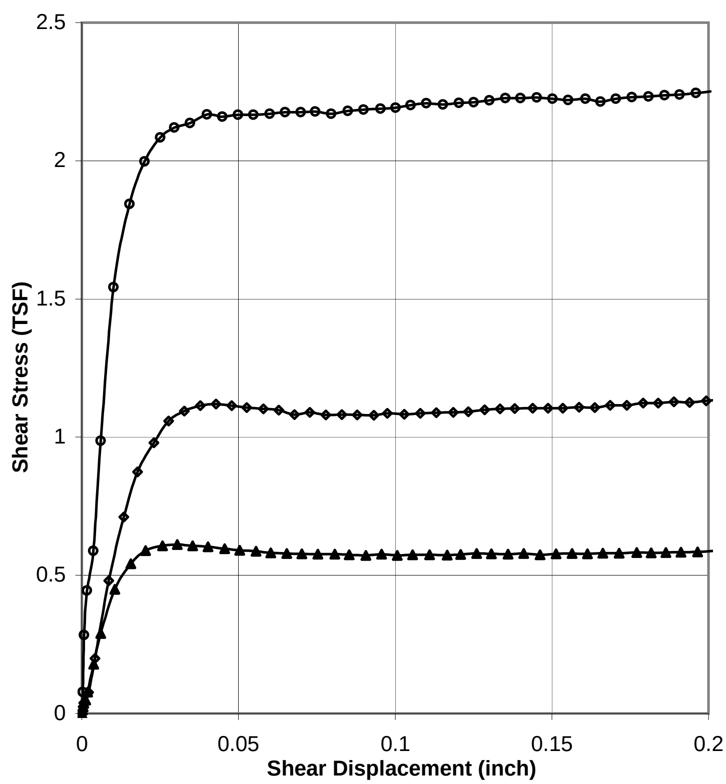
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	2.67

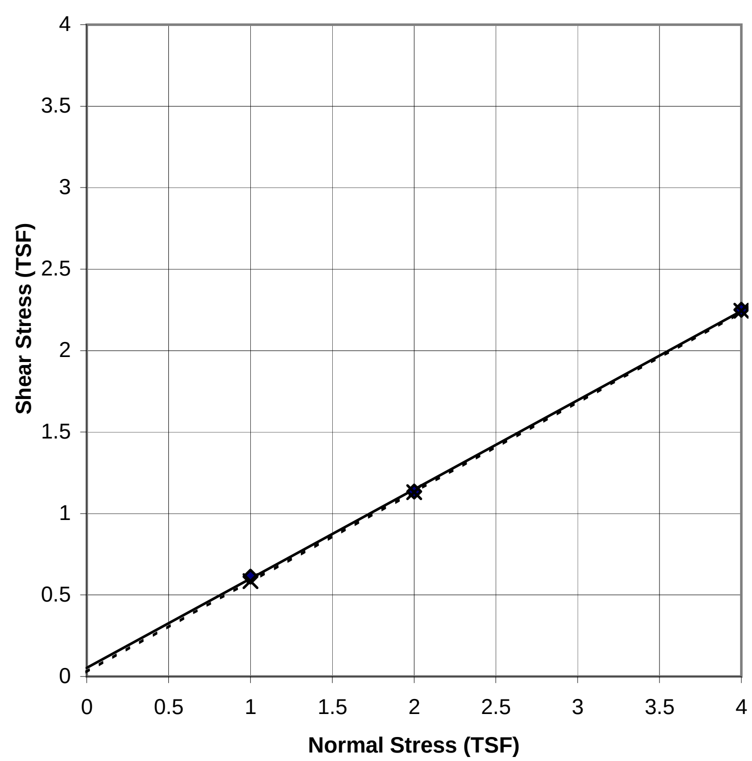


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	3.2	3.2	3.2	
Dry Density (pcf)	100.8	100.8	100.8	
Before Shear				
Thickness (In.)	0.90	0.89	0.90	
Water Content (%)	23.7	23.3	23.6	
Dry Density (pcf)	102.1	102.7	102.2	
Normal Stress	1.00	2.00	4.00	
Shear Stress	0.61	1.13	2.25	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions			At Given Shear Disp. Of:		0.2
Friction Angle:	= **28.7**	**deg.**	Friction Angle:	= **28.9**	**deg.**
Apparent Cohesion	**0.053**	**TSF**	Apparent Cohesion	**0.028**	**TSF**





Direct Shear Test
ASTM: D3080

Job No.: 9428

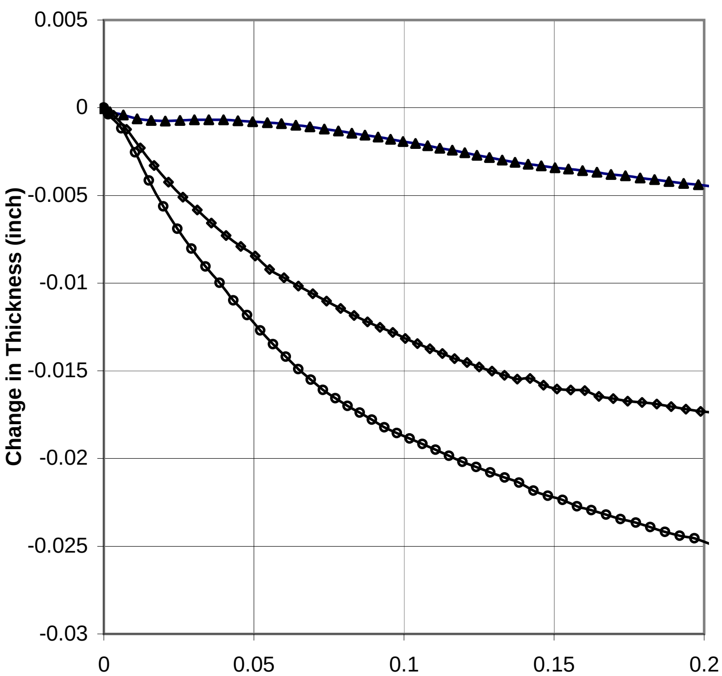
Project/Client:	**Lilydale / Barr Engineering Company**				
Boring No.:	**SB-3-14**	Sample No.	**69**	Depth:	**54-55.5**
Location:				Sample Type:	**SB**
Soil Type:	**Lean Clay with Sand (CL)**				

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	**0.001** (in/min)

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.001 inches/minute.

(*) = Assumed Specific Gravity

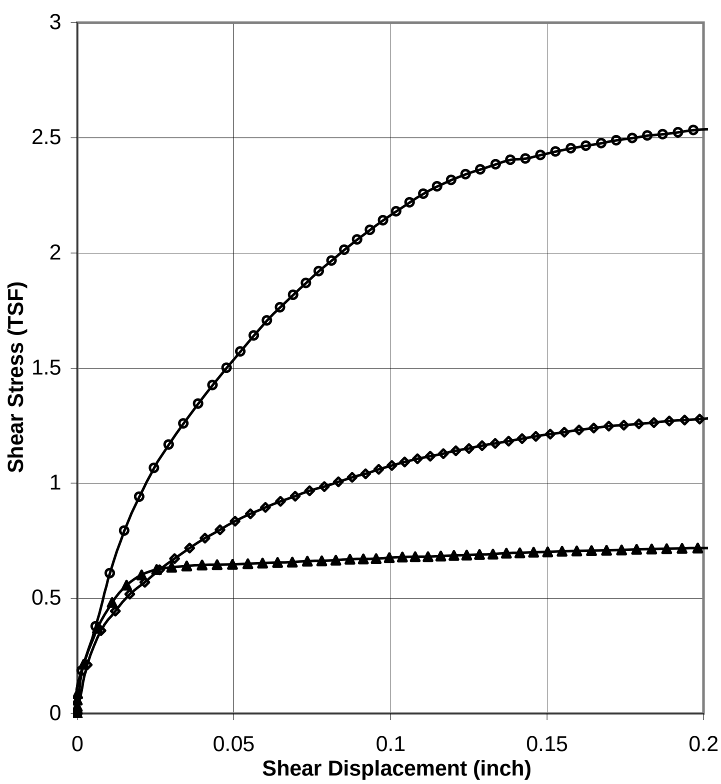
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.68**

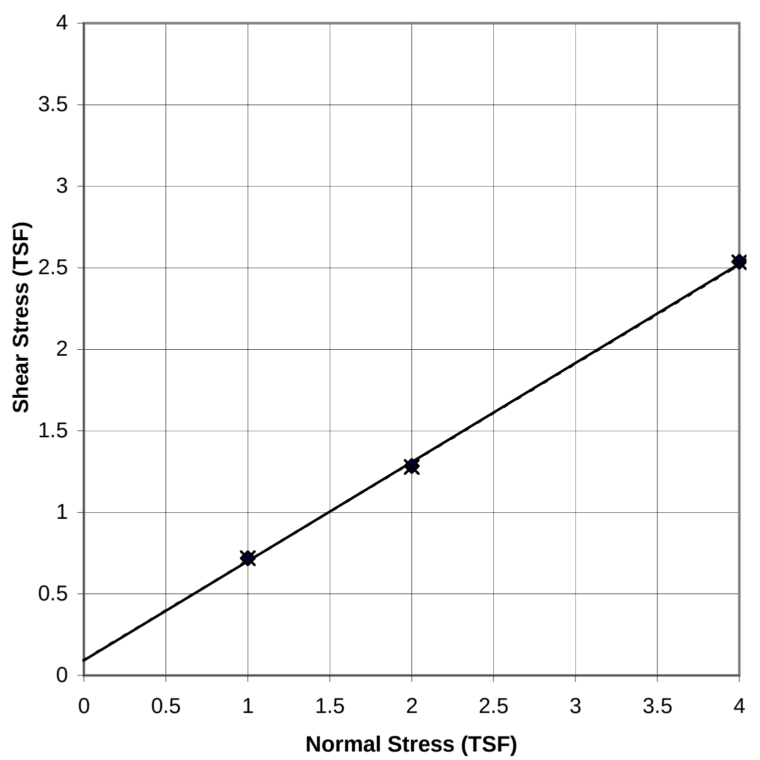


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	12.2	12.2	12.2	
Dry Density (pcf)	118.3	118.3	118.3	
Before Shear				
Thickness (In.)	0.90	0.88	0.86	
Water Content (%)	14.6	13.7	12.5	
Dry Density (pcf)	120.2	122.2	125.4	
Normal Stress	1.00	2.00	4.00	
Shear Stress	0.72	1.28	2.54	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions			At Given Shear Disp. Of:		0.2
Friction Angle:	= **31.3**	**deg.**	Friction Angle:	= **31.3**	**deg.**
Apparent Cohesion	**0.092**	**TSF**	Apparent Cohesion	**0.091**	**TSF**





Direct Shear Test

ASTM: D3080

Job No.: 9444

Project/Client: **Cherokee Heights / Barr Engineering Company**

Boring No.: **STP-B-1** Sample No. **K-34** Depth: **16-18**

Location: Sample Type: **SB**

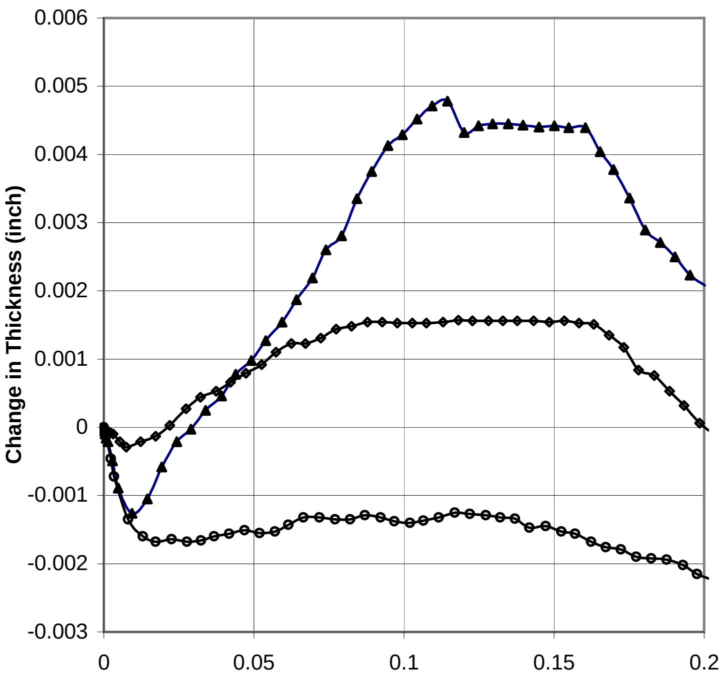
Soil Type: **Sand, fine grained (SP)**

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	
0.005 (in/min)	

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

(*) = Assumed Specific Gravity

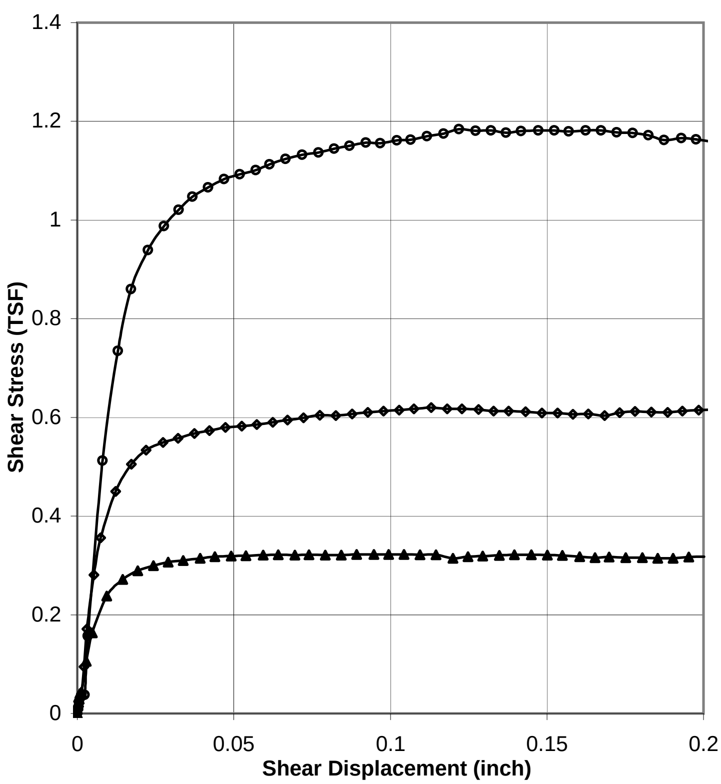
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.67**

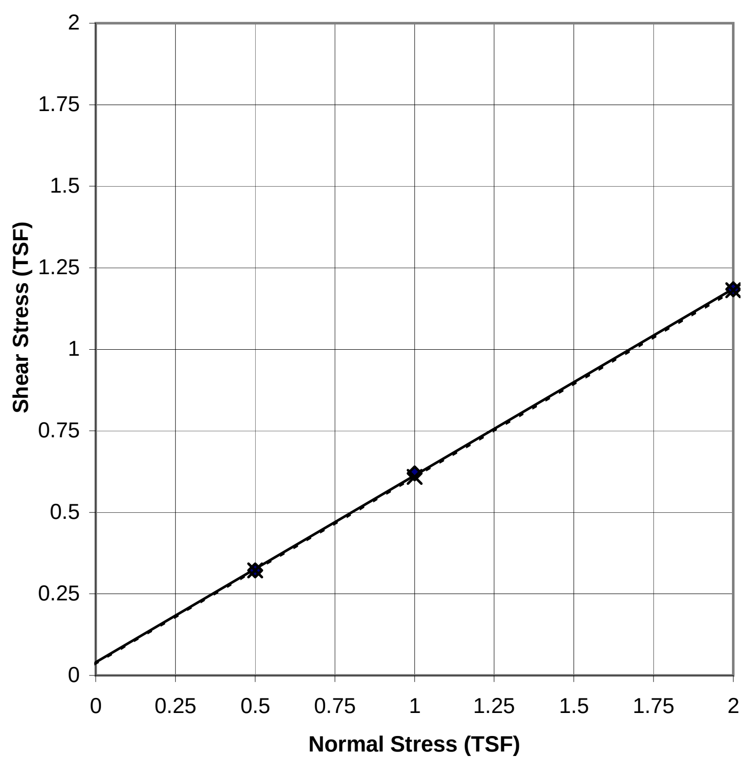


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	1.3	1.3	1.3	
Dry Density (pcf)	101.0	101.0	101.0	
Before Shear				
Thickness (In.)	0.89	0.89	0.89	
Water Content (%)	23.2	23.0	23.0	
Dry Density (pcf)	103.0	103.2	103.3	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.32	0.62	1.18	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.15
Friction Angle:	= **29.8 deg.**	Friction Angle:	= **29.8 deg.**
Apparent Cohesion	**0.040 TSF**	Apparent Cohesion	**0.035 TSF**





Direct Shear Test
ASTM: D3080

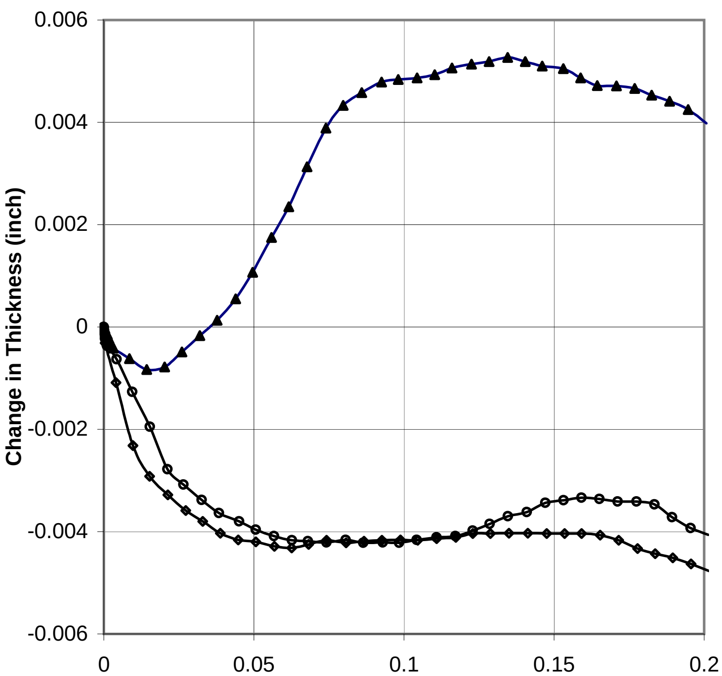
Job No.: 9444

Project/Client: **Cherokee Heights / Barr Engineering Company**
Boring No.: **STP-B-1** Sample No. **K-40** Depth: **28-30**
Location: Sample Type: **SB**
Soil Type: **Clayey Sand with a little gravel (SC)**

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	
0.001 (in/min)	
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.68**

Remarks: Specimens compacted to in-situ conditions at as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.001 inches/minute.

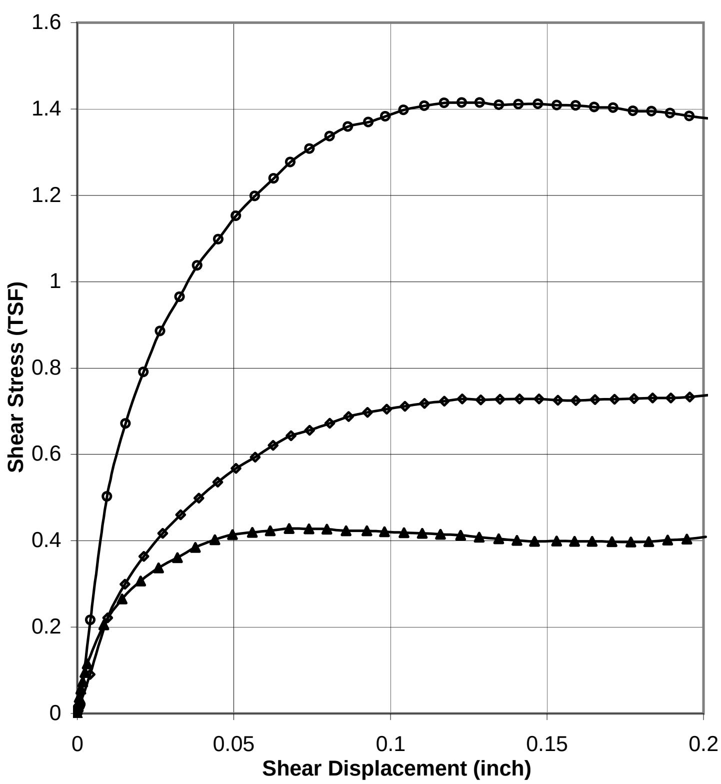
(*) = Assumed Specific Gravity

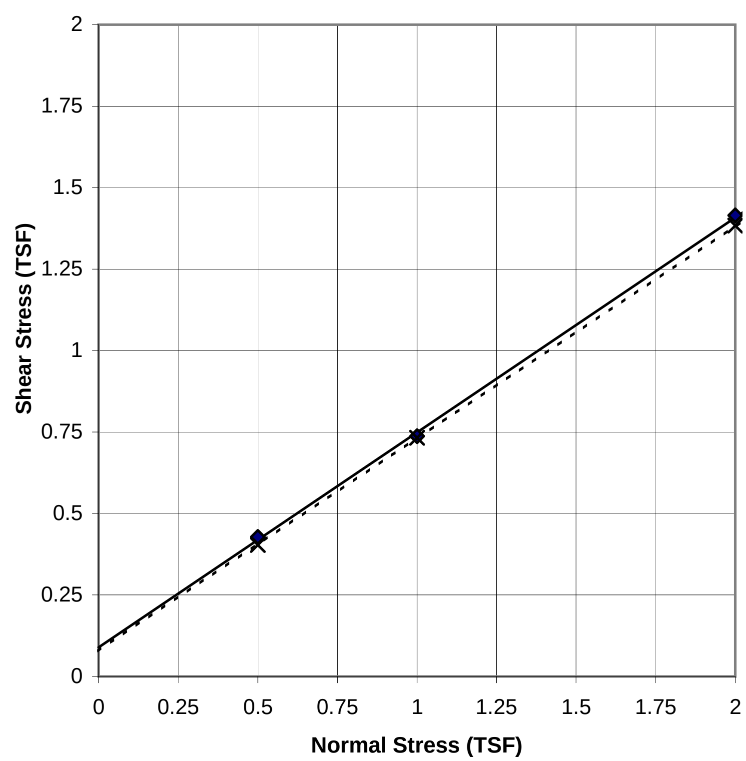


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	10.6	10.6	10.6	
Dry Density (pcf)	129.0	129.0	129.0	
Before Shear				
Thickness (In.)	0.89	0.88	0.87	
Water Content (%)	10.1	9.3	8.7	
Dry Density (pcf)	131.8	134.0	135.6	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.43	0.74	1.41	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of:	0.2
Friction Angle:	= **33.4 deg.**	Friction Angle:	= **33.1 deg.**
Apparent Cohesion	**0.090 TSF**	Apparent Cohesion	**0.078 TSF**





Direct Shear Test
ASTM: D3080

Job No.: 9444

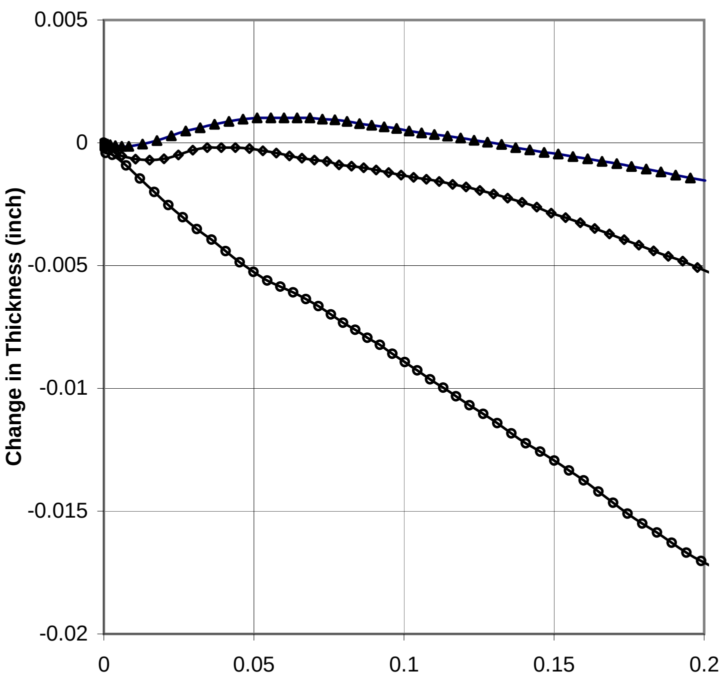
Project/Client: **Cherokee Heights / Barr Engineering Company**
Boring No.: **STP-B-2** Sample No. **K-19** Depth: **36-38**
Location: Sample Type: **SB**
Soil Type: **Sand, Fine Grained (SP)**

Test Date:	**7/8/2014**
Date Reported:	**7/20/2014**
Shear Rate	
0.005 (in/min)	

Remarks: Specimens compacted to a medium dense condition as received moisture content using -#10 material; Inundated after applying normal load. Consolidated and sheared to given displacements at constant rate of 0.005 inches/minute.

(*) = Assumed Specific Gravity

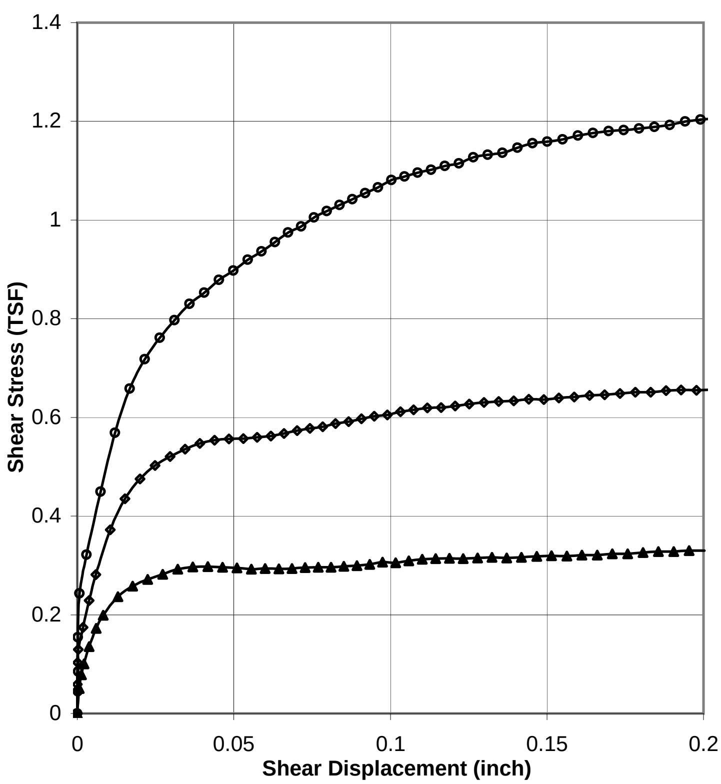
Liquid Limit:	
Plastic Limit:	
Plasticity Index:	
Specific Gravity (*):	**2.67**

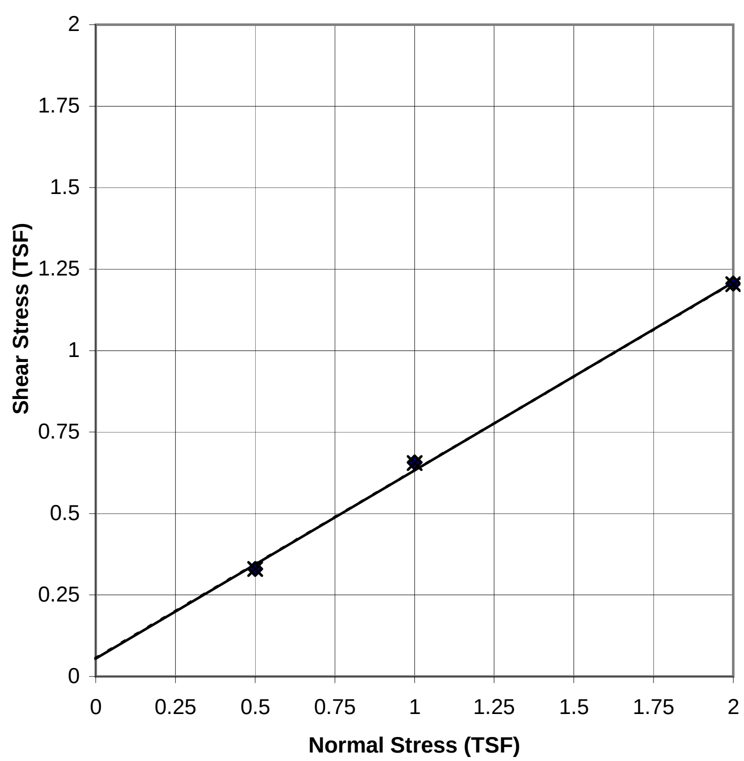


Failure Criterion:				
Max Stress	A	B	C	D
Initial	▲	◇	○	X
Diameter (In.)	2.50	2.50	2.50	
Thickness (In.)	0.91	0.91	0.91	
Water Content (%)	4.6	4.6	4.6	
Dry Density (pcf)	97.8	97.8	97.8	
Before Shear				
Thickness (In.)	0.90	0.90	0.89	
Water Content (%)	25.9	25.5	24.9	
Dry Density (pcf)	98.6	99.1	100.0	
Normal Stress	0.50	1.00	2.00	
Shear Stress	0.33	0.66	1.21	

"These tests are for informational purposes only and must be reviewed by a qualified professional engineer to verify that the test parameters shown are appropriate for any particular design."

Peak Conditions		At Given Shear Disp. Of: 0.2	
Friction Angle:	= **30.0 deg.**	Friction Angle:	= **30.0 deg.**
Apparent Cohesion	**0.055 TSF**	Apparent Cohesion	**0.055 TSF**





Unconfined Compressive Strength

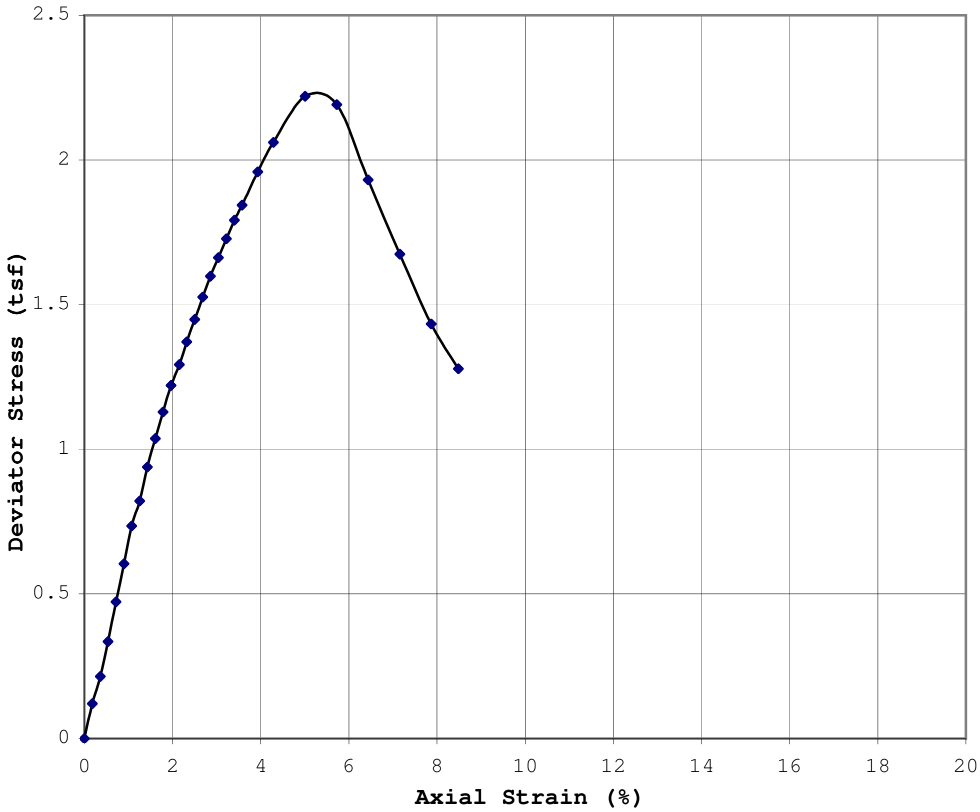
Unconfined Stress/Strain Curves

ASTM: D2166

Project: Lilydale Regional Park | Job: 9428

Client: Barr Engineering Company | Date: 7/8/14

Remarks:



Boring: SB-3-14 Depth: 6-8

Sample #: 42

Soil Type: Clayey Sand w/a little gravel (SC)

Strain Rate (in/min): 0.030

Sample Type: SB

Dia. (in) 1.39 Ht. (in) 2.80

Height to Diameter Ratio: 2.0

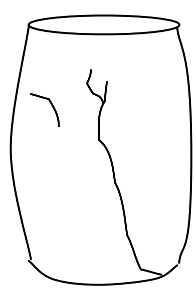
Unconfined Comp. Strength: 2.22 tsf

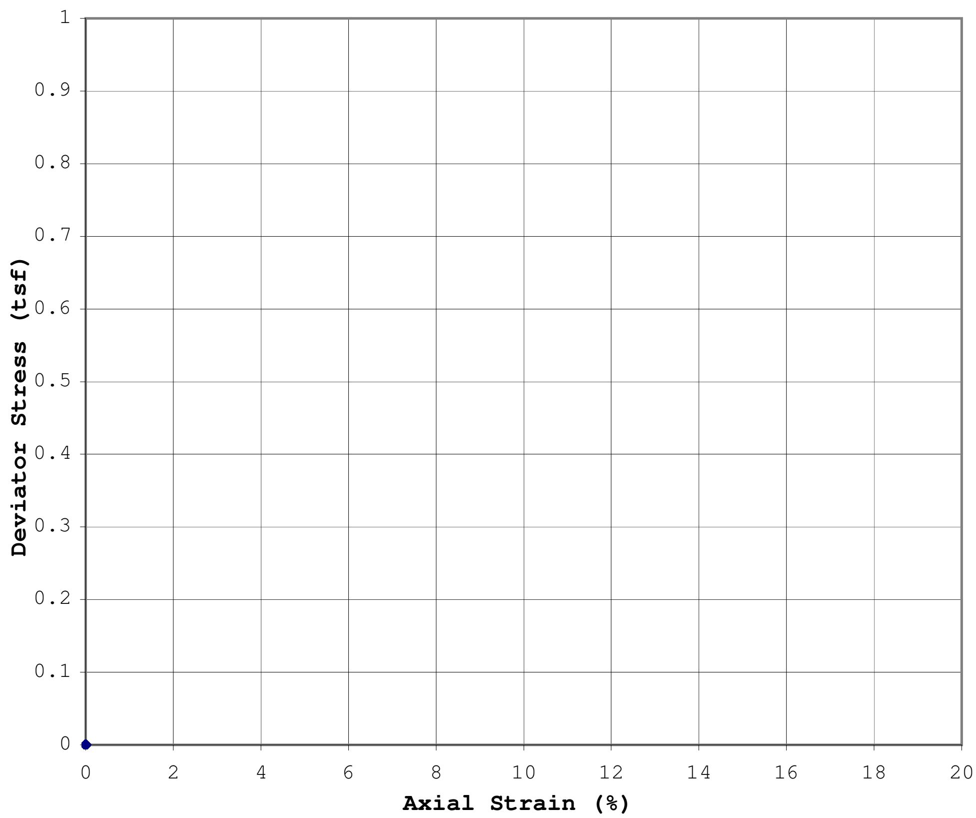
Strain at Failure (%): 5.0

W.C. (%): 9.2

Yd (pcf): 126.6

Sketch of Specimen After Failure





Boring: Depth:

Sample #:

Soil Type:

Strain Rate (in/min):

Sample Type:

Dia. (in): Ht. (in):

Height to Diameter Ratio:

Unconfined Comp. Strength: tsf

Strain at Failure (%):

W.C. (%):

Yd (pcf):

Sketch of Specimen After Failure

2401 W 66th Street

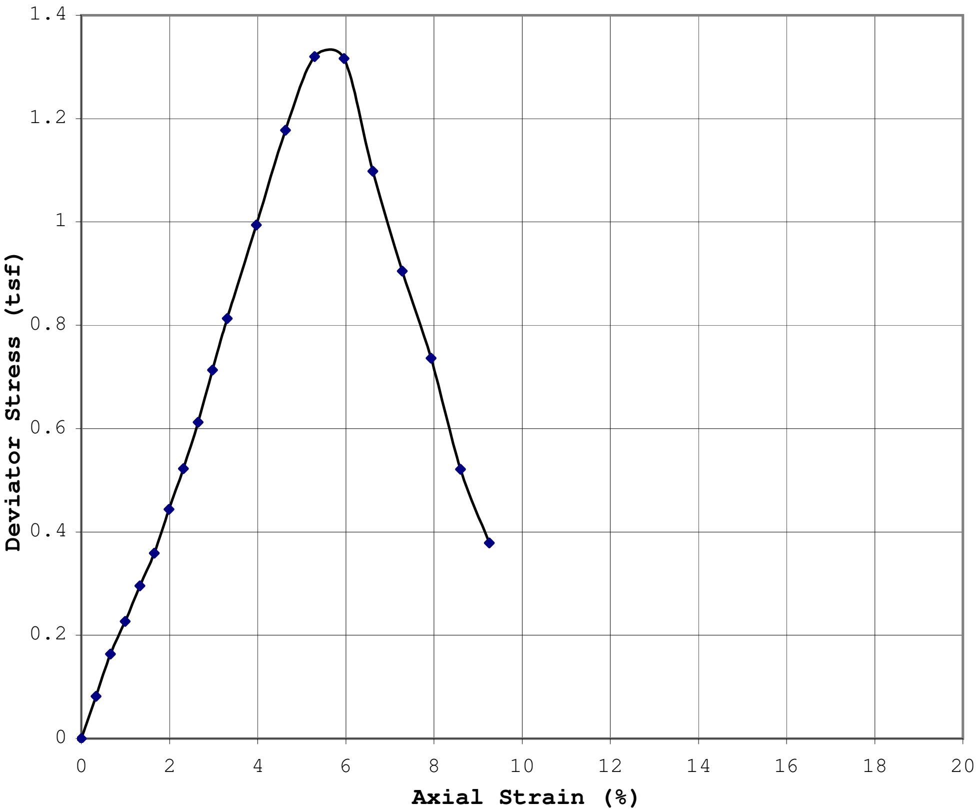
SOIL ENGINEERING TESTING, INC.

Richfield, Minnesota 55423-2031

Unconfined Stress/Strain Curves

ASTM: D2166

Project: Cherokee Heights
Client: Barr Engineering Company
Remarks:
Job: 9444
Date: 7/8/14



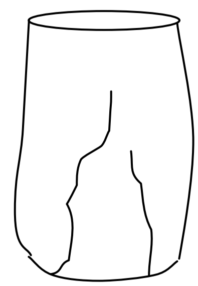
Boring: STP-B-1 Depth: 36-38
Sample #: K44
Soil Type: Clayey Sand w/some patches of Silty Sand (SC)

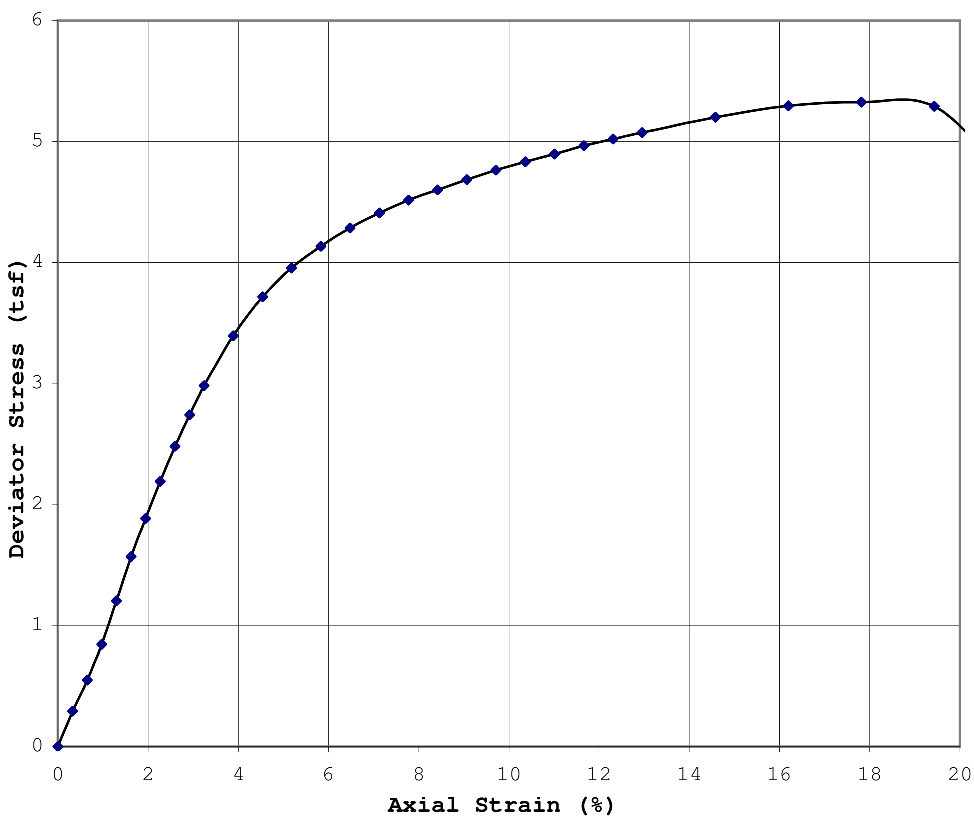
Strain Rate (in/min): 0.030
Sample Type: SB
Dia. (in) 1.45 Ht. (in) 3.02
Height to Diameter Ratio: 2.1

Unconfined Comp. Strength: 1.32 tsf
Strain at Failure (%): 5.3

W.C. (%): 10.3
Yd (pcf): 127.8

Sketch of Specimen After Failure





Boring: STP-B-1 Depth: 54-56
Sample #: K55
Soil Type: Lean Clay w/sand and a trace of gravel (CL)

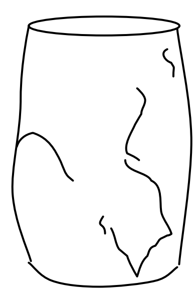
Strain Rate (in/min): 0.030
Sample Type: SB

Dia. (in): 1.42 Ht. (in): 3.09
Height to Diameter Ratio: 2.2

Unconfined Comp. Strength: 5.33 tsf
Strain at Failure (%): 17.8

W.C. (%): 15.7
Yd (pcf): 112.8

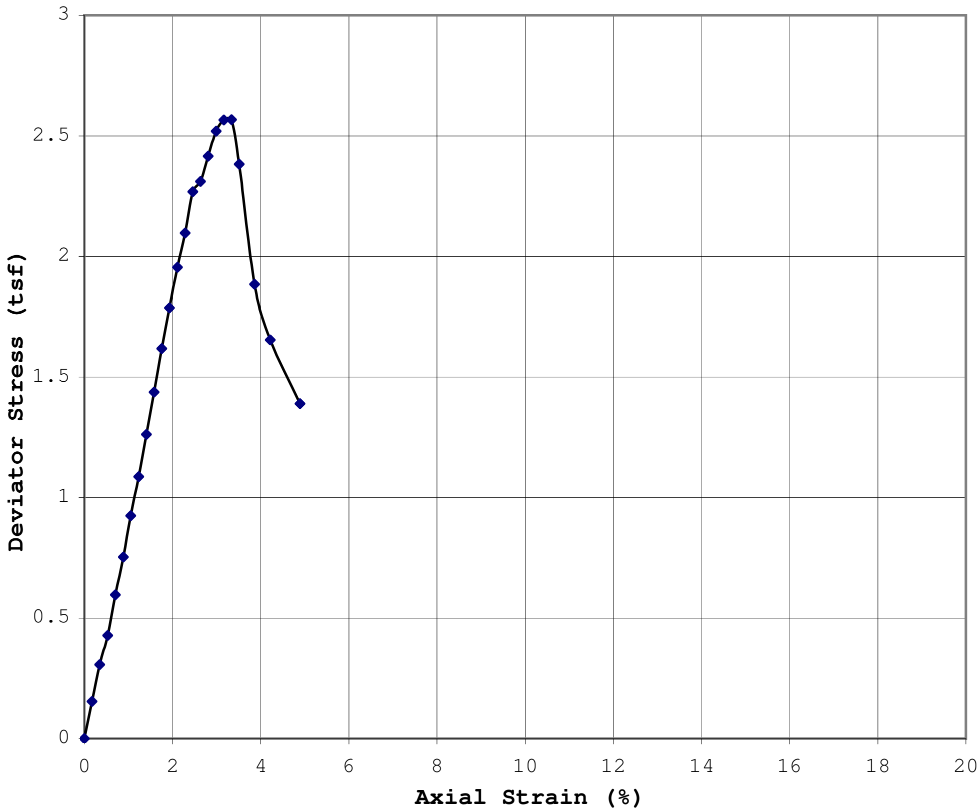
Sketch of Specimen After Failure



Unconfined Stress/Strain Curves

ASTM: D2166

Project: Cherokee Heights
Job: 9444
Client: Barr Engineering Company
Date: 7/8/14
Remarks:



Boring: STP-B-2 Depth: 16.5-17
Sample #: K9a

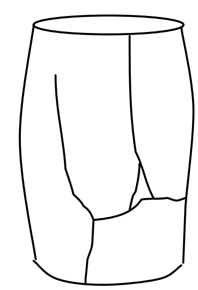
Soil Type: Silty Clayey Sand (SC-SM)

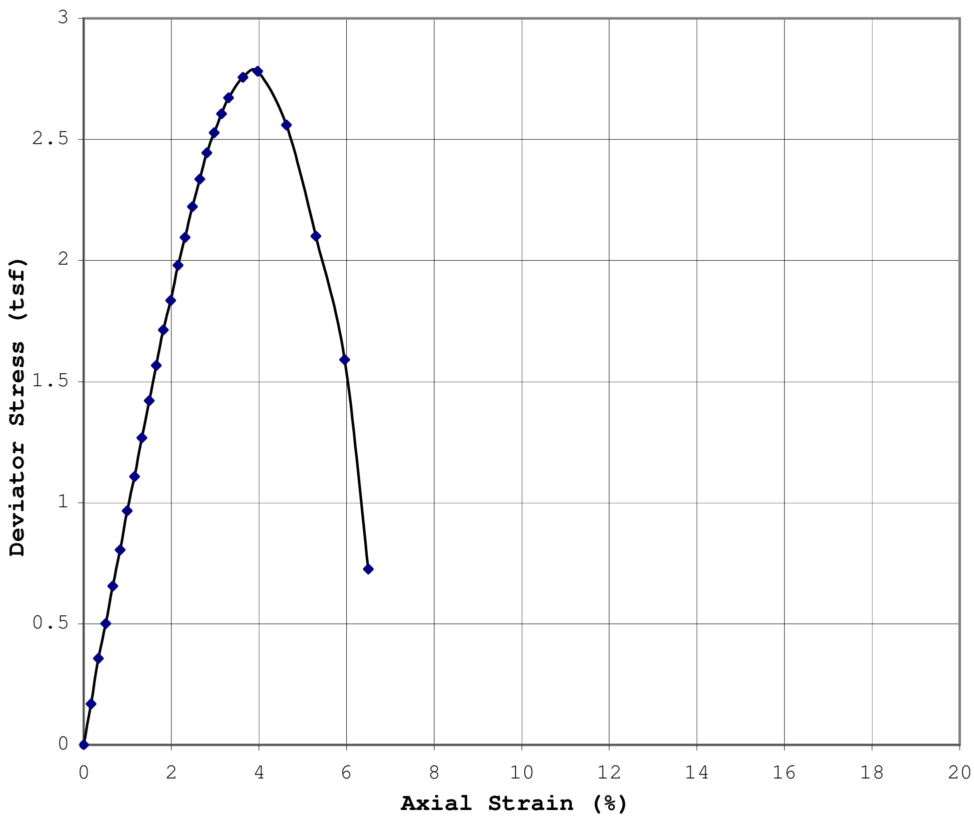
Strain Rate (in/min): 0.030
Sample Type: SB
Dia. (in) 1.52 Ht. (in) 2.85
Height to Diameter Ratio: 1.9

Unconfined Comp. Strength: 2.57 tsf
Strain at Failure (%): 3.3

W.C. (%): 8.0
Yd (pcf): 130.5

Sketch of Specimen After Failure





Boring: STP-B-2 Depth: 18-20
Sample #: K10
Soil Type: Clayey Sand w/a little gravel (SC/SC-SM)

Strain Rate (in/min): 0.030
Sample Type: SB

Dia. (in): 1.43 Ht. (in): 3.02
Height to Diameter Ratio: 2.1

Unconfined Comp. Strength: 2.78 tsf
Strain at Failure (%): 4.0

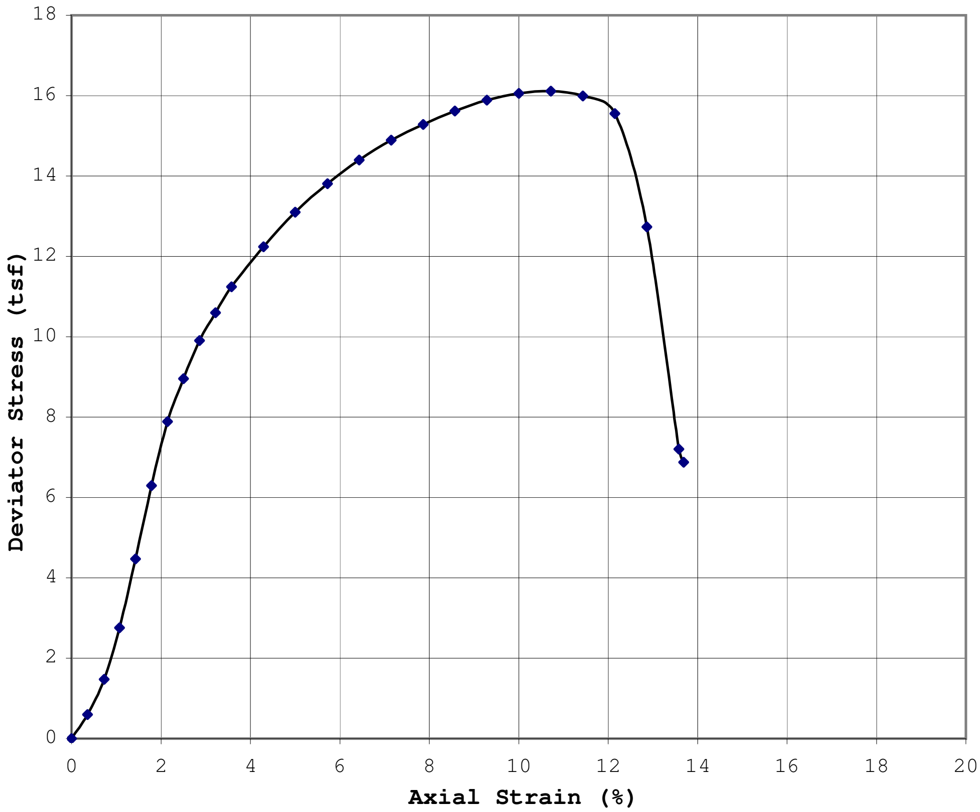
W.C. (%): 7.9
Yd (pcf): 129.8

Sketch of Specimen After Failure

Unconfined Stress/Strain Curves

ASTM: D2166

Project: Cherokee Heights
Job: 9444
Client: Barr Engineering Company
Date: 7/8/14
Remarks:



Boring: STP-B-2 Depth: 48-50
Sample #: K25

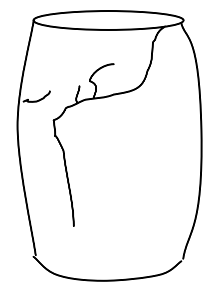
Soil Type: Sandy Lean Clay (CL)

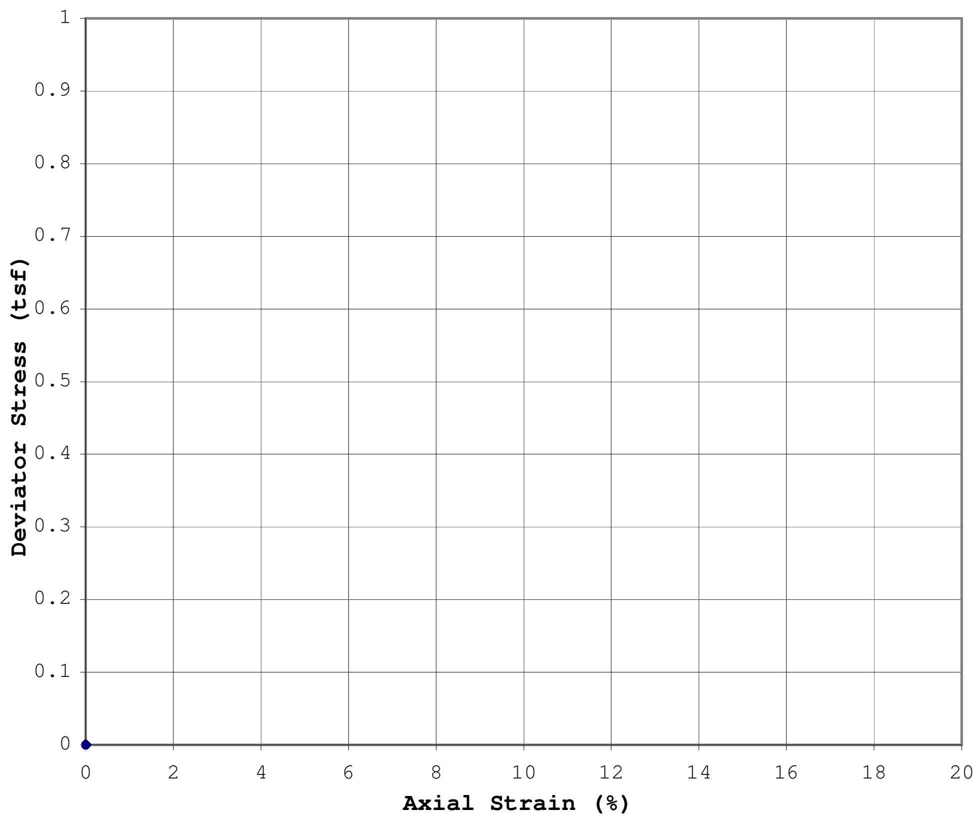
Strain Rate (in/min): 0.030
Sample Type: SB
Dia. (in) 1.36 Ht. (in) 2.80
Height to Diameter Ratio: 2.1

Unconfined Comp. Strength: 16.11 tsf
Strain at Failure (%): 10.7

W.C. (%): 12.4
Yd (pcf): 123.8

Sketch of Specimen After Failure





Boring: Depth:
Sample #:

Soil Type:

Strain Rate (in/min):
Sample Type:

Dia. (in): Ht. (in):
Height to Diameter Ratio:

Unconfined Comp. Strength: tsf
Strain at Failure (%):

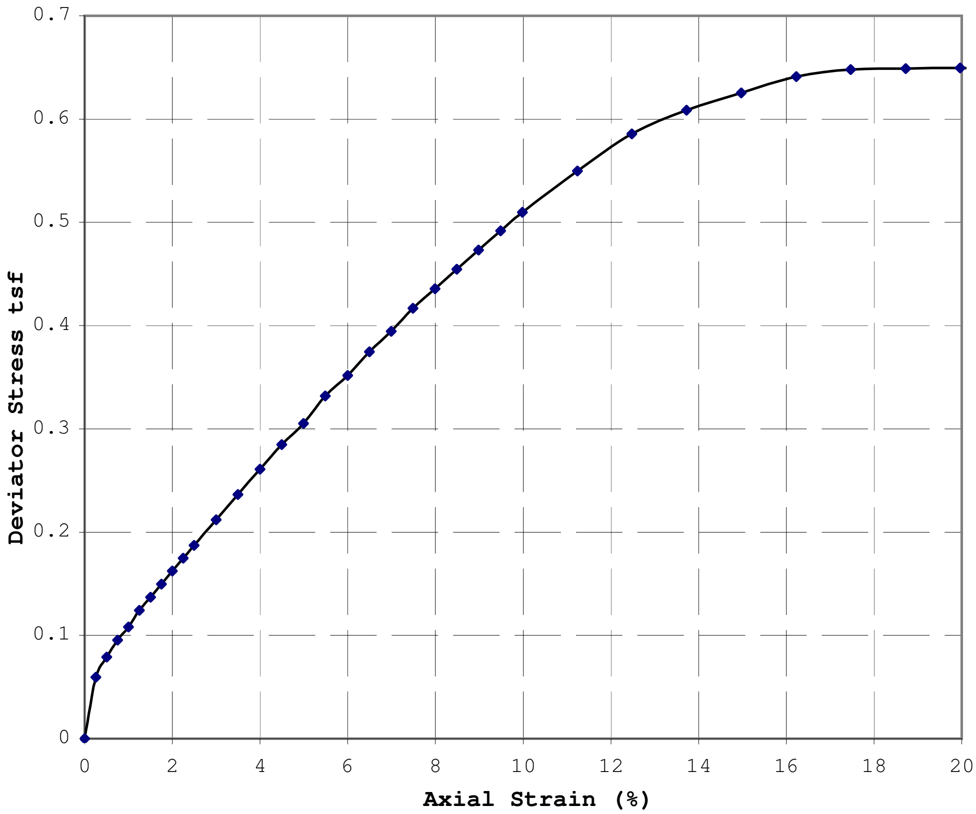
W.C. (%):
Yd (pcf):

Sketch of Specimen After Failure

2401 W 66th Street
SOIL ENGINEERING TESTING, INC.
Richfield, Minnesota 55423-2031

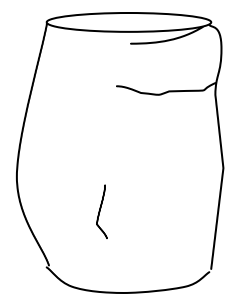
Triaxial U-U Stress/Strain Curves (ASTM:D2850)

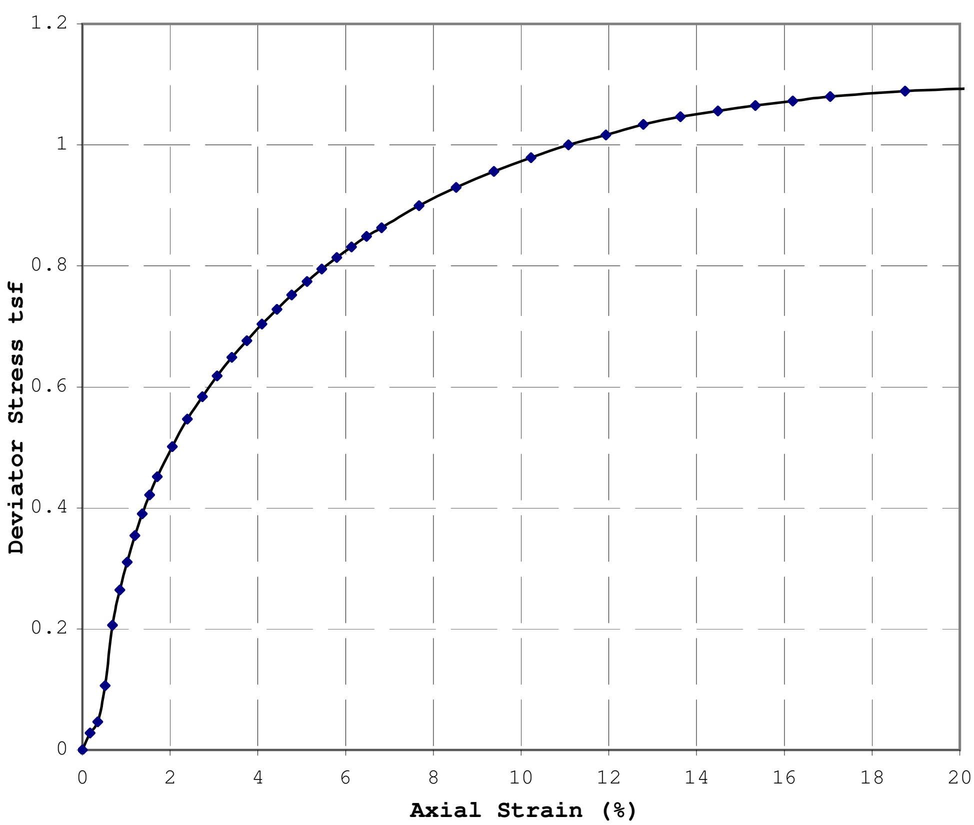
Project: Cherokee Heights — Job: 9444
Client: Barr Engineering Company — Date: 7/16/14
Remarks: Specimens trimmed to given sizes; Allowed to adjust under applied confining pressures for about 10 minutes.



Boring:	STP-B-2	Depth:	4-6
Sample #:			
Soil Type:	Silty Clay w/roots (CL-ML)		
Strain Rate (in/min):	0.045		
Sample Type:	3T		
Dia. (in)	1.93	Ht. (in)	4.01
Height to Diameter Ratio:	2.08		
Max Deviator Stress:	**0.65**	**tsf**	
Strain at Failure (%):	**22.5**		
Confining Pressure:	0.5	tsf	
W.C. (%)	25.6		
Yd (pcf):	98.1		

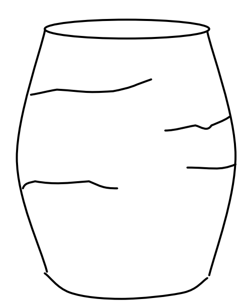
Sketch of Specimen After Failure





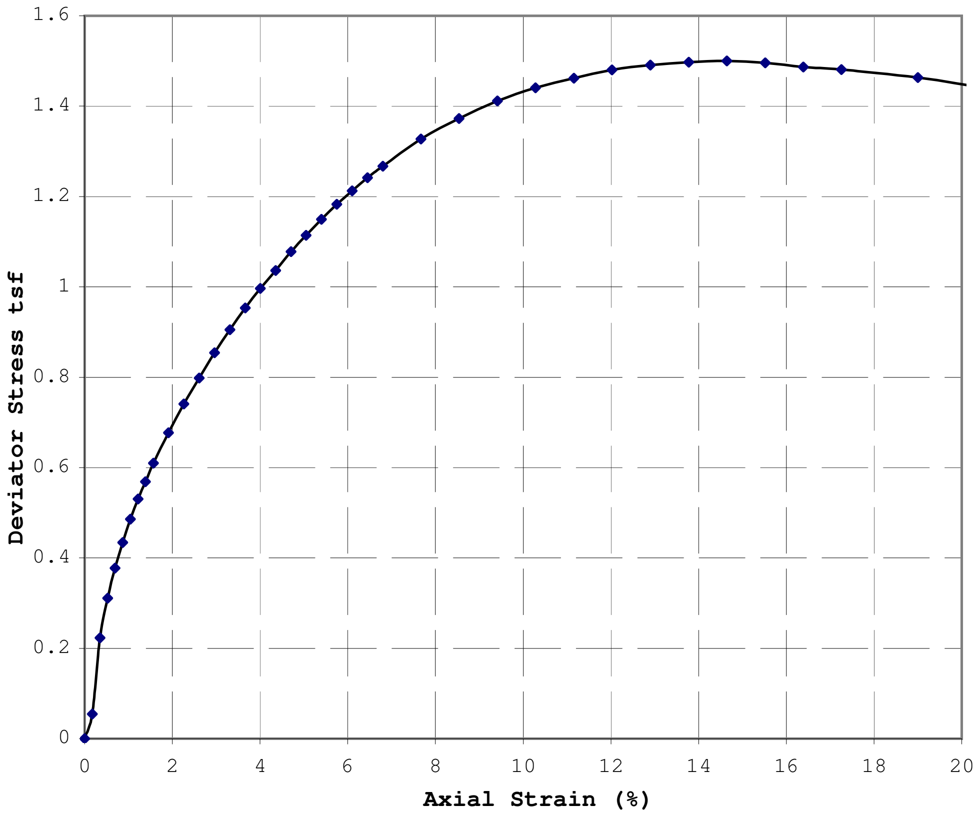
Boring:	STP-B-2	Depth:	8-9.5 (top)
Sample #:			
Soil Type:	Silty Sand (SM/SC-SM)		
Strain Rate (in/min):	0.060		
Sample Type:	3T		
Dia. (in):	2.82	Ht. (in):	5.87
Height to Diameter Ratio:	2.08		
Max Deviator Stress:	**1.09**	**tsf**	
Strain at Failure (%):	**20.7**		
Confining Pressure:	0.5	tsf	
W.C. (%):	9.3		
Yd (pcf):	122.2		

Sketch of Specimen After Failure



Triaxial U-U Stress/Strain Curves (ASTM:D2850)

Project: Cherokee Heights | Job: 9444
Client: Barr Engineering Company | Date: 7/16/14
Remarks: Specimens trimmed to given sizes; Allowed to adjust under applied confining pressures for about 10 minutes.

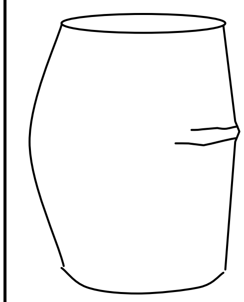


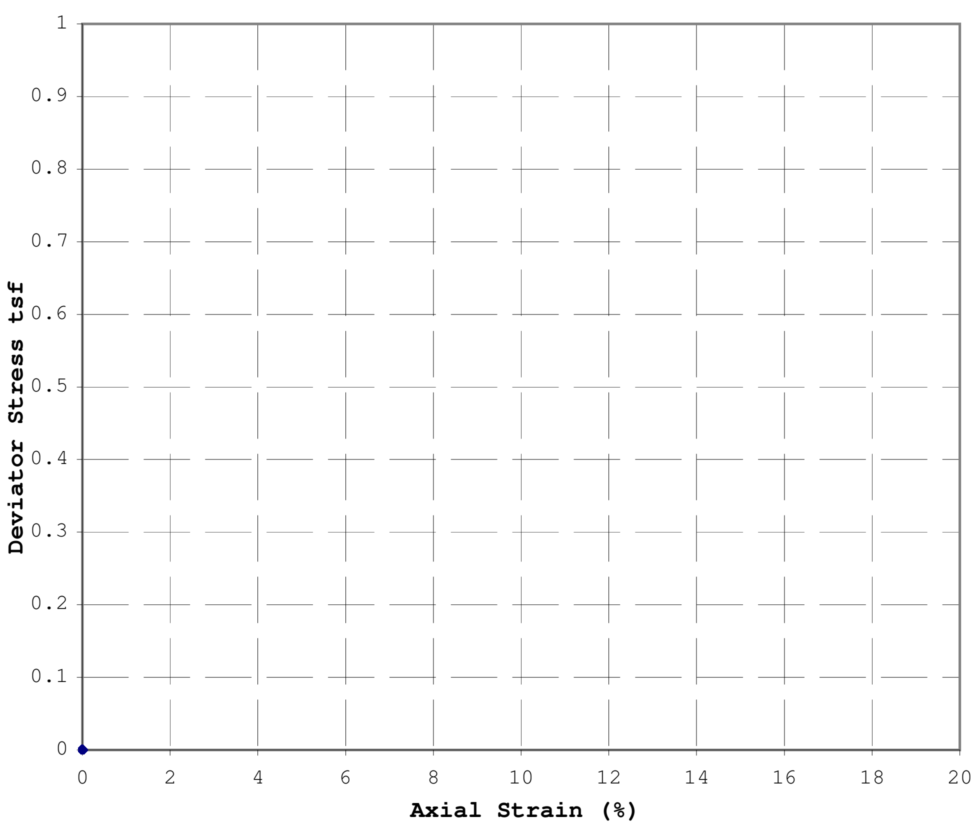
Boring: STP-B-2 Depth: 30-32
Sample #:
Soil Type: Clayey Sand w/a little gravel and a layer of Silty Sand (SC)

Strain Rate (in/min): 0.060
Sample Type: 3T
Dia. (in) 2.89 Ht. (in) 5.74
Height to Diameter Ratio: 1.98

Max Deviator Stress: **1.50** **tsf**
Strain at Failure (%): **14.6**
Confining Pressure: tsf
W.C. (%) 12.2
Yd (pcf): 126.6

Sketch of Specimen After Failure





Boring: Depth:
Sample #:
Soil Type:

Strain Rate (in/min):
Sample Type:

Dia. (in): Ht. (in):
Height to Diameter Ratio:

Max Deviator Stress: **tsf**
Strain at Failure (%):
Confining Pressure: tsf
W.C. (%):
Yd (pcf):

Sketch of Specimen After Failure

Rock Testing

Unconfined Compressive Strength of Intact Rock (ASTM:D7012) Method C

Job: 9428
Date: 07/08/14

Project: Lilydale Regional Park
Client: Barr Engineering Company

Sample Identification

Boring: Box 1
Location:
Sample: 2
Depth: 75.5

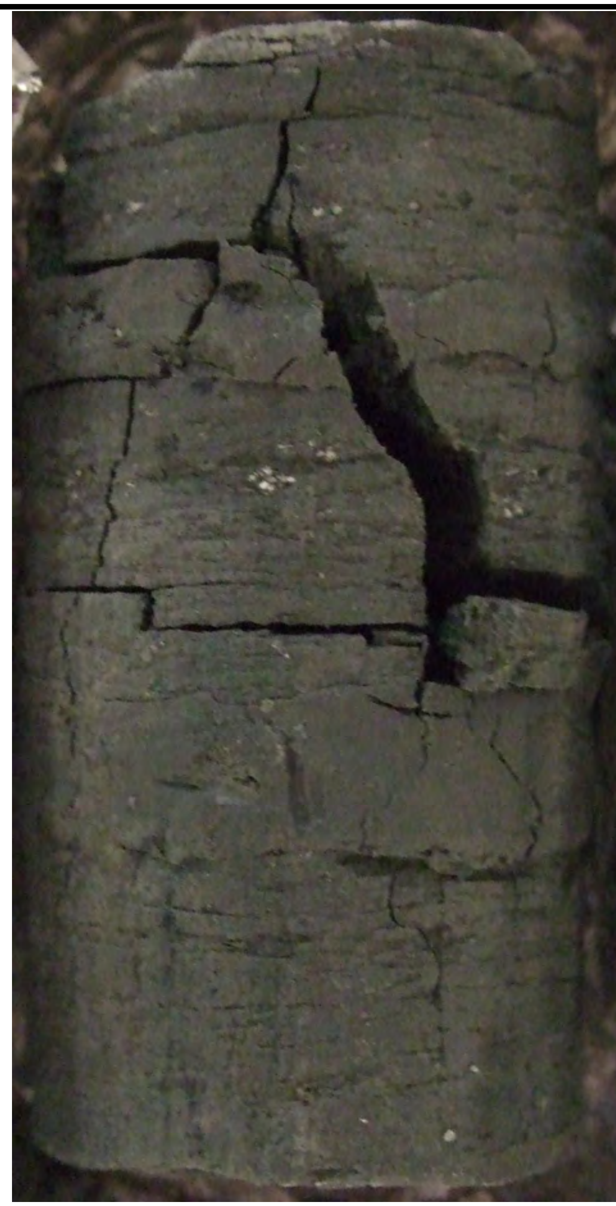
Laboratory Analysis

Visual Classification: Core

Specimen Dimensions	
Ht (in):	3.65
Dia (in):	1.78
Area (in2):	2.49
Moisture Content %	13.7%
Wet Density (PCF)	135.3
Dry Density (PCF)	119.0
Ht to Dia. Ratio:	2.05 : 1

Peak Strength			
4.9	TSF	68	PSI

Remarks:: Specimen cut to given dimension without the use of water.

Before Test	After Test
	

Unconfined Compressive Strength of Intact Rock (ASTM:D7012) Method C

Job:	9428
Date:	07/08/14

Project:	Lilydale Regional Park
Client:	Barr Engineering Company

Sample Identification

Boring:	Box 1	**Location:**	
Sample:	1	**Depth:**	78

Laboratory Analysis

Visual Classification:	Core

Specimen Dimensions	
Ht (in):	3.79
Dia (in):	1.78
Area (in2):	2.48
Moisture Content %	2.1%
Wet Density (PCF)	160.1
Dry Density (PCF)	156.8
Ht to Dia. Ratio:	2.13 : 1

Peak Strength			
210.6	TSF	2924	PSI

Remarks:: Specimen cut to given dimension without the use of water.

Before Test	After Test
	

Unconfined Compressive Strength of Intact Rock (ASTM:D7012) Method C		Job:	9428
		Date:	07/08/14

Project:	Lilydale Regional Park
Client:	Barr Engineering Company

Sample Identification

Boring:	Box 2	Location:	
Sample:	1	Depth:	89.5

Laboratory Analysis

Visual Classification:	Core

Specimen Dimensions	
Ht (in):	3.58
Dia (in):	1.77
Area (in2):	2.47
Moisture Content %	17.3%
Wet Density (PCF)	134.9
Dry Density (PCF)	114.9
Ht to Dia. Ratio:	2.02 : 1

Peak Strength			
8.4	TSF	117	PSI

Remarks:: Specimen cut to given dimension without the use of water.

Before Test	After Test
	

Unconfined Compressive Strength of Intact Rock (ASTM:D7012) Method C

Job:	9428
Date:	07/08/14

Project:	Lilydale Regional Park
Client:	Barr Engineering Company

Sample Identification

Boring:	Box 3	Location:	
Sample:	1	Depth:	99.5

Laboratory Analysis

Visual Classification:	Core

Specimen Dimensions

Ht (in):	3.64
Dia (in):	1.78
Area (in2):	2.48
Moisture Content %	13.0%
Wet Density (PCF)	139.4
Dry Density (PCF)	123.4
Ht to Dia. Ratio:	2.05 : 1

Peak Strength

6.2	TSF	87	PSI

Remarks:: Specimen cut to given dimension without the use of water.

Before Test	After Test
	

Unconfined Compressive Strength of Intact Rock (ASTM:D7012) Method C

Job:	9428
Date:	07/08/14

Project:	Lilydale Regional Park
Client:	Barr Engineering Company

Sample Identification

Boring:	Box 4	Location:	
Sample:	1	Depth:	102.5

Laboratory Analysis

Visual Classification:	Core

Specimen Dimensions	
Ht (in):	3.62
Dia (in):	1.79
Area (in2):	2.51
Moisture Content %	6.4%
Wet Density (PCF)	149.5
Dry Density (PCF)	140.4
Ht to Dia. Ratio:	2.03 : 1

Peak Strength

21.5	TSF	299	PSI

Remarks:: Specimen cut to given dimension without the use of water.

Before Test	After Test
	

Permeability

Hydraulic Conductivity Test Data ASTM D5084

Project: Cherokee Heights Date: 7/16/2014

Reported To: Barr Engineering Company Job No.: 9444

Boring No.:	STP-B-1	STP-B-2	STP-B-2				
Sample No.:							
Depth (ft):	8-10	4-6	8-9.5				
Location:							
Sample Type:	3T	3T	3T				
Soil Type:	Sand w/silt (SP-SM)	Silty Clay (CL-ML)	Silty Clayey Sand w/a little gravel (SC-SM)				
Atterberg Limits							
LL							
PL							
PI							
Permeability Test	Undisturbed	Undisturbed	Undisturbed				
Before Test Conditions: Saturation %:							
Porosity:							
Ht. (in):	3.35	2.56	2.93				
Dia. (in):	2.86	2.84	2.91				
Dry Density (pcf):	104.7	92.8	121.2				
Water Content:	13.7%	27.4%	9.7%				
Test Type:	Falling	Falling	Falling				
Max Head (ft):	5.0	5.0	5.0				
Confining press. (Effective-psi):	2.0	2.0	2.0				
Trial No.:	12-16	12-16	12-16				
Water Temp ℃:	23.0	23.0	23.0				
% Compaction							
% Saturation (After Test)	95.3%	95.1%	95.1%				
Coefficient of Permeability							
K @ 20 ℃ (cm/sec)	**1.6×10^{-4}**	**2.8×10^{-7}**	**2.0×10^{-6}**				
K @ 20 ℃ (ft/min)	**3.2×10^{-4}**	**5.5×10^{-7}**	**3.9×10^{-6}**				
Notes:							

Attachment D

Site Inspection Photographs

Attachment D
Site Inspection Photographs

Photo 1 West Clay Pit and area below Bruce Vento Overlook from the air (photo provided by the City)

Photo 2 Scarp adjacent to storm sewer outlet in Cherokee Heights ravine (May 2014 site visit)

Photo 3 Cherokee Heights ravine slope failure (July 2014 site visit)

Photo 4 Scarp from historic slope failure, pre-2014 slide (taken from Brickyard Trail Low Falls waterfall area during the May 2014 site visit)

Photo 5 2014 slope failure from above (July 2014 site visit)

Photo 6 2014 slope failure from below (July 2014 site visit)

Photo 7 Large slide, looking up through newly eroded stream channel (July 2014 site visit)

Photo 8 Soil deposited at base of slide and newly eroded stream channel (July 2014 site visit)

Photo 9 Erosion of lower Brickyard Trail and plugged culvert resulting from the Northwest Slope Failure (July 2014 site visit)

Photo 10 2013 slide area, from top of East Clay Pit Falls, as observed during the May 2014 site visit

Photo 11 2013 side area, from below, as observed during the July 2014 site visit

Photo 12 Silty sand soil over shale bedrock in West Clay Pit (May 2014 site visit)

Photo 13 Close-up of overhanging soil and root zone (West Clay Pit) (May 2014 site visit)

Photo 14 Middle Clay Pit wall (note fresh soil scarp in upper right corner) (July 2014 site visit)

Photo 15   Middle Clay Pit with snow/ice (from seepage) on face of shale (May 2014 site visit)

Photo 16   Weeping rock outcrop in Middle Clay Pit (July 2014 site visit)

Photo 17 View of slope failure above Brickyard Trail (this is the source of soil on the trail) (May 2014 site visit)

Photo 18 Soil on Brickyard Trail (May 2014 site visit)

Photo 19 View of slope failure above Brickyard Trail (this is the source of soil on the trail) (July 2014 site visit)

Photo 20 Soil on Brickyard Trail from slope failure shown in previous photo (July 2014 site visit)

Photo 21 Lower falls along Brickyard Trail (May 2014 site visit)

Photo 22 Slide below the Bruce Vento Spur of the Brickyard Trail (July 2014 site visit)

Photo 23 "Sinkhole" along Brickyard Trail – Bluff Section (note sunken fence post) (July 2014 site visit)

Photo 24 Soil overhang at Bruce Vento Overlook (May 2014 site visit)

Photo 25 Central fossil digging area (Fossil Site 1 on Figure 1-2)

Attachment E

Geotechnical Modeling Results

North End

Figure E-1 North End Drained Friction Angle
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions
File Name: Lilydale_north end.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand   Model: Mohr-Coulomb   Unit Weight: 119 pcf   Cohesion': 0 psf   Phi': 29 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 147 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 130 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 120 pcf

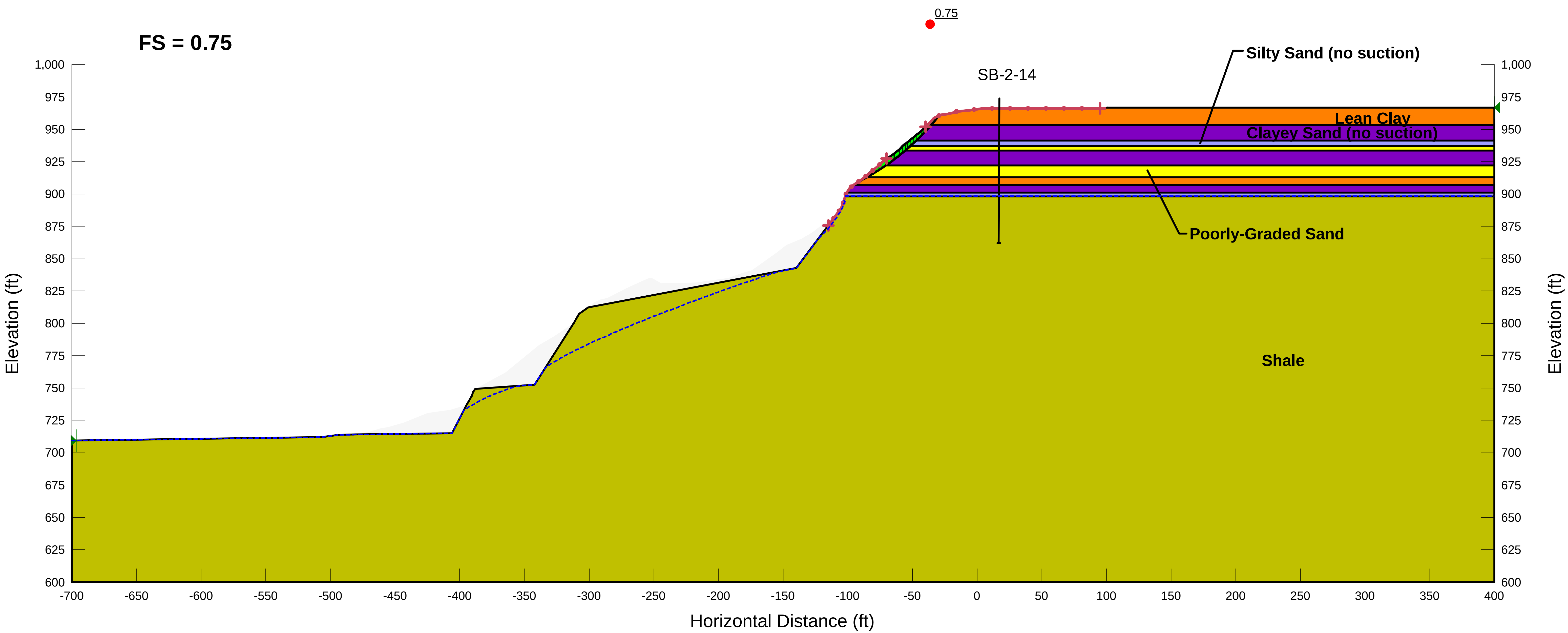


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Figure E-2 North End Drained Friction Angle at Stability
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions
File Name: Lilydale_north end.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

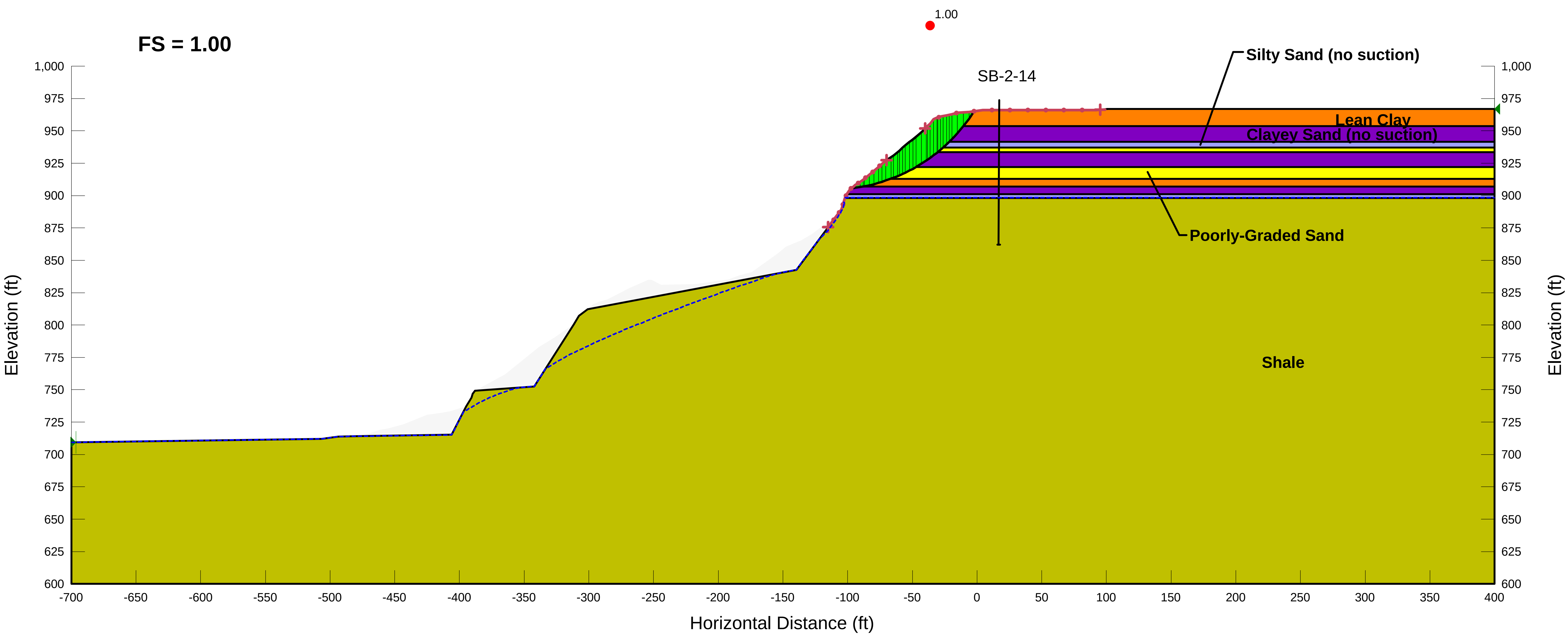

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Figure E-3 North End Drained Friction Angle with Suction

Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions with Suction
File Name: Lilydale_north end.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

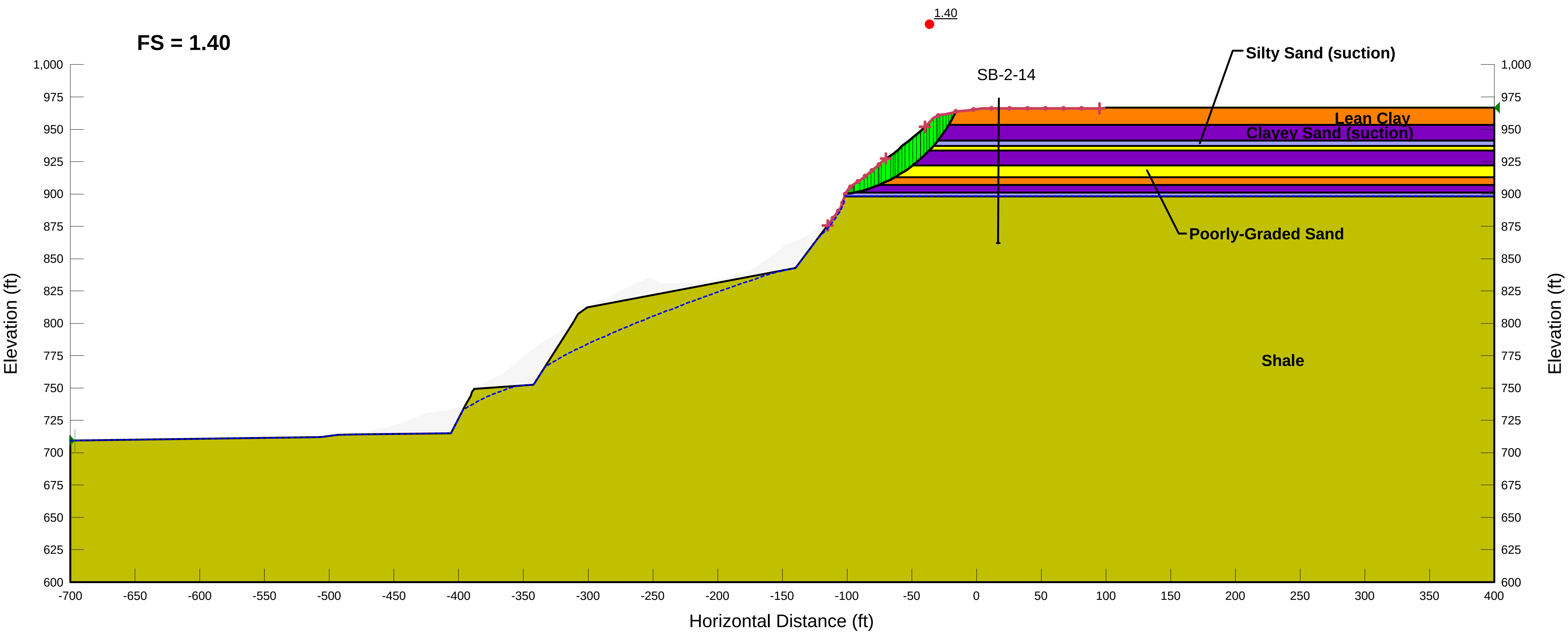

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Figure E-4 North End Drained Friction Angle with Rainfal
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.1 Slope -5yr-24hr Rain Event (SAT)
File Name: Lilydale_north end.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

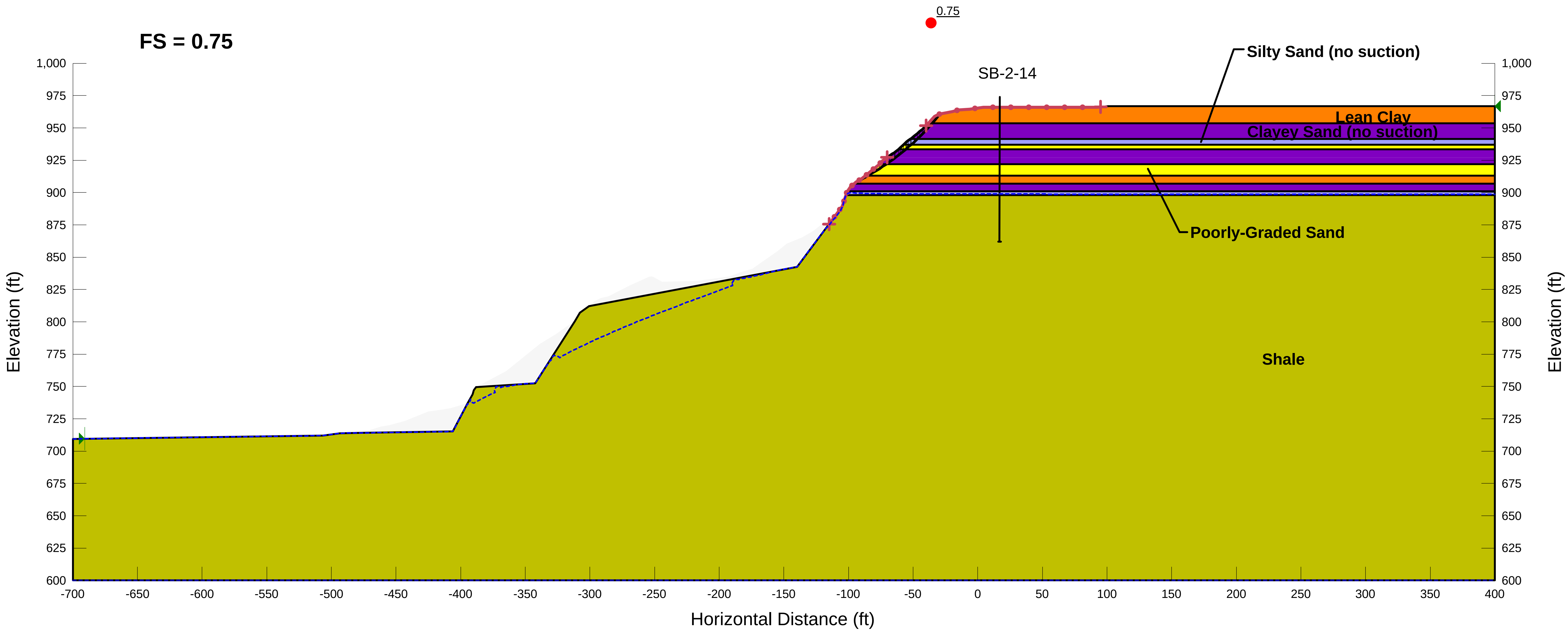

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Figure E-5 North End Drained Friction Angle with Suction with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.2 Slope - 5yr-24hr Rain Event with Suction (SAT)
File Name: Lilydale_north end.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

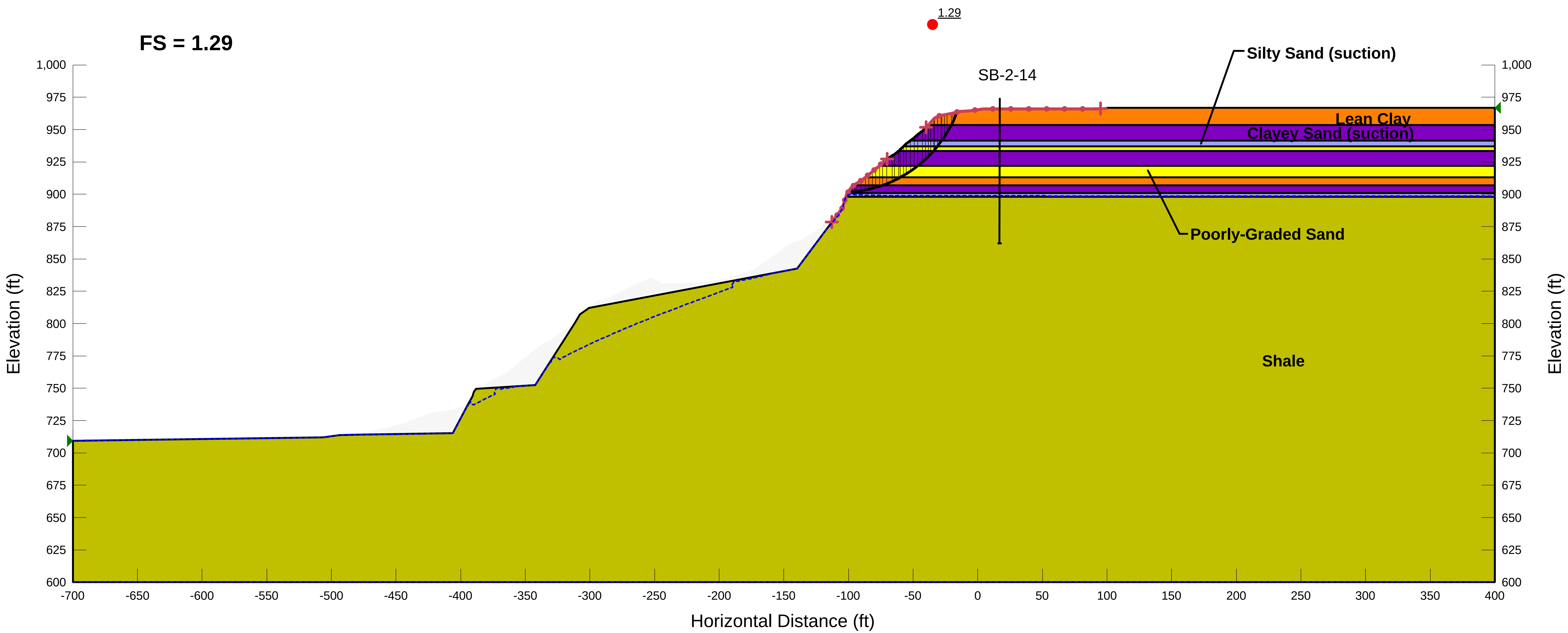

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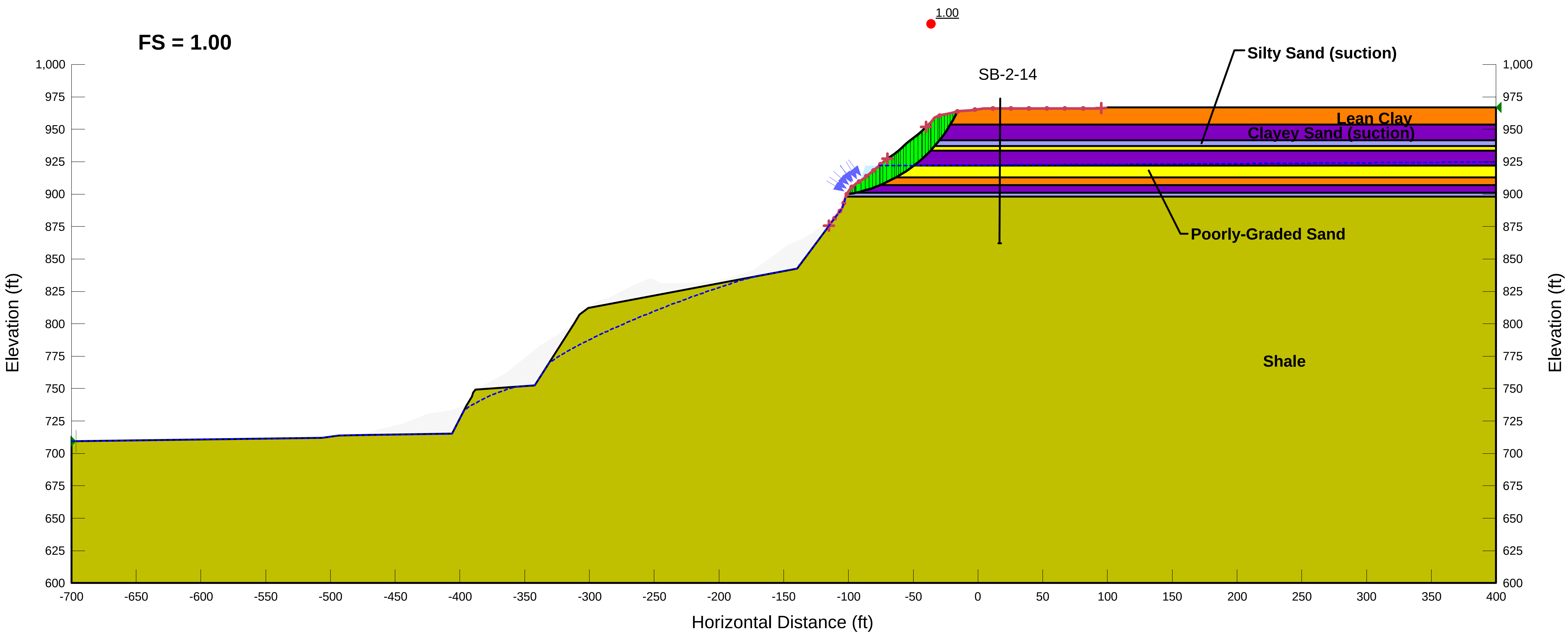
Figure E-6 North End Drained Friction Angle with Suction with High Groundwater
Lilydale Regional Park
Seepage and Slope Stability Analysis
2.1 Slope - High Groundwater with Suction (2)
File Name: Lilydale_north end.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf



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Waterfall Landslide Slope 1

Figure E-7 Waterfall Landslide Slope 1 Drained Friction Angle

Lilydale Regional Park

Seepage and Slope Stability Analysis

1.0.1 Slope - Existing Conditions_slope 1

File Name: Lilydale_waterfall landslide.gsz

Date Saved: 1/18/2015

Name: Poorly-Graded Sand   Model: Mohr-Coulomb   Unit Weight: 119 pcf   Cohesion': 0 psf   Phi': 29 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 147 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 130 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 120 pcf

FS = 0.66

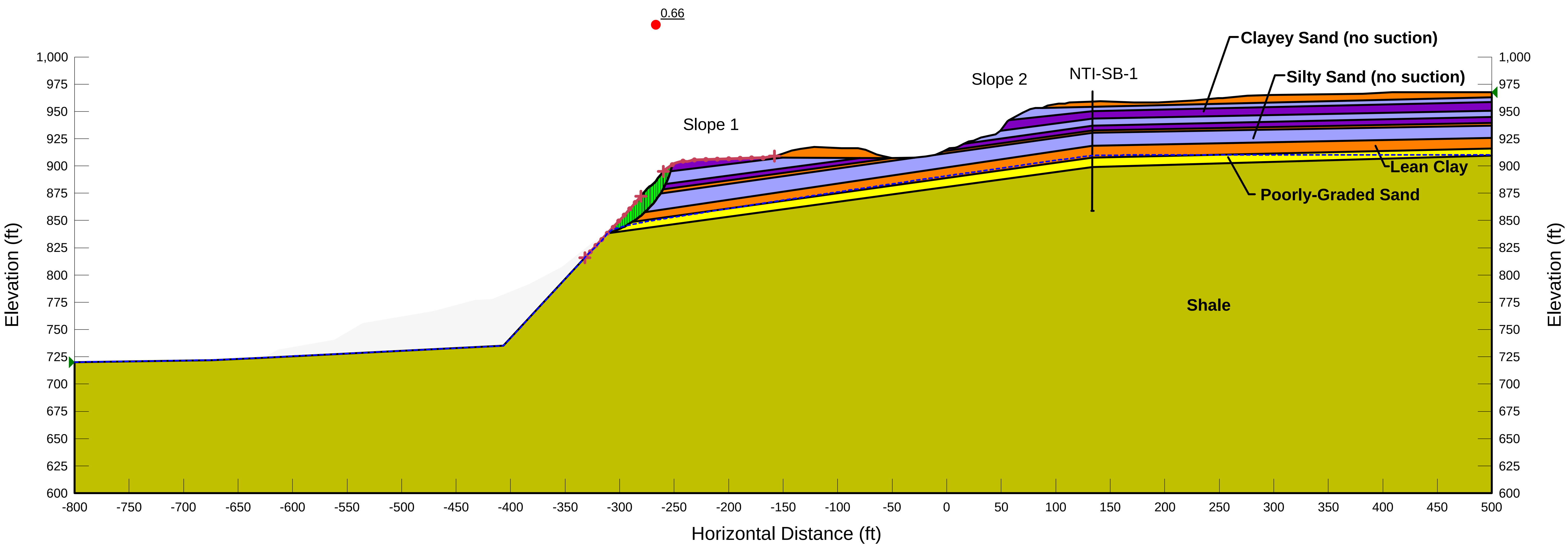

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Figure E-8 Waterfall Landslide Slope 1 Drained Friction Angle at Stability
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions_slope 1
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

FS = 1.00

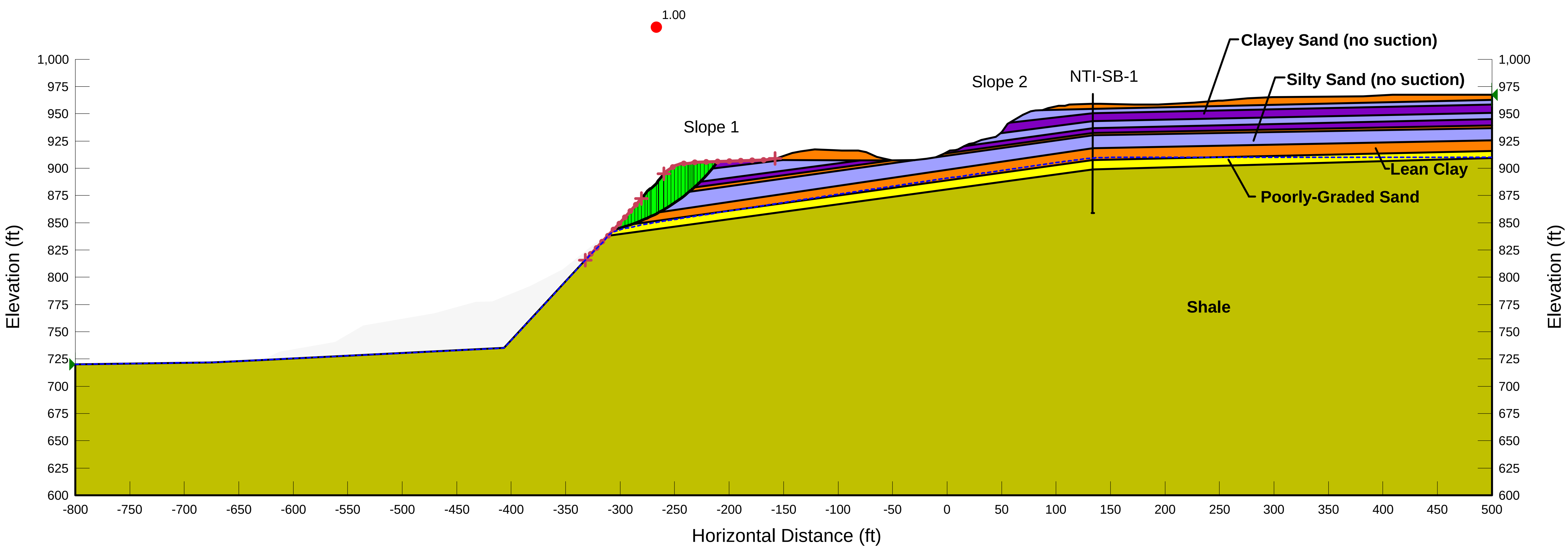

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Figure E-9 Waterfall Landslide Slope 1 Drained Friction Angle with Suction
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.2 Slope - Existing Conditions with Suction_slope 1
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

FS = 1.18

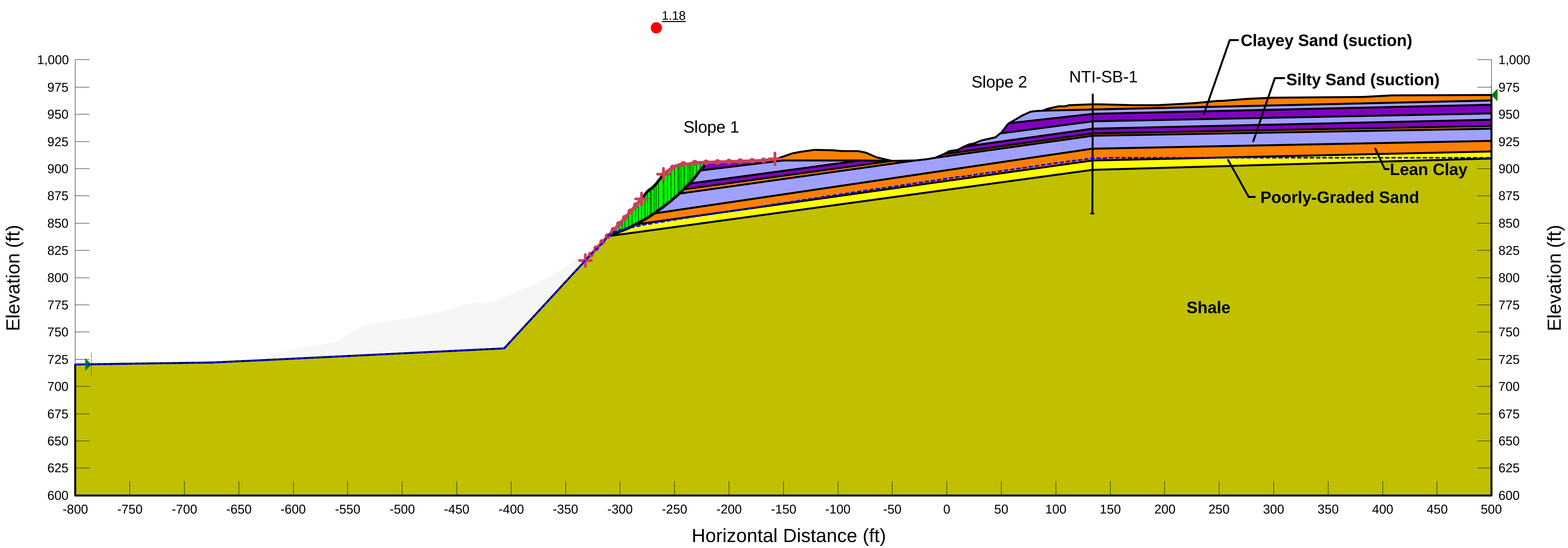

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Figure E-10. Waterfall Landslide Slope 1 Drained Friction Angle with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.1 Slope -Rain Event_slope 1 (SAT)
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

FS = 0.59

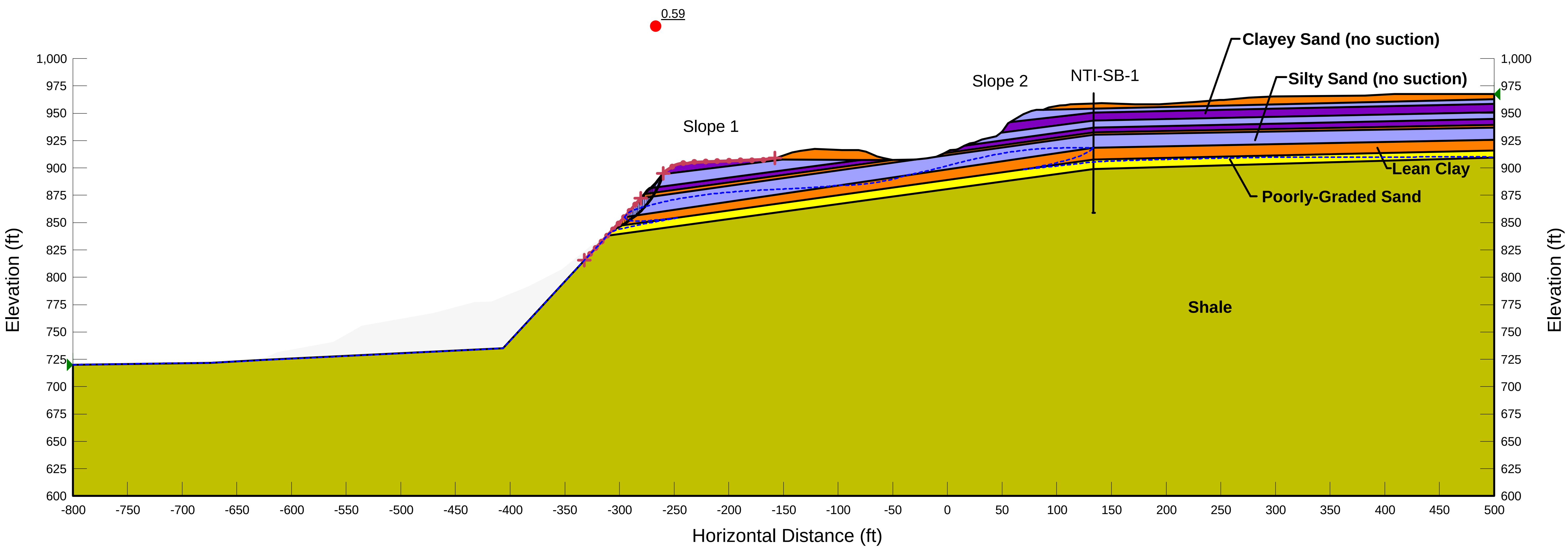

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Figure E-11. Waterfall Landslide Slope 1 Drained Friction Angle with Suction with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.2 Slope -Rain Event with Suction_slope 1 (SAT)
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

FS = 0.78

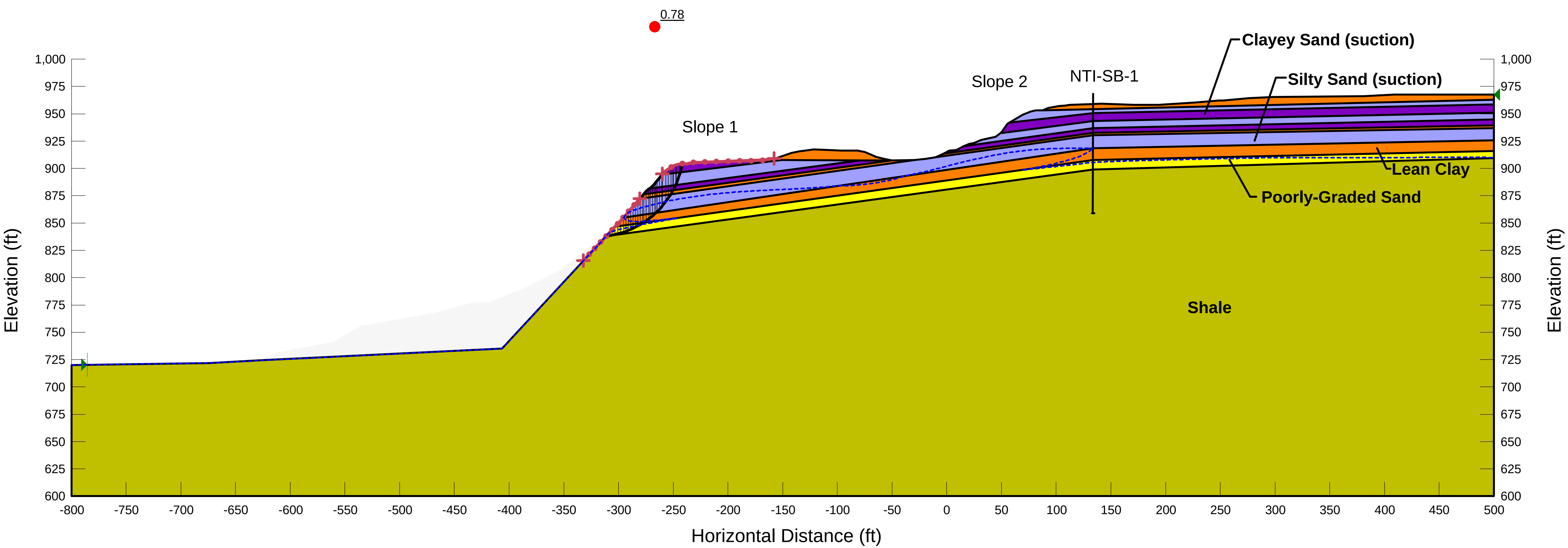

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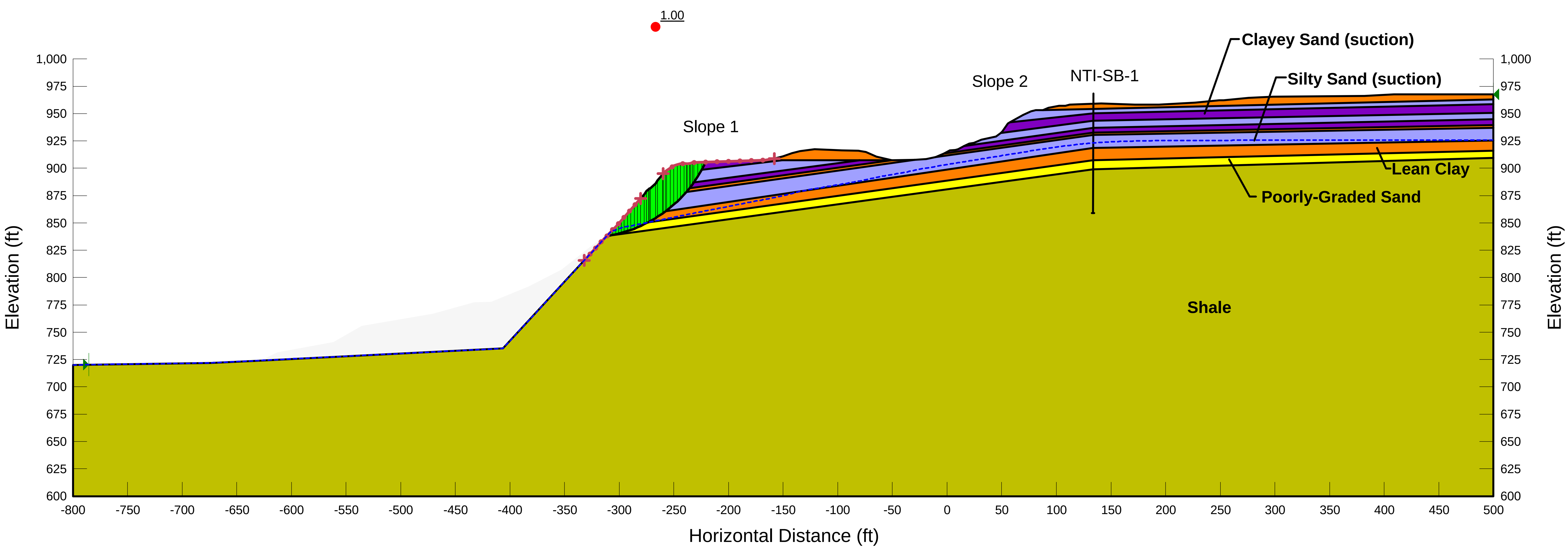
Figure E-12 Waterfall Landslide Slope 1 Drained Friction Angle with Suction with High Groundwater
Lilydale Regional Park
Seepage and Slope Stability Analysis
2.1 Slope - High Groundwater with Suction_slope 1 (3)
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

FS = 1.00



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Waterfall Landslide Slope 2

Figure E-13 Waterfall Landslide Slope 2 Drained Friction Angle
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.3 Slope - Existing Conditions_slope 2
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

FS = 0.83

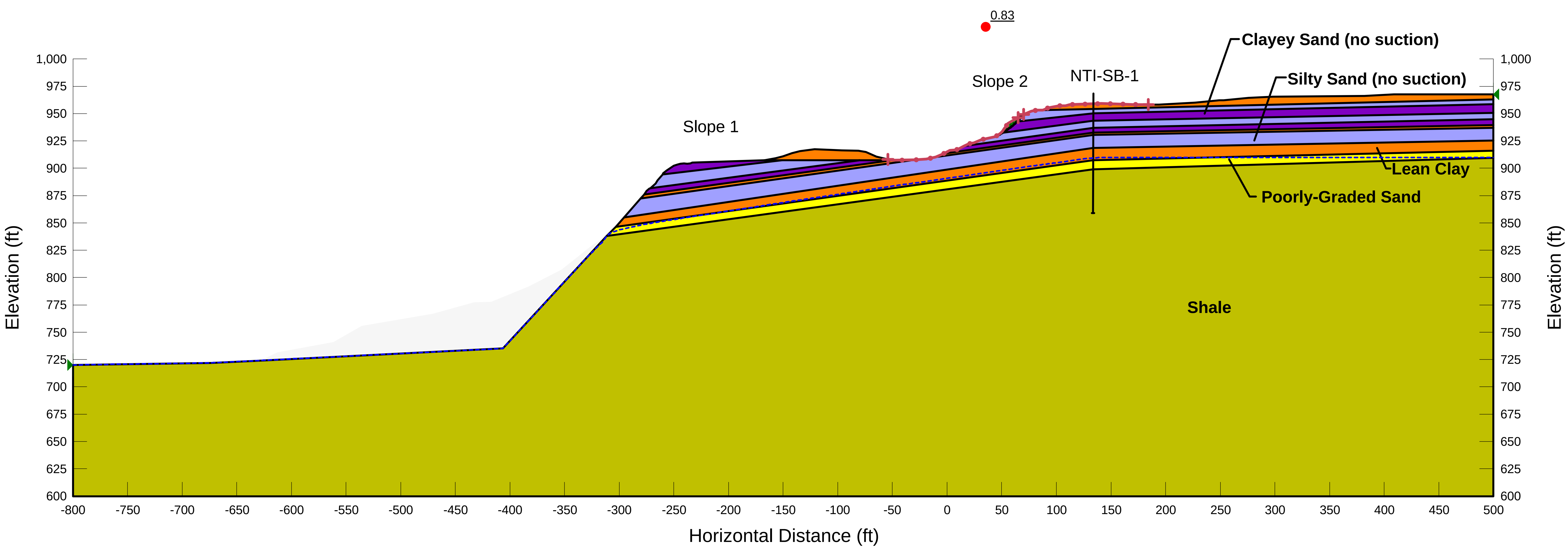

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Figure E-14 Waterfall Landslide Slope 2 Drained Friction Angle at Stability
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.3 Slope - Existing Conditions_slope 2
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

FS = 1.00

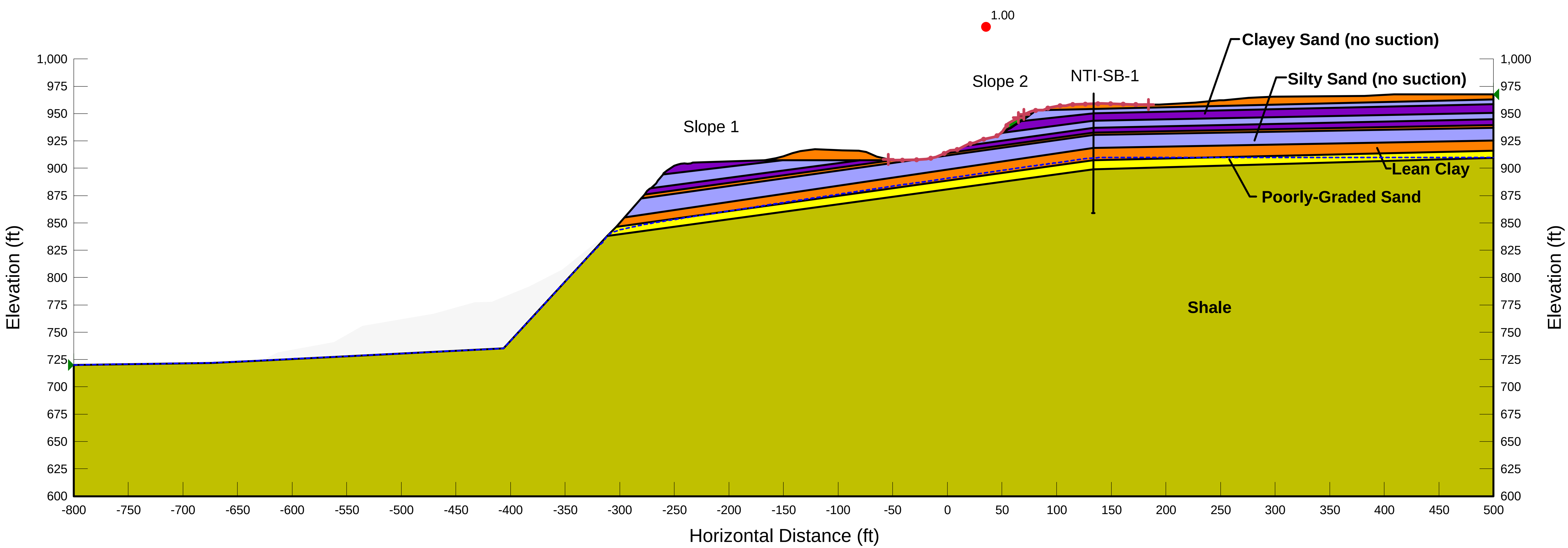

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Figure E-15 Waterfall Landslide Slope 2 Drained Friction Angle with Suction
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.4 Slope - Existing Conditions with Suction_slope 2
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/18/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

FS = 2.34

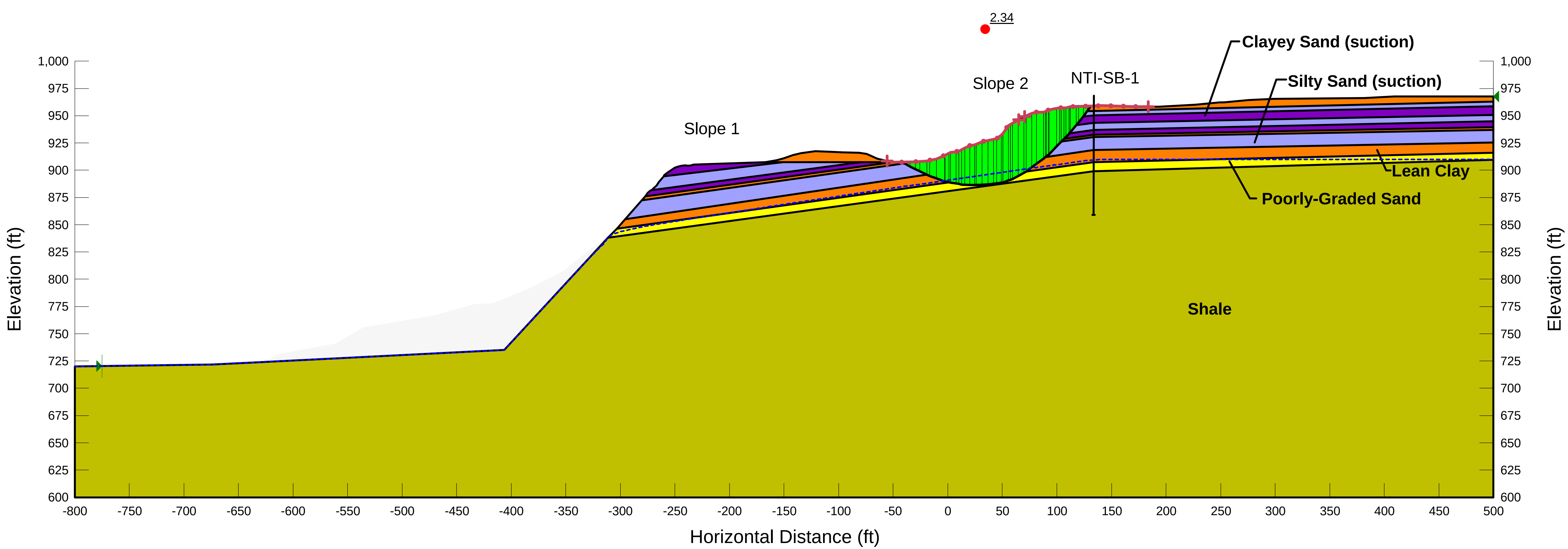

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Figure E-16 Waterfall Landslide Slope 2 Drained Friction Angle with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.3 Slope - Rain Event_slope 2 (SAT)
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

FS = 0.83

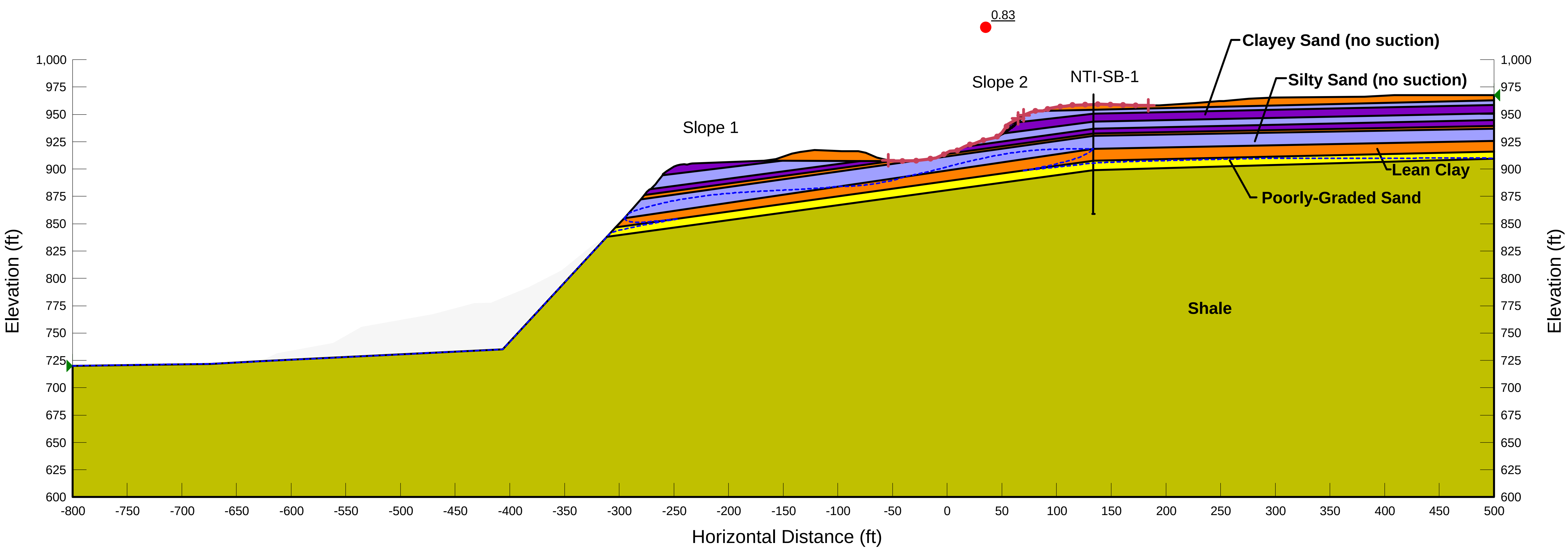

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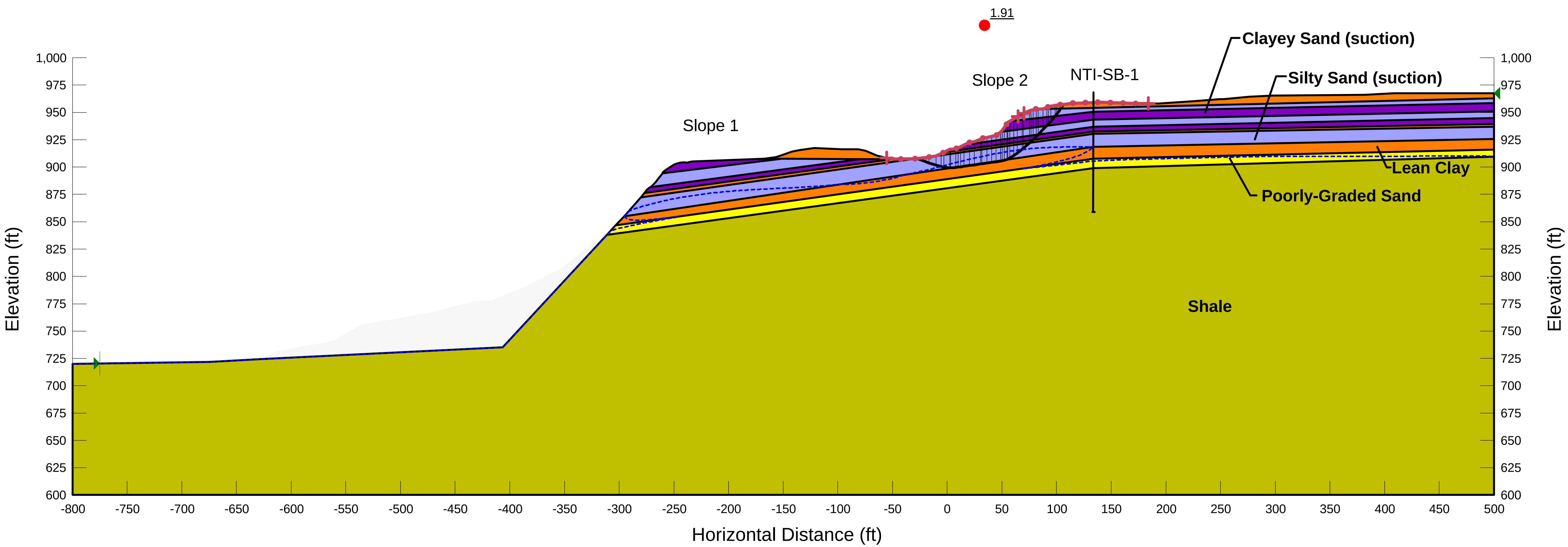
Figure E-17 Waterfall Landslide Slope 2 Drained Friction Angle with Suction with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.4 Slope - Rain Event with Suction_slope 2 (SAT)
File Name: Lilydale_waterfall landslide.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

FS = 1.91



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Cherokee Heights Slope 1

Figure E-18 Cherokee Heights Slope 1 Drained Friction Angle
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions Slope 1
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 0.70

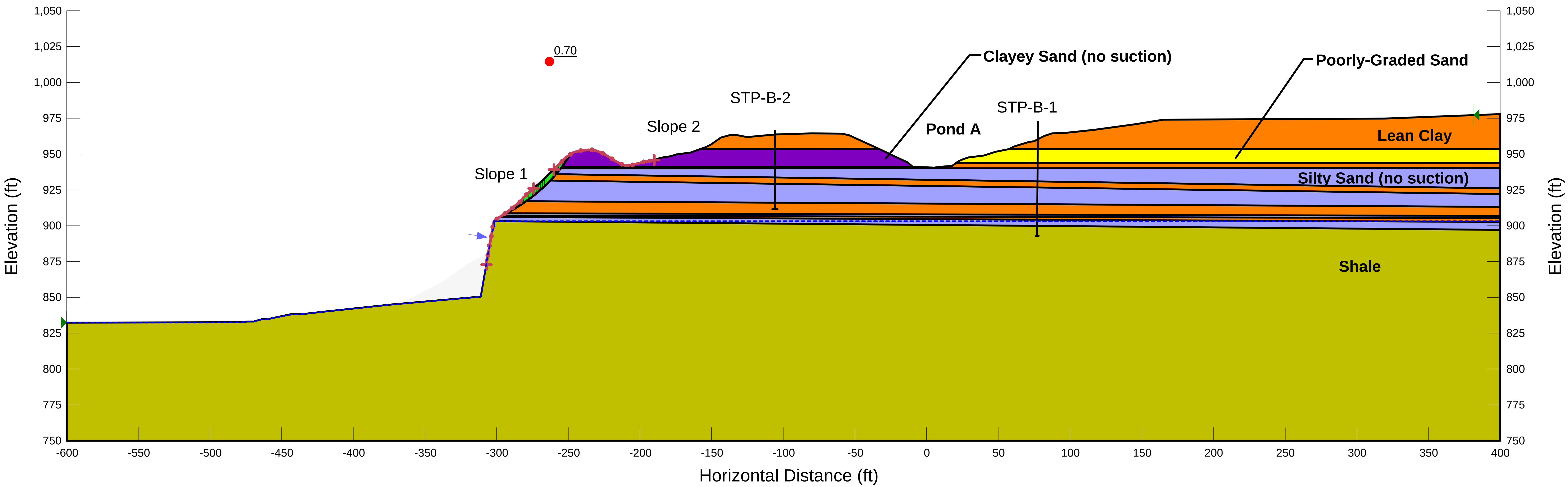

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Figure E-19 Cherokee Heights Slope 1 Drained Friction Angle at Stability
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions Slope 1
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 1.00

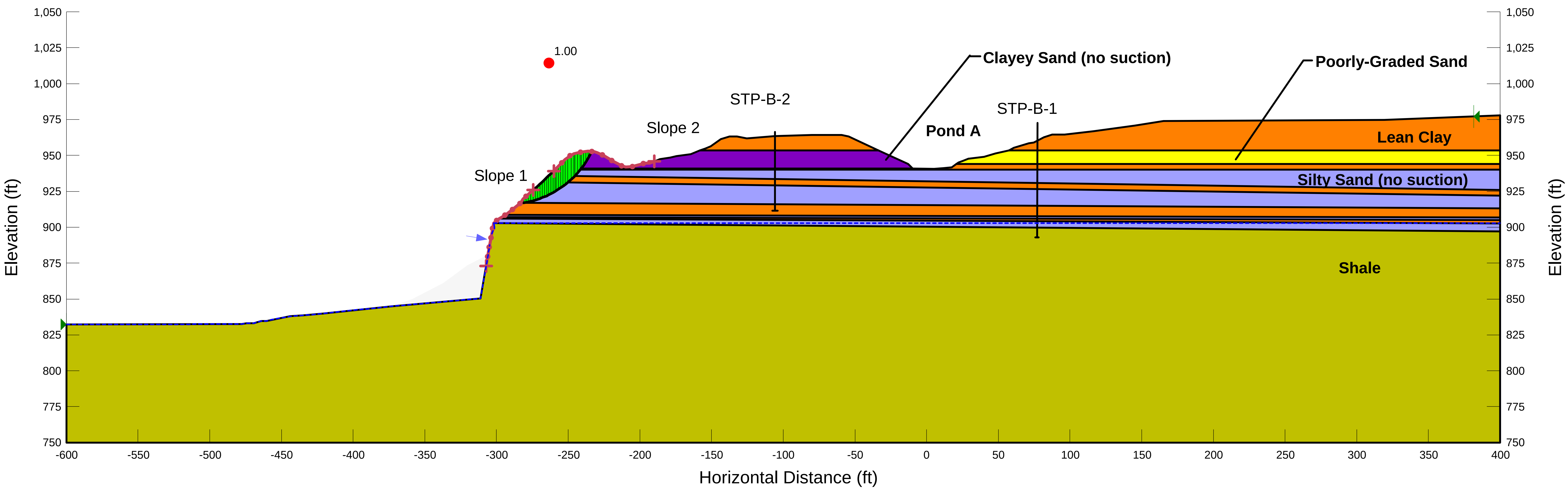

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Figure E-20 Cherokee Heights Slope 1 Drained Friction Angle with Suction
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.2 Slope - Existing Conditions Slope 1 with suction
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 1.53

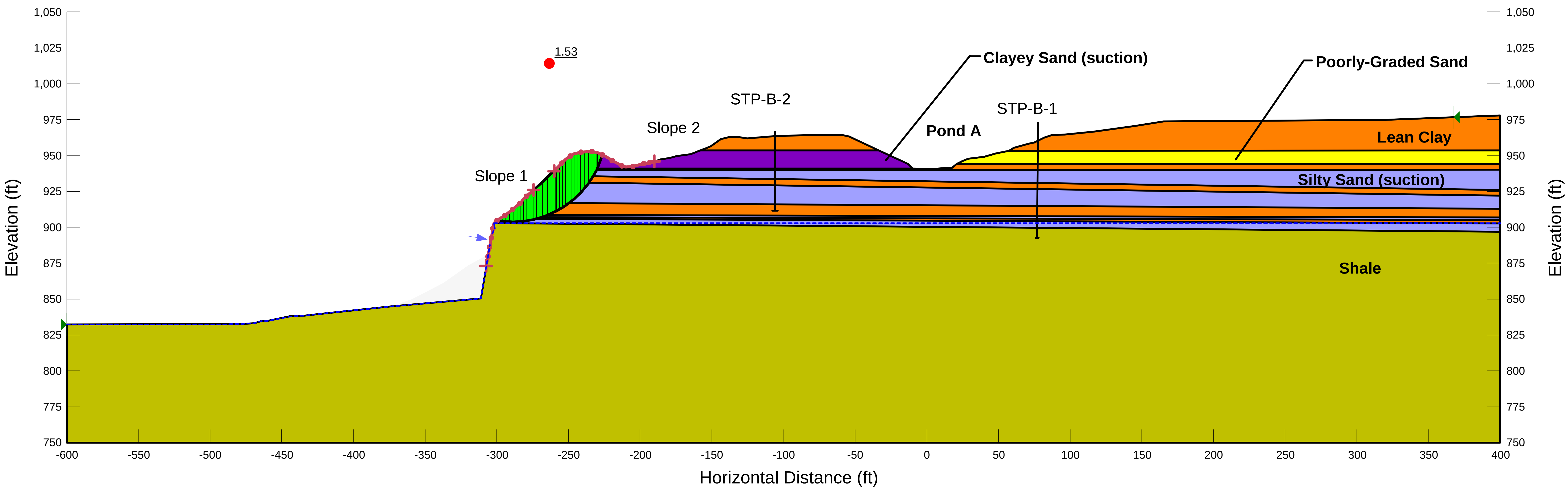

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Figure E-21 Cherokee Heights Slope 1 Drained Friction Angle with Rainfall
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.1 Slope - 5yr 24 hr Rain Event Slope 1 (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 0.70

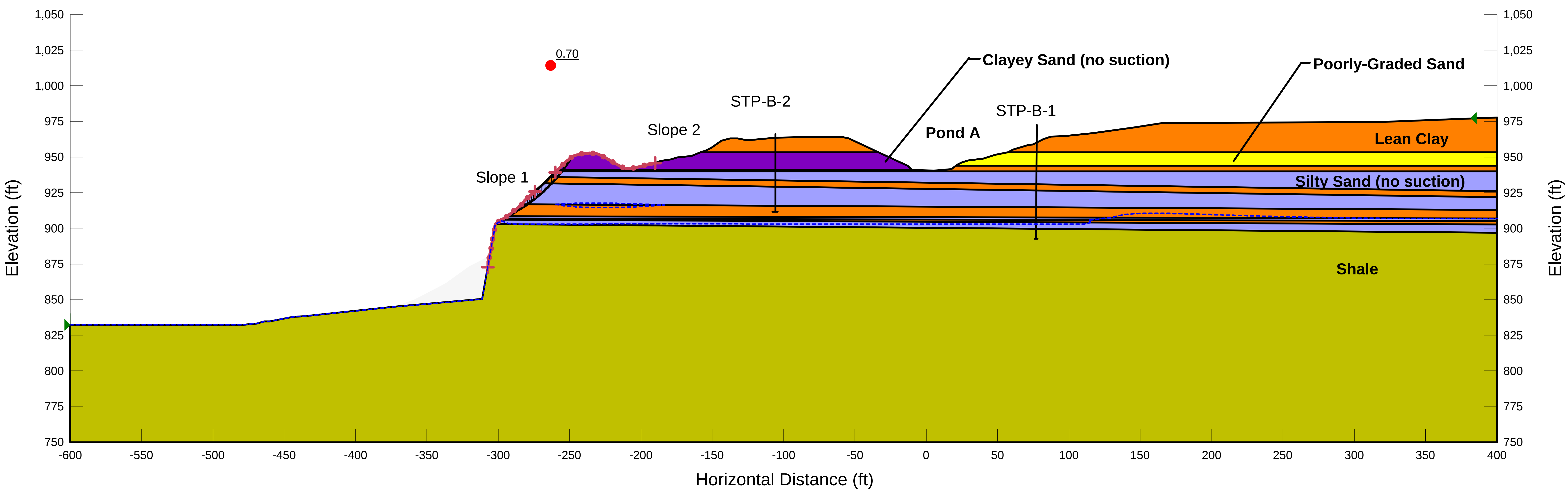

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Figure E-22 Cherokee Heights Slope 1 Drained Friction Angle with Suction with Rainfall
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.2 Slope -5yr 24 hr Rain Event Slope 1 with suction (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand   Model: Mohr-Coulomb   Unit Weight: 119 pcf   Cohesion': 0 psf   Phi': 29 °   Phi-B: 0 °
Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 120 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °
Name: Silty Sand (suction)   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 33 °   Vol. WC. Function: Silty Sand (suction)   Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction)   Model: Mohr-Coulomb   Unit Weight: 147 pcf   Cohesion': 0 psf   Phi': 33 °   Vol. WC. Function: Clayey Sand (suction)   Residual Water Content (% of Sat WC): 10 %

FS = 1.11

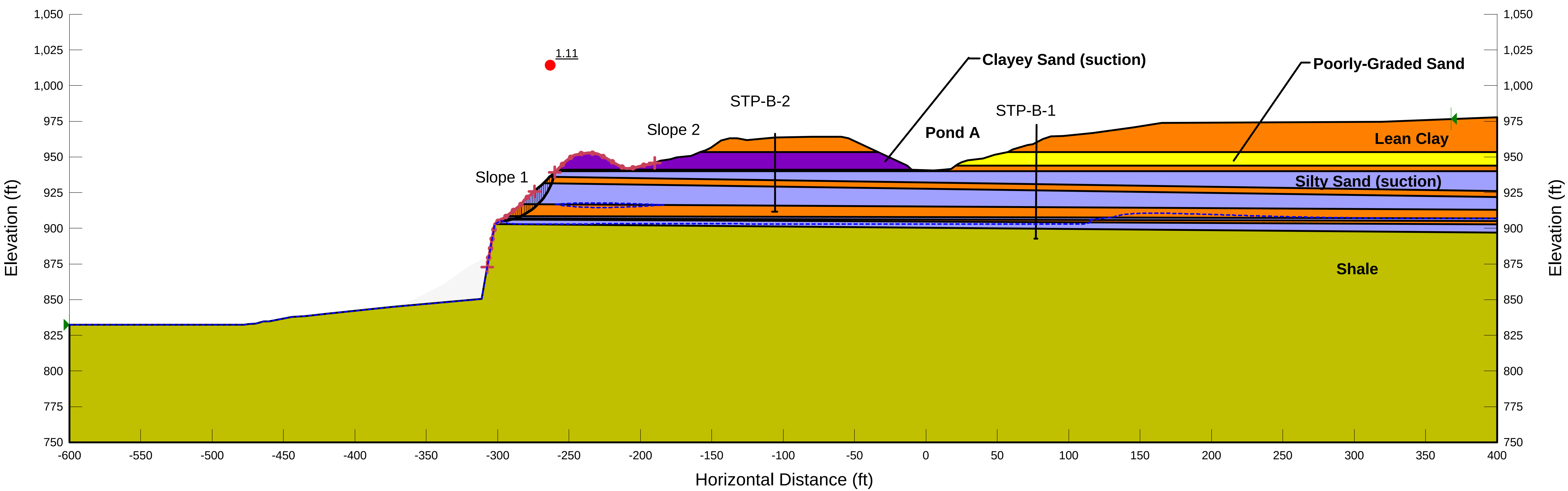

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Figure E-23 Cherokee Heights Slope 1 Drained Friction Angle with Suction with High Groundwater

Cherokee Heights

Seepage and Slope Stability Analysis

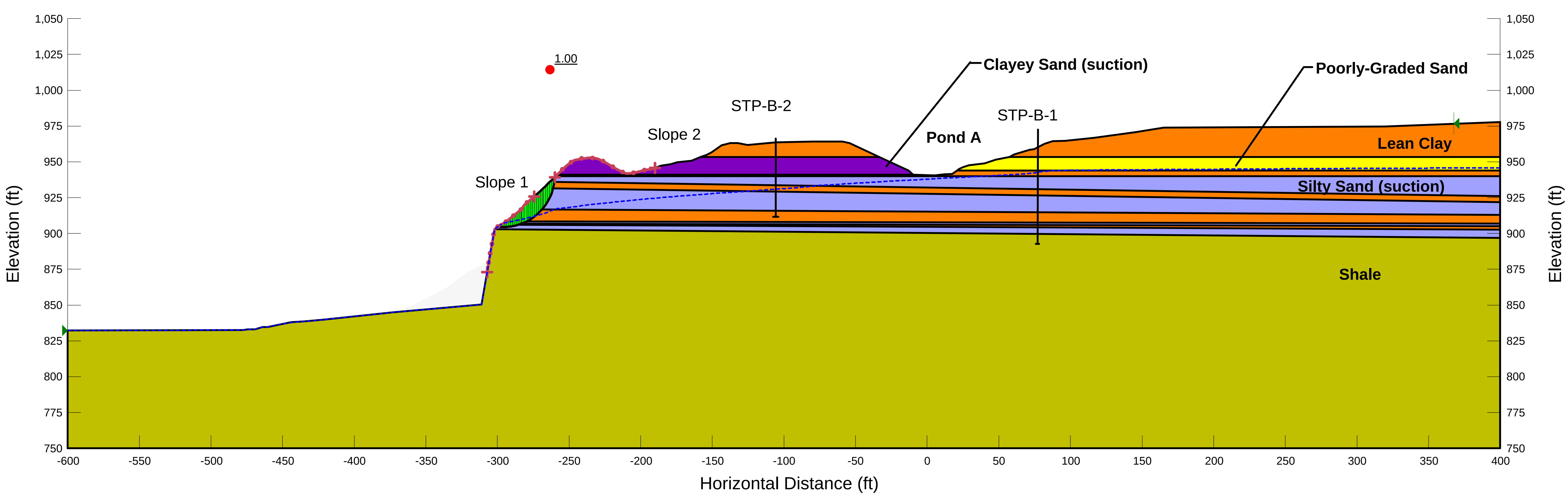
2.1 Slope - Slope 1 with High Groundwater

File Name: Lilydale_cherokee heights culvert.gsz

Date Saved: 12/26/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 1.00



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Cherokee Heights Slope 1, Ponding

Figure E-24 Cherokee Heights Slope 1, Ponding Drained Friction Angle

Cherokee Heights
Seepage and Slope Stability Analysis
1.2.1 Slope - Ponding FS=1.5_ Slope 1
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand   Model: Mohr-Coulomb   Unit Weight: 109 pcf   Cohesion': 0 psf   Phi': 29 °   Phi-B: 0 °
Name: Silty Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 133 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °
Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 133 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °
Name: Clayey Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 137 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 120 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °

FS = 0.70

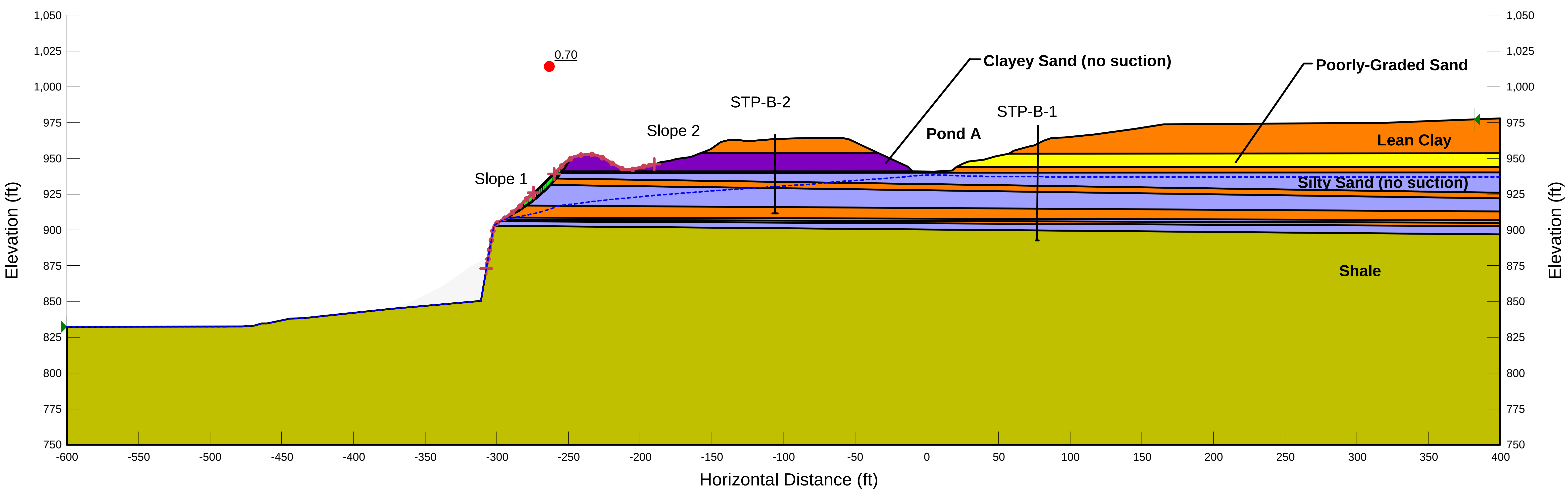

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Figure E-25 Cherokee Heights Slope 1, Ponding Drained Friction Angle at Stability
Cherokee Heights
Seepage and Slope Stability Analysis
1.2.1 Slope - Ponding FS=1.5_ Slope 1
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 1.00

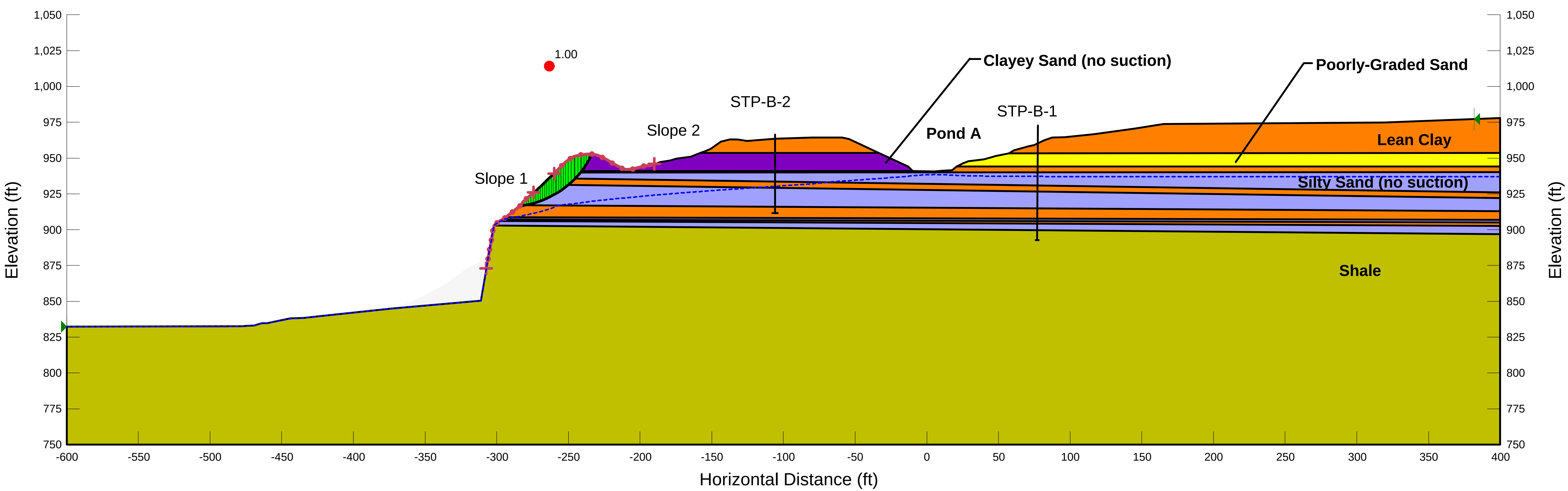

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Figure E-26 Cherokee Heights Slope 1, Ponding Drained Friction Angle with Suction
Cherokee Heights
Seepage and Slope Stability Analysis
1.5.2 Slope - Ponding FS=1.5_Slope 1 with suction
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 1.03

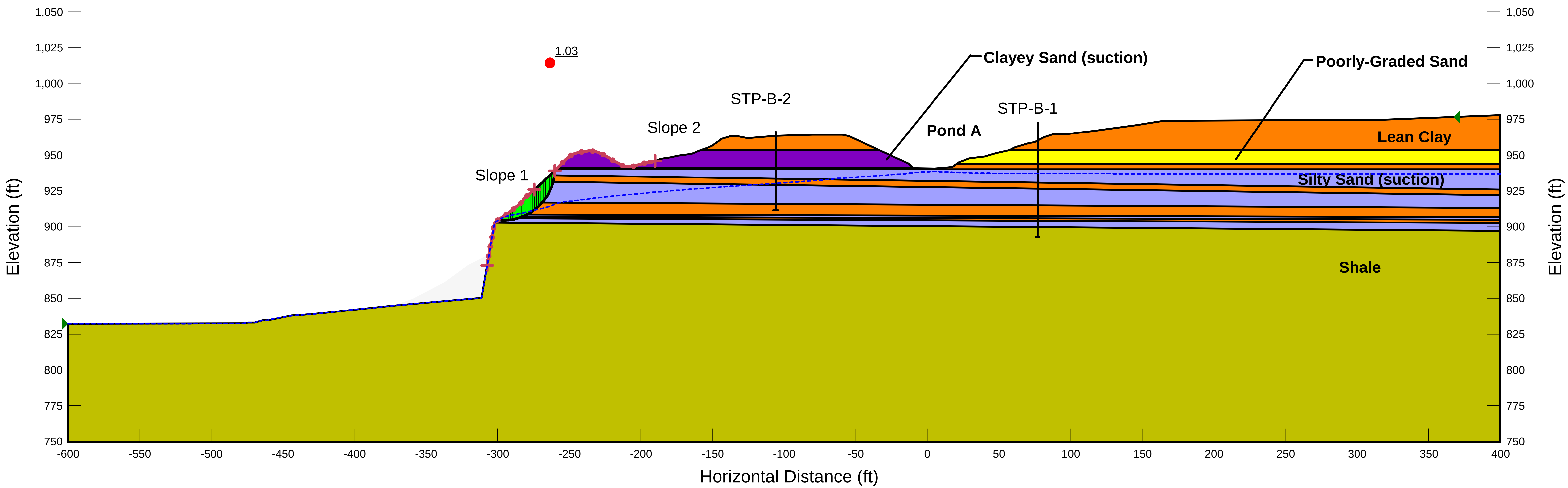

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Figure E-27 Cherokee Heights Slope 1, Ponding Drained Friction Angle with Rainfall
Cherokee Heights
Seepage and Slope Stability Analysis
1.2b.1 Slope -5yr 24hr Rain Event & Ponding Slope 1 (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 0.47

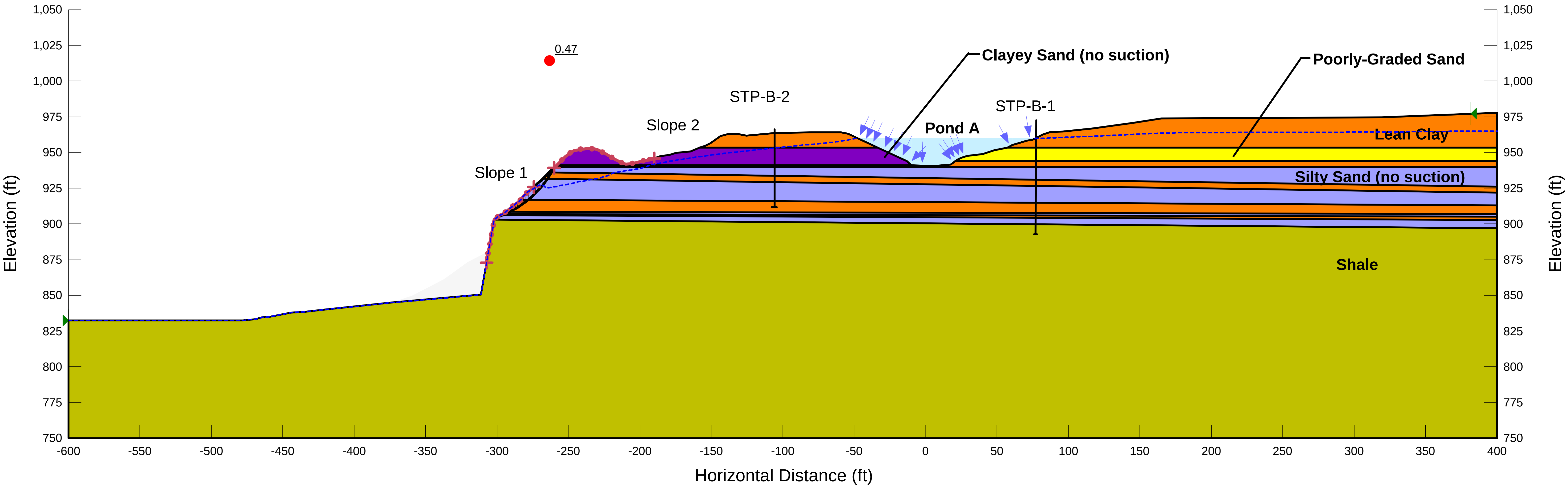

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Figure E-28 Cherokee Heights Slope 1, Ponding Drained Friction Angle with Suction with Rainfall

Cherokee Heights

Seepage and Slope Stability Analysis

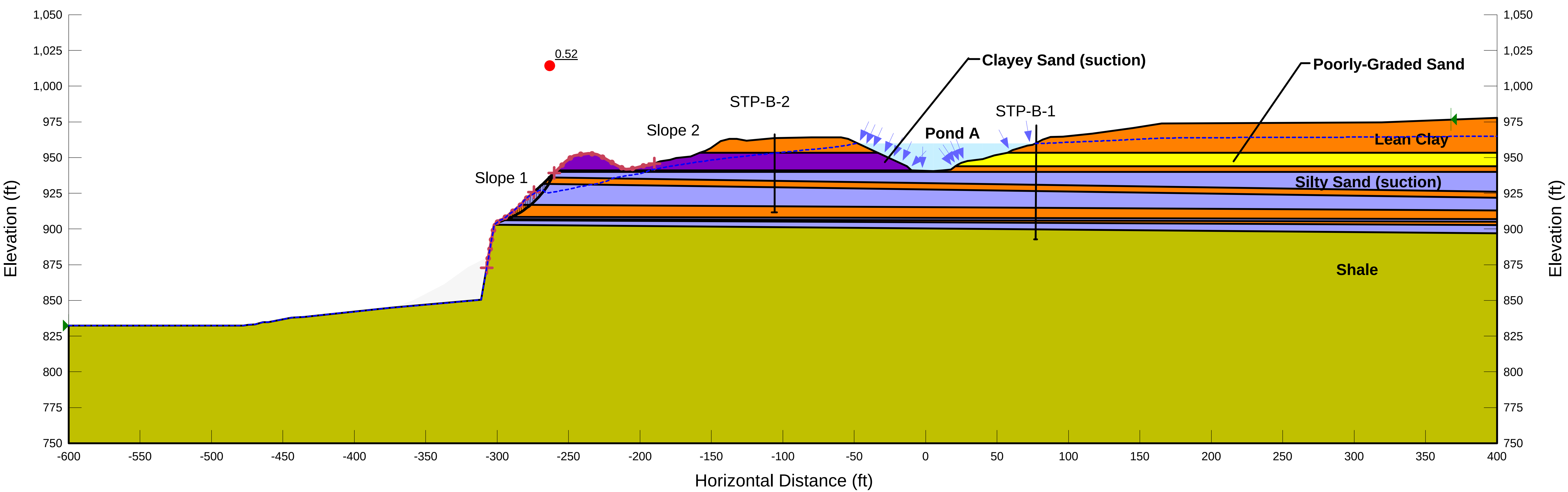
1.2b.2 Slope -5yr 24hr Rain Event & Ponding Slope 1 with suction (SAT)

File Name: Lilydale_cherokee heights culvert.gsz

Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 0.52



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Cherokee Heights Slope 2

Figure E-29 Cherokee Heights Slope 2 Drained Friction Angle
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.3 Slope - Existing Conditions Slope 2
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 1.34

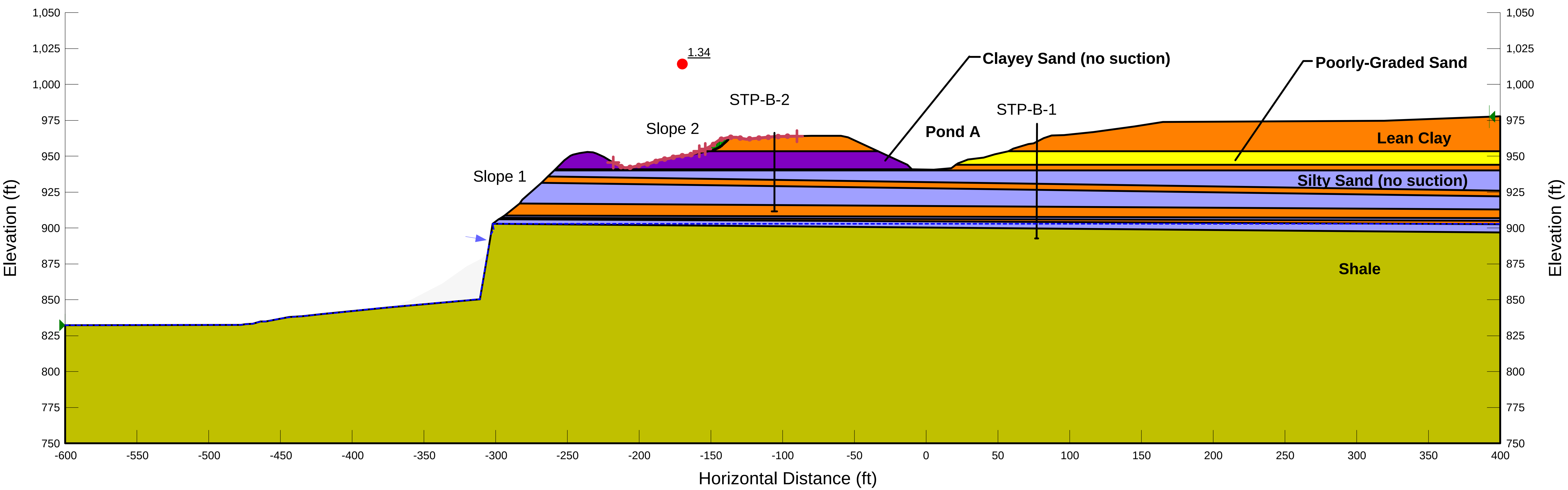

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Figure E-30 Cherokee Heights Slope 2 Drained Friction Angle with Suction
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.4 Slope - Existing Conditions Slope 2 with Suction
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 1.53

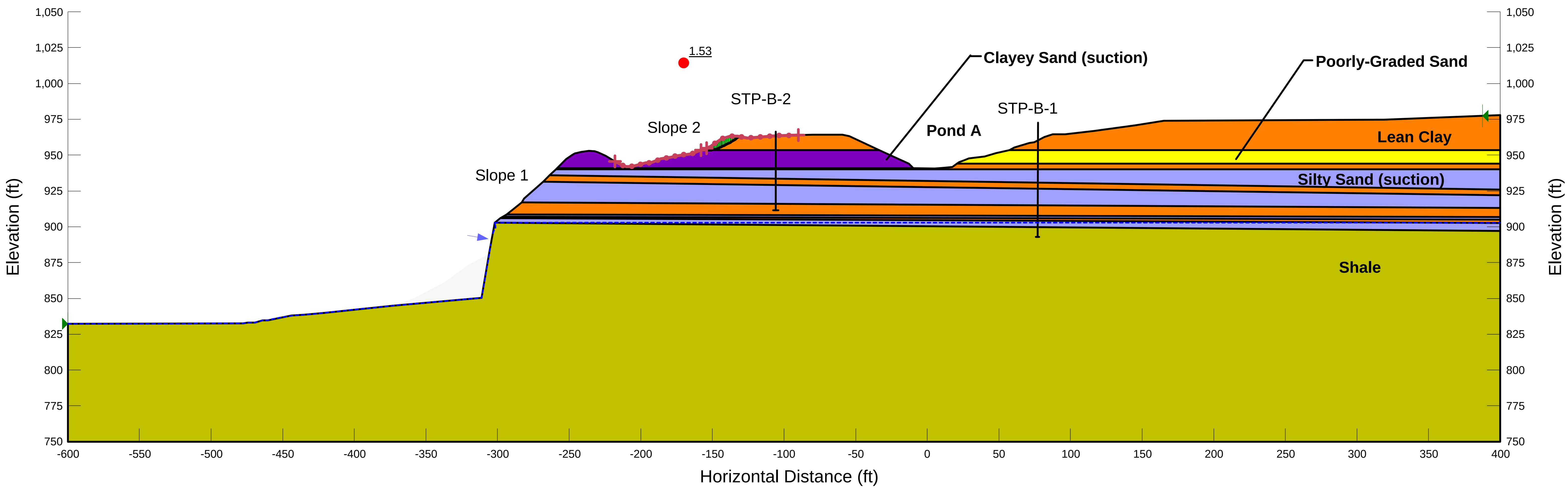

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Figure E-31 Cherokee Heights Slope 2 Drained Friction Angle with Rainfall
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.3 Slope -5yr 24 hr Rain Event Slope 2 (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 1.48

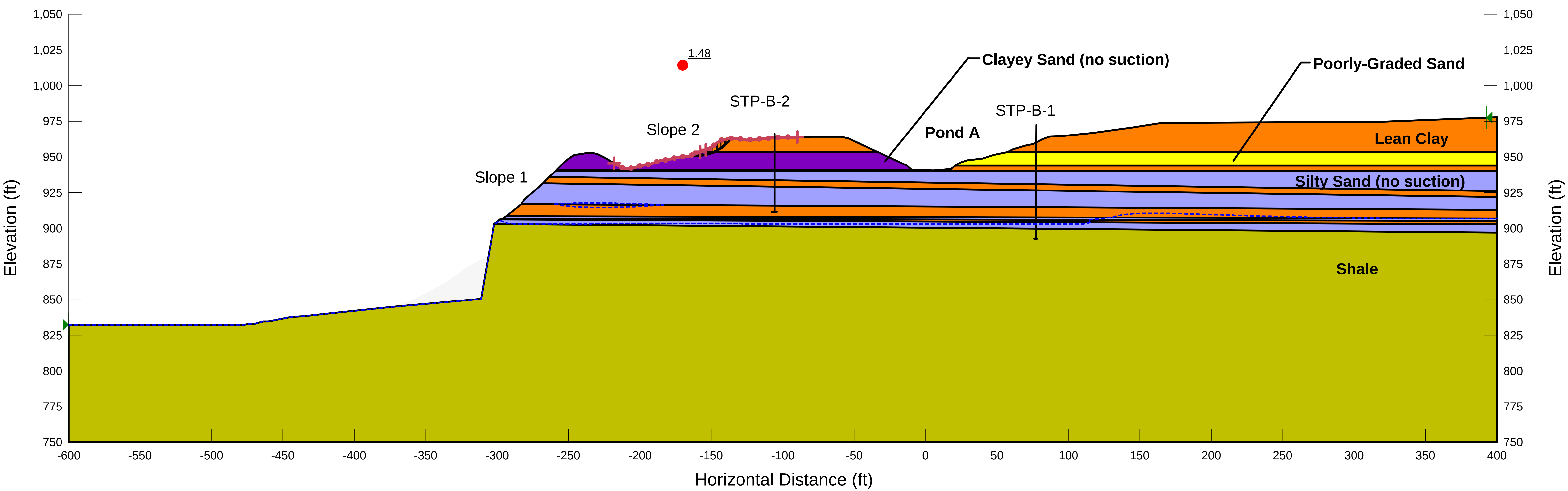

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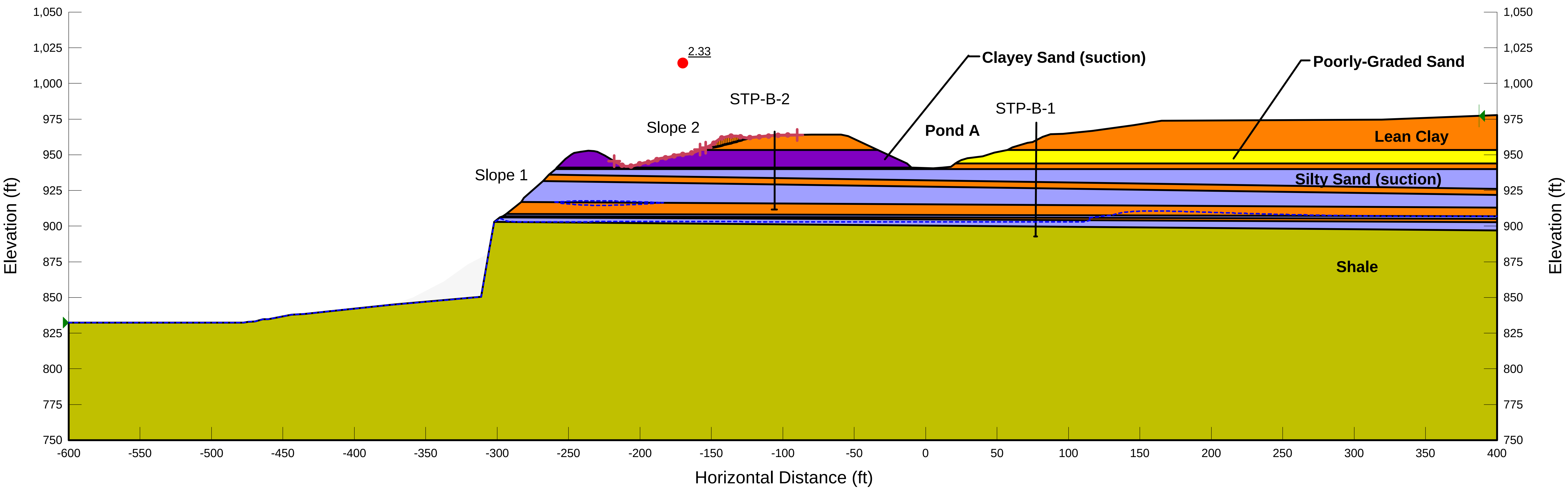
Figure E-32 Cherokee Heights Slope 2 Drained Friction Angle with Suction with Rainfall
Cherokee Heights
Seepage and Slope Stability Analysis
1.0.4 Slope - 5yr 24 hr Rain Event Slope 2 with Suction (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 2.33



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Cherokee Heights Slope 2, Ponding

Figure E-33 Cherokee Heights Slope 2, Ponding Drained Friction Angle
Cherokee Heights
Seepage and Slope Stability Analysis
1.5.3 Slope - Ponding FS=1.5_Slope 2
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand   Model: Mohr-Coulomb   Unit Weight: 109 pcf   Cohesion': 0 psf   Phi': 29 °   Phi-B: 0 °
Name: Silty Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 133 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °
Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 133 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °
Name: Clayey Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 137 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 120 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °

FS = 1.34

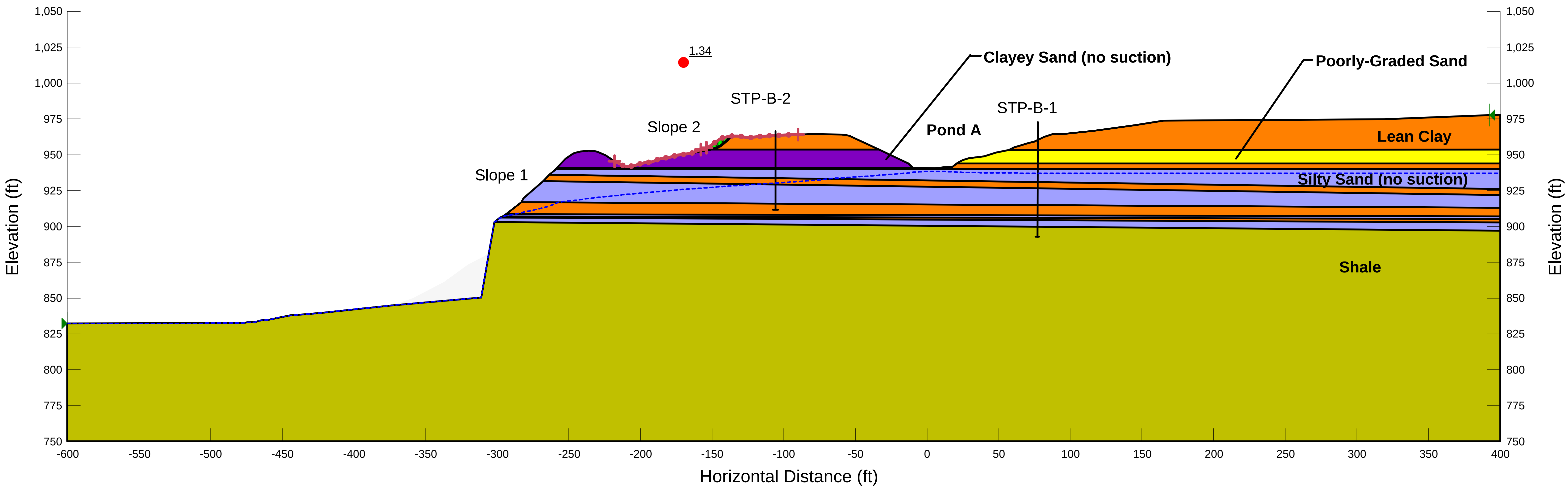

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Figure E-34 Cherokee Heights Slope 2, Ponding Drained Friction Angle with Suction
Cherokee Heights
Seepage and Slope Stability Analysis
1.5.4 Slope - Ponding FS=1.5_ Slope 2 with Suction
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 12/21/2014

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 109 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 133 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 137 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 1.53

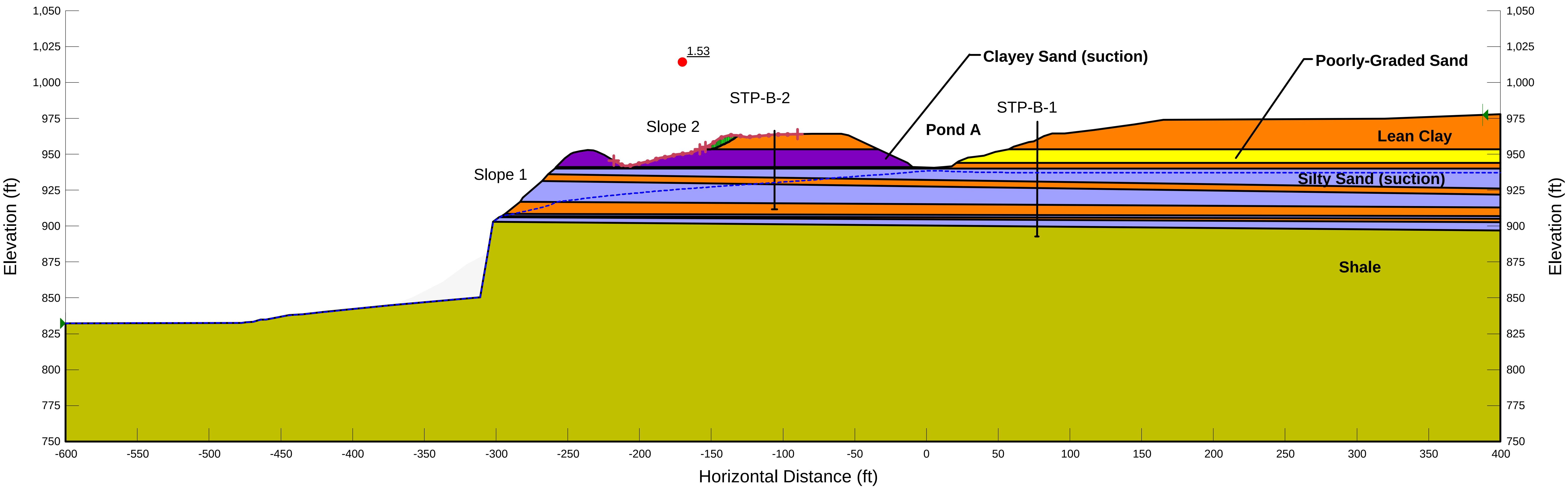

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Figure E-35 Cherokee Heights Slope 2, Ponding Drained Friction Angle with Rainfall

Cherokee Heights
Seepage and Slope Stability Analysis
1.2b.3 Slope -5yr 24hr Rain Event & Ponding Slope 2 (SAT)
File Name: Lilydale_cherokee heights culvert.gsz
Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Silty Sand (no suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °

FS = 1.48

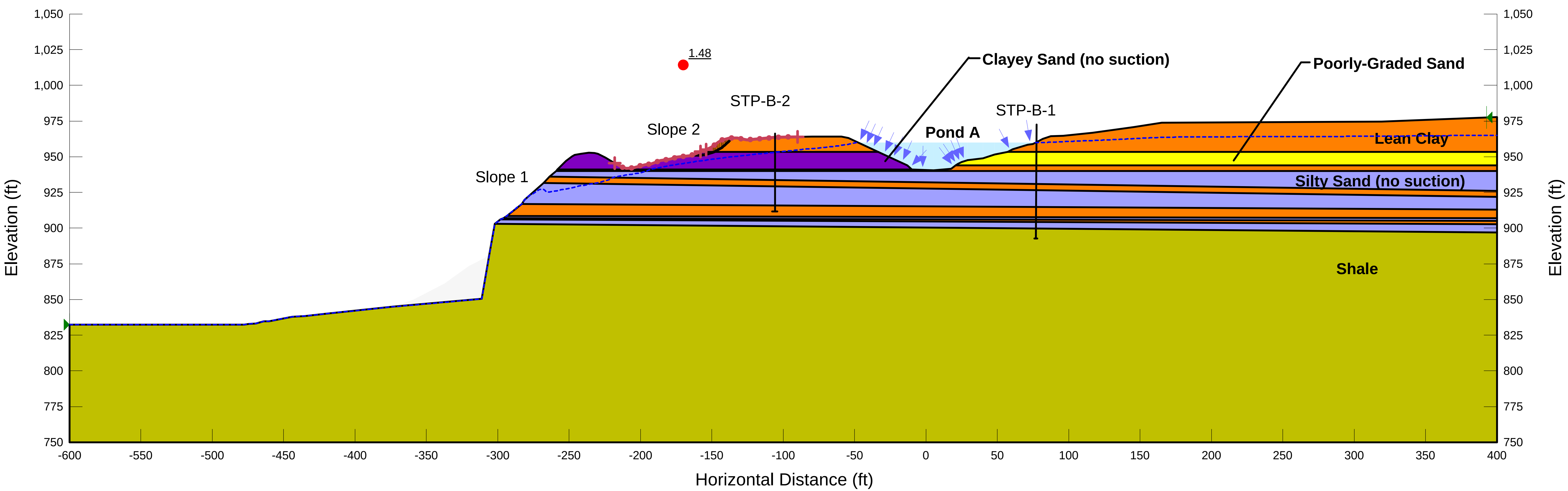

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Figure E-36 Cherokee Heights Slope 2, Ponding Drained Friction Angle with Suction with Rainfall

Cherokee Heights

Seepage and Slope Stability Analysis

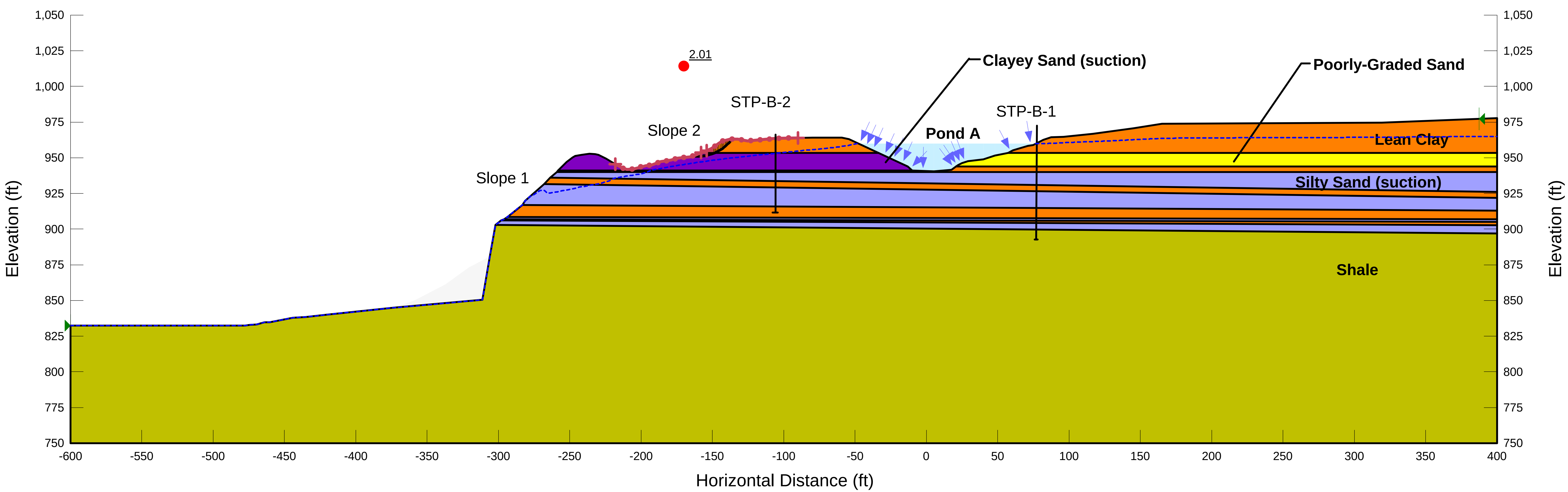
1.2b.4 Slope -5yr 24hr Rain Event & Ponding Slope 2 with Suction (SAT)

File Name: Lilydale_cherokee heights culvert.gsz

Date Saved: 1/19/2015

Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 °
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 °
Name: Shale Model: Mohr-Coulomb Unit Weight: 120 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 °
Name: Silty Sand (suction) Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Silty Sand (suction) Residual Water Content (% of Sat WC): 10 %
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 %

FS = 2.01



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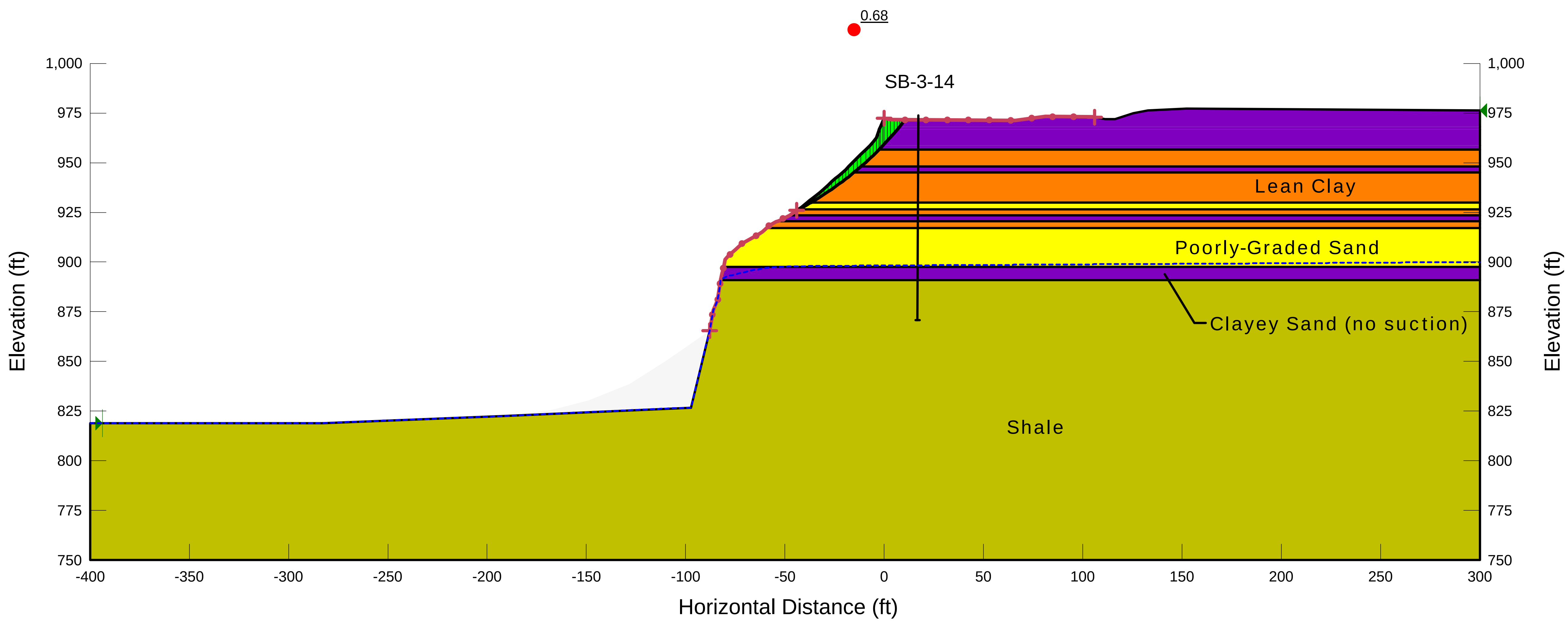
Middle Clay Pit

Figure E-37 Middle Clay Pit Drained Friction Angle
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.1.1 Slope - Existing Conditions
File Name: middle clay pit_trans_rain.gsz
Date Saved: 12/21/2014

FS = 0.68



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

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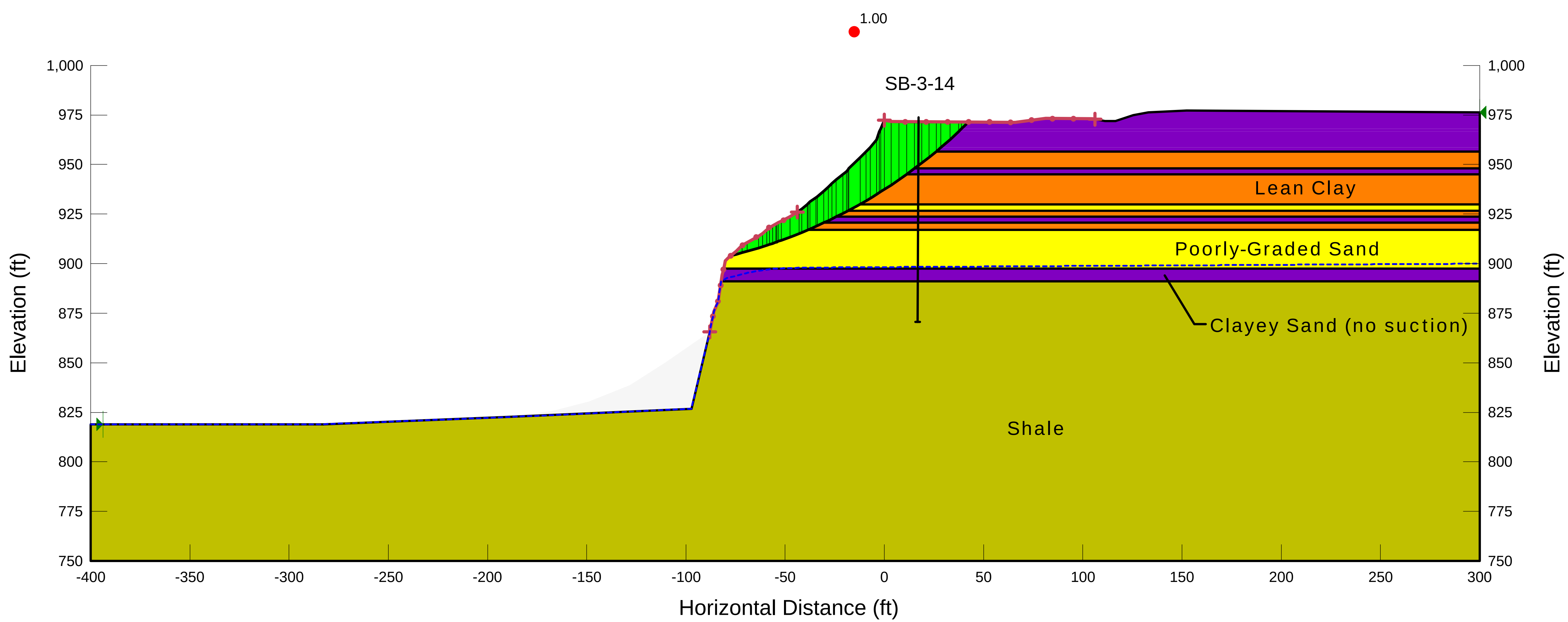
Figure E-38 Middle Clay Pit Drained Friction Angle at Stability
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.1.1 Slope - Existing Conditions
File Name: middle clay pit_trans_rain.gsz
Date Saved: 12/21/2014

FS = 1.00



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

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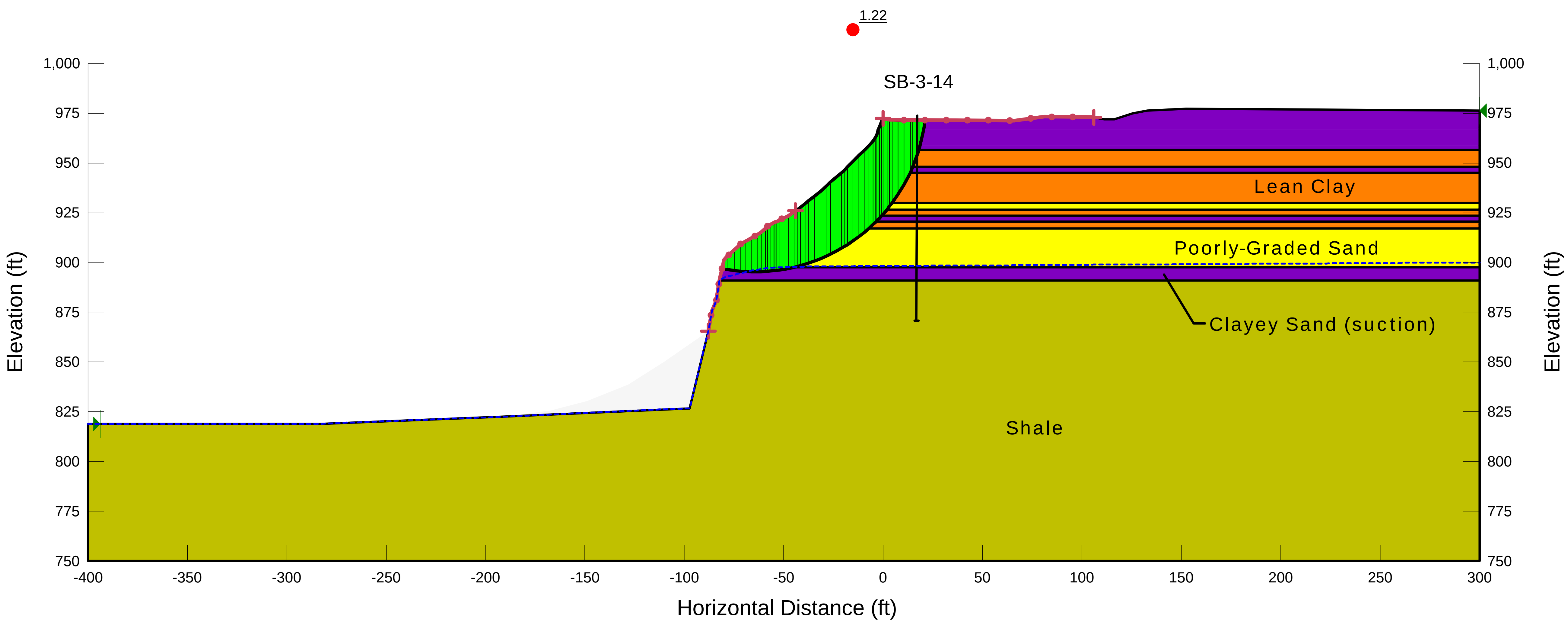
Figure E-39 Middle Clay Pit Drained Friction Angle with Suction
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.1.2 Slope - Existing Conditions with Suction
File Name: middle clay pit_trans_rain.gsz
Date Saved: 11/25/2014

FS = 1.22



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 9,800 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

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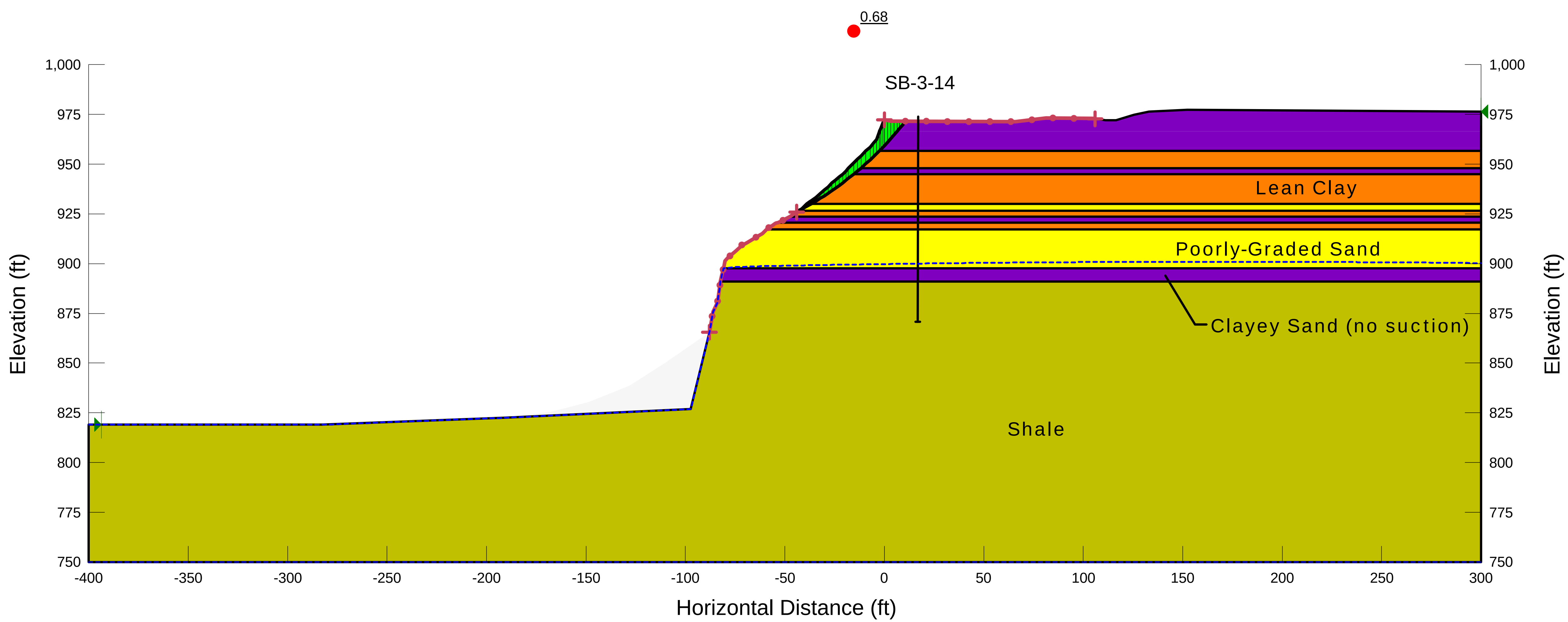
Figure E-40 Middle Clay Pit Drained Friction Angle with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2.1b Slope - Rain Event (SAT)
File Name: middle clay pit_trans_rain.gsz
Date Saved: 1/19/2015

FS = 0.68



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

Figure E-41 Middle Clay Pit Drained Friction Angle with Suction with Rainfall

Lilydale Regional Park

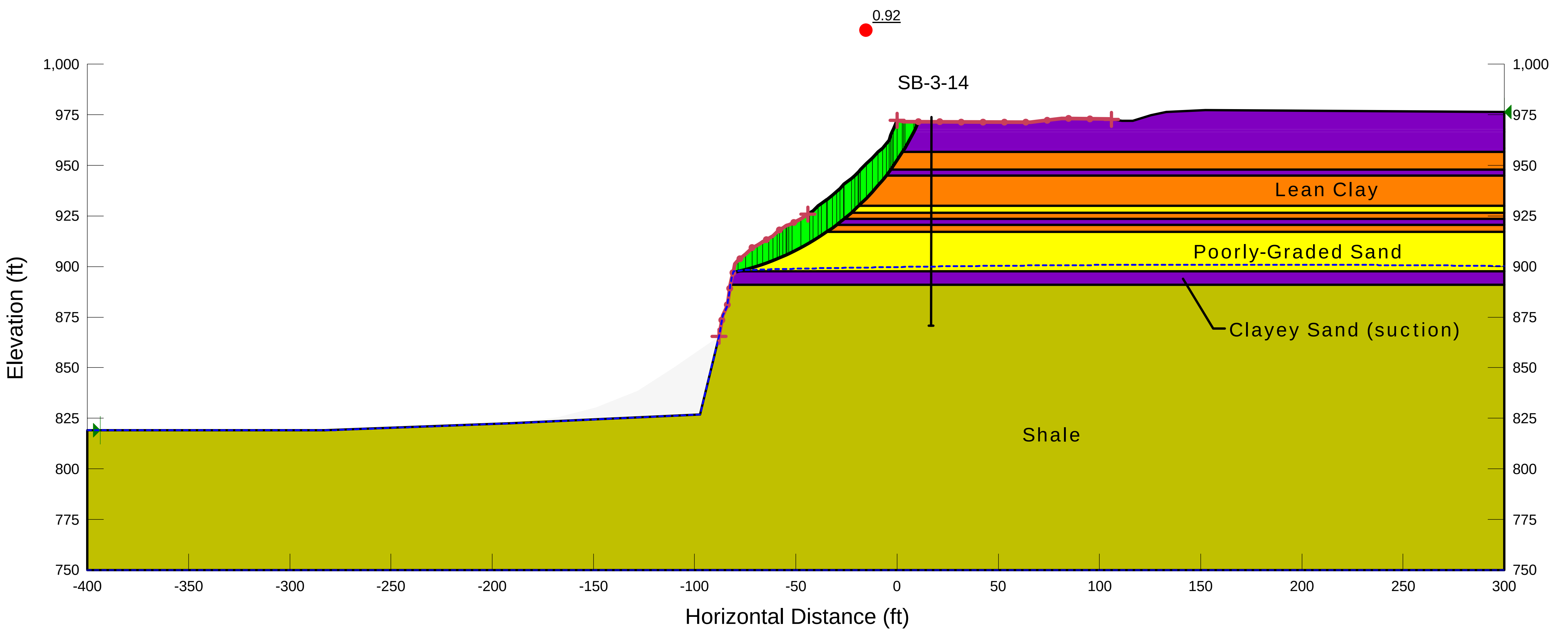
Seepage and Slope Stability Analysis

1.2.2b Slope - Rain Event with Suction (SAT)

File Name: middle clay pit_trans_rain.gsz

Date Saved: 1/19/2015

FS = 0.92



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf

Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf

Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

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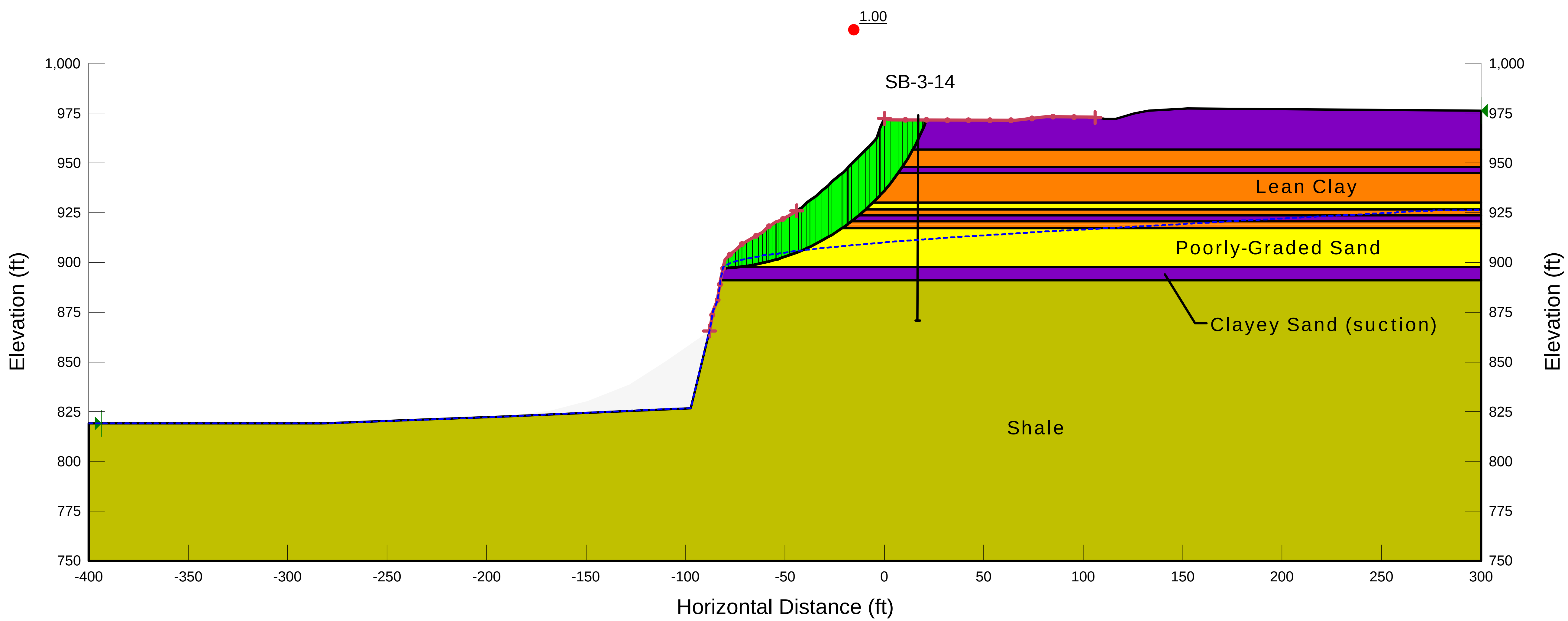
Figure E-42 Middle Clay Pit Drained Friction Angle with Suction with High Groundwater
Lilydale Regional Park
Seepage and Slope Stability Analysis
2.1 Slope - High GW with Suction
File Name: middle clay pit_trans_rain.gsz
Date Saved: 12/27/2014

FS = 1.00



Name: Poorly-Graded Sand Model: Mohr-Coulomb Unit Weight: 119 pcf Cohesion': 0 psf Phi': 29 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 109 pcf
Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

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West Clay Pit

Figure E-43 West Clay Pit Drained Friction Angle

Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.1 Slope - Existing Conditions
File Name: Lilydale_west clay pit_SC.gsz
Date Saved: 12/21/2014

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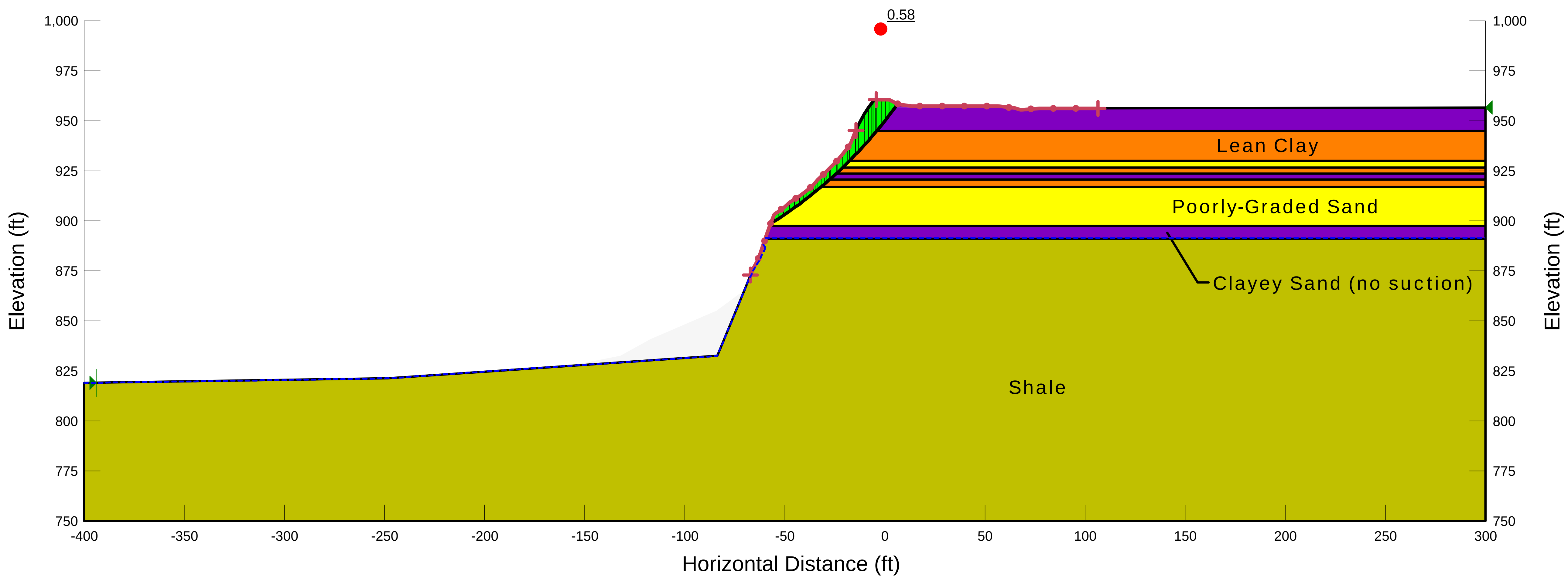

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Name: Lean Clay Model: Mohr-Coulomb Unit Weight: 143 pcf Cohesion': 0 psf Phi': 30 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 133 pcf
Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

Figure E-44 West Clay Pit Drained Friction Angle at Stability
Lilydale Regional Park
Seepage and Slope Stability Analysis 1.0.1 Slope - Existing Conditions
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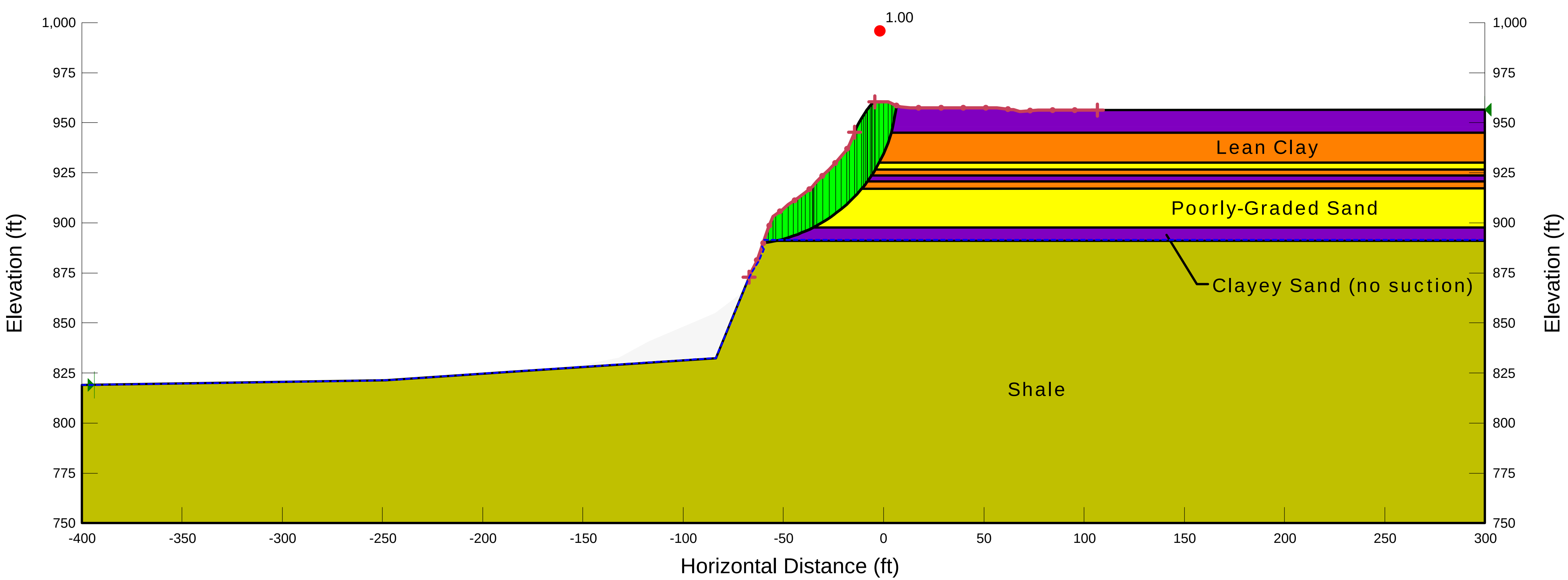

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Name: Clayey Sand (no suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf

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Figure E-45 West Clay Pit Drained Friction Angle with Suction
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.0.2 Slope - Existing Conditions with Suction
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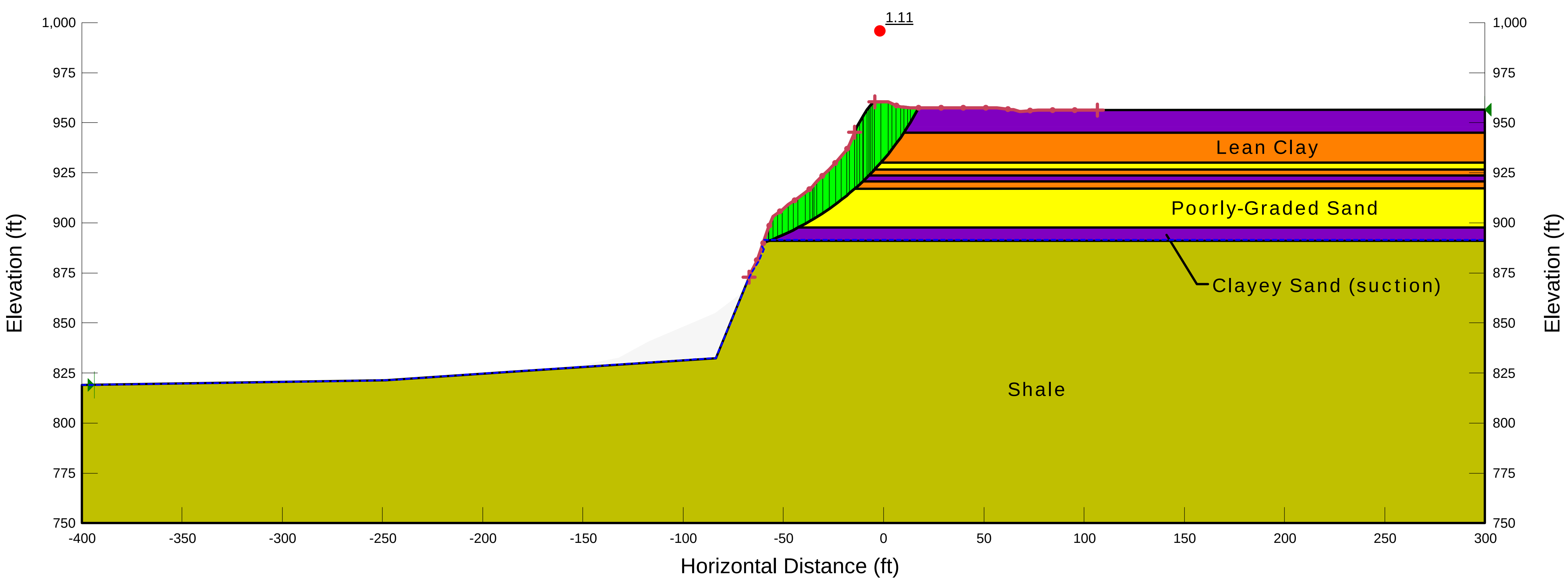

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Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

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Figure E-46 West Clay Pit Drained Friction Angle with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.1 Slope - Rain Event (SAT)
File Name: Lilydale_west clay pit_SC.gsz
Date Saved: 1/19/2015

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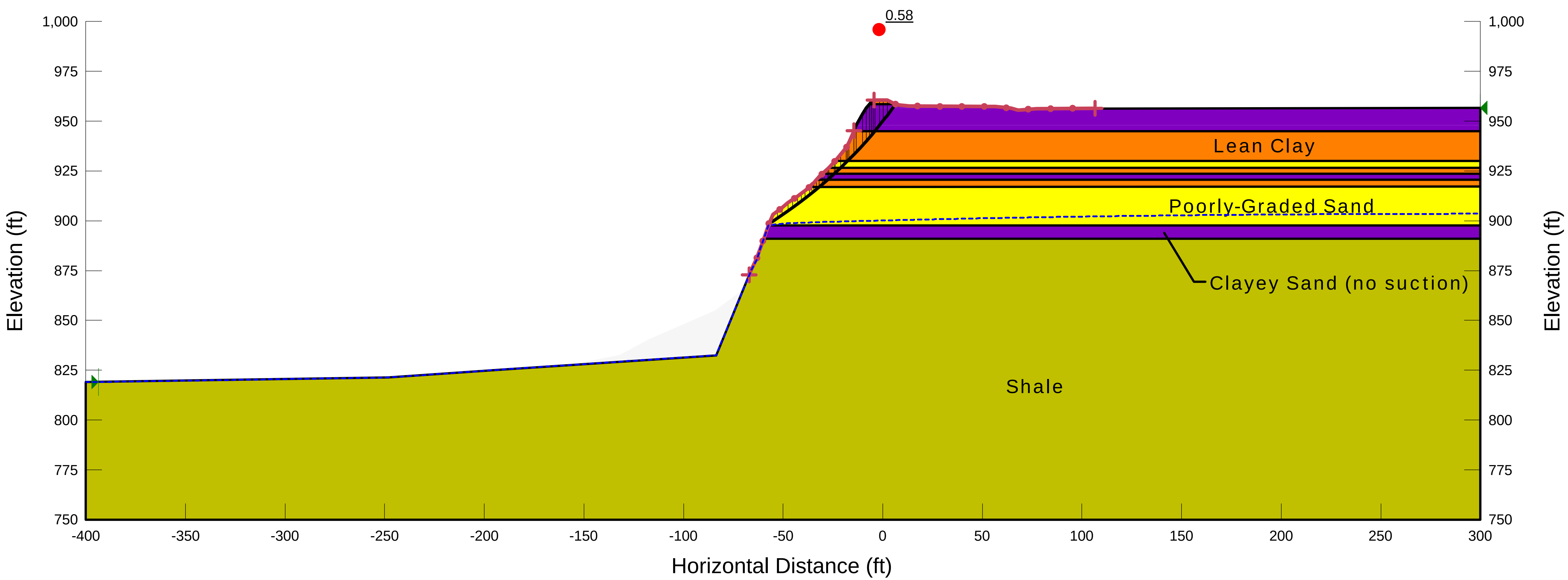

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Name: Clayey Sand (no suction)   Model: Mohr-Coulomb   Unit Weight: 147 pcf   Cohesion': 0 psf   Phi': 33 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 137 pcf
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 130 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 120 pcf

Figure E-47 West Clay Pit Drained Friction Angle with Suction with Rainfall
Lilydale Regional Park
Seepage and Slope Stability Analysis
1.2b.2 Slope - Rain Event with Suction (SAT)
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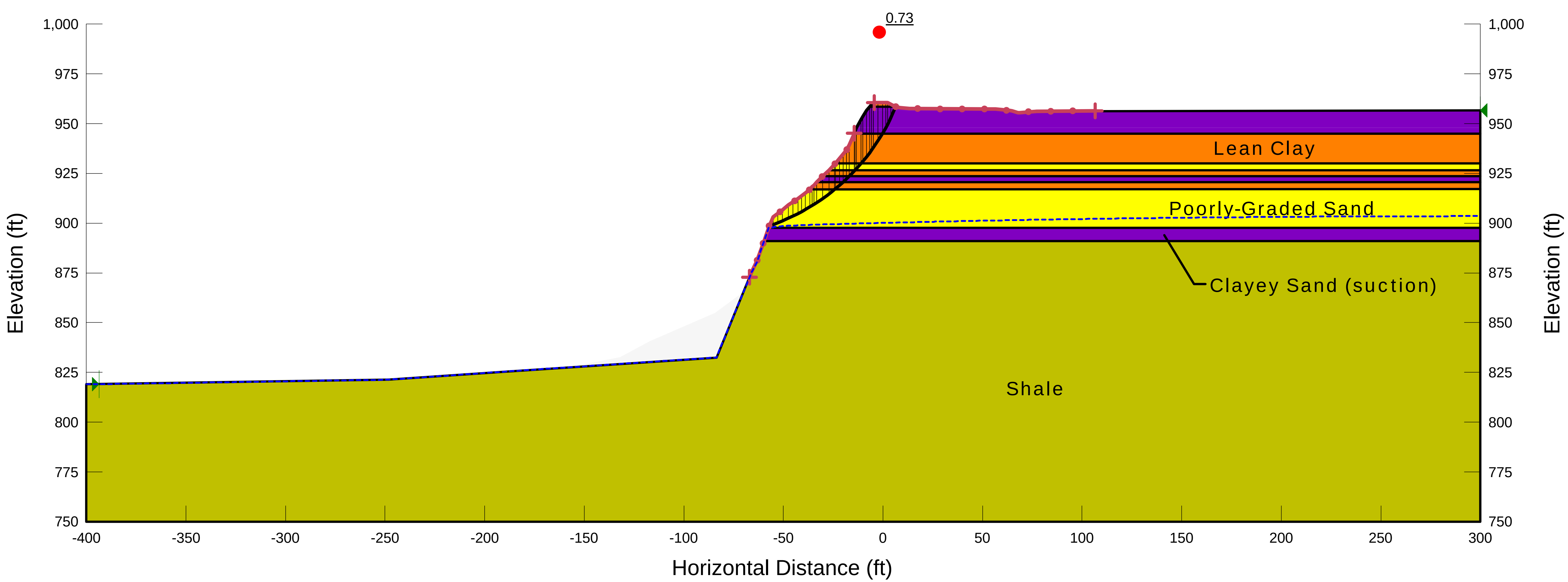

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Name: Shale Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 4,900 psf Phi': 0 ° Phi-B: 0 ° Constant Unit Wt. Above Water Table: 120 pcf
Name: Clayey Sand (suction) Model: Mohr-Coulomb Unit Weight: 147 pcf Cohesion': 0 psf Phi': 33 ° Vol. WC. Function: Clayey Sand (suction) Residual Water Content (% of Sat WC): 10 % Constant Unit Wt. Above Water Table: 137 pcf

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Figure E-48 West Clay Pit Drained Friction Angle with Suction with High Groundwater
Lilydale Regional Park
Seepage and Slope Stability Analysis
2.1 Slope - high GW with Suction
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Date Saved: 12/27/2014

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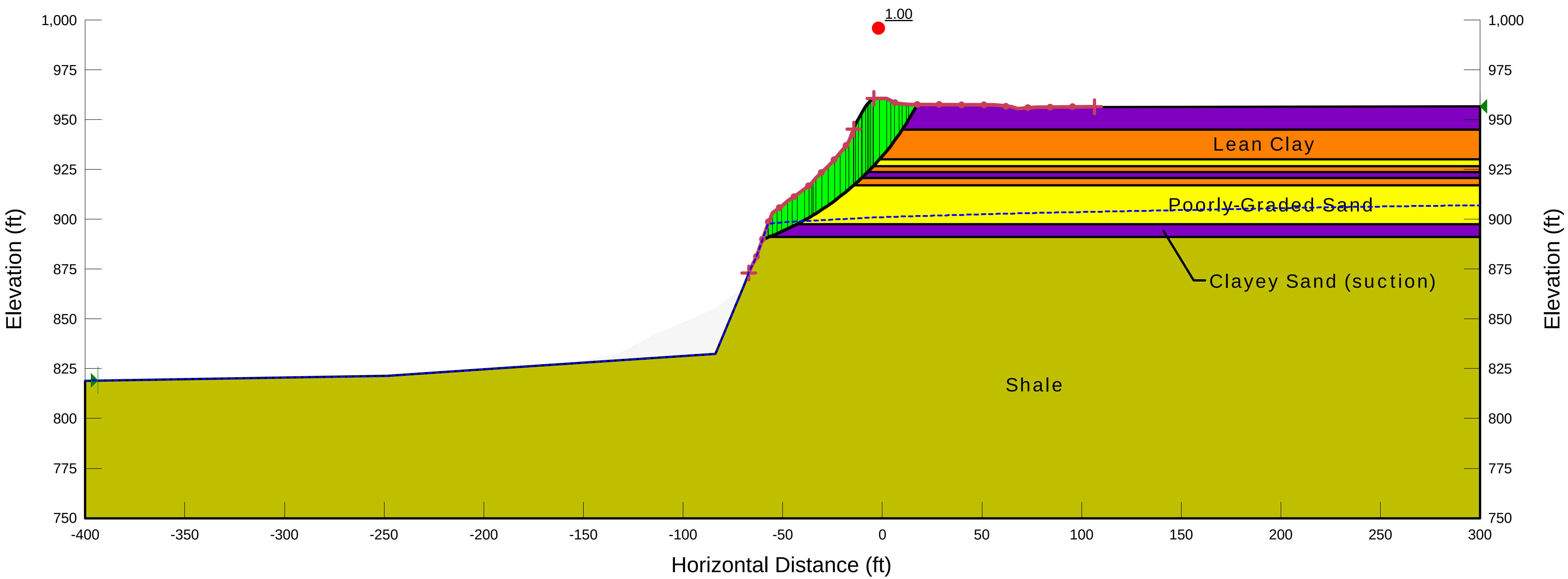

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Name: Lean Clay   Model: Mohr-Coulomb   Unit Weight: 143 pcf   Cohesion': 0 psf   Phi': 30 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 133 pcf
Name: Shale   Model: Mohr-Coulomb   Unit Weight: 130 pcf   Cohesion': 4,900 psf   Phi': 0 °   Phi-B: 0 °   Constant Unit Wt. Above Water Table: 120 pcf
Name: Clayey Sand (suction)   Model: Mohr-Coulomb   Unit Weight: 147 pcf   Cohesion': 0 psf   Phi': 33 °   Vol. WC. Function: Clayey Sand (suction)   Residual Water Content (% of Sat WC): 10 %   Constant Unit Wt. Above Water Table: 137 pcf

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Appendix D

Stormwater Modeling Methodology

Prepared for
City of St. Paul Department of Parks and Recreation

January 28, 2015

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Minneapolis, MN 55435-4803
Phone: 952.832.2600
Fax: 952.832.2601

Appendix D
Stormwater Modeling Methodology
January 28, 2015

Contents

List of Tables

1.0 Hydrologic and Hydraulic Modeling Methodology

The U.S. EPA's Storm Water Management Model (SWMM), with a computerized graphical interface provided by XP Software (XP-SWMM), was chosen as the computer modeling package for this study. XP-SWMM uses rainfall and watershed characteristics to generate local runoff, which is routed simultaneously through complicated pipe and overland flow networks. The model can account for detention in ponding areas, backflow in pipes, surcharging of manholes, as well as tailwater conditions that may exist and affect upstream storage or pipe flows. XP-SWMM Version 2014, was used to model the storm sewer, ponding, channel flow and overland flow systems for the Brickyard Area of Lilydale Regional Park and its tributary watershed.

1.1 Hydrologic Modeling

Three major types of information are required by XP-SWMM for hydrologic modeling: (1) watershed characteristics, (2) rainfall data, and (3) infiltration characteristics. This data is used by XP-SWMM to generate inflow hydrographs at various points in the drainage network. The following sections describe each of these data sets.

1.1.1 Watershed Data

The amount of runoff from a watershed depends on numerous factors, including the total watershed area, the soil types within the watershed, the percent of impervious area, the runoff path through the watershed, and the slope of the land within the watershed. ArcGIS (geographic information systems) software was used extensively in assessing the above mentioned characteristics of each watershed within the study area.

1.1.1.1 Watershed Area

The watershed delineation was performed using the Minnesota Department of Natural Resources' (MNDNR's) 2011 LiDAR elevation data set covering Dakota County along with the storm sewer system (manholes, catch basins, and pipes) layout and aerial imagery. A total of 55 subwatersheds were delineated for this area - 34 subwatersheds in the Lilydale Regional Park area and 21 subwatersheds contributing stormwater flow to the park via the upstream storm sewer system. The delineated subwatersheds are shown in Large Figure 4-1 of the main report.

1.1.1.2 Land Use Data

Land use data was obtained to estimate both the percentage of directly and indirectly connected imperviousness within each watershed. The directly-connected impervious fraction consists of the impervious surfaces that are "connected" directly to stormwater conveyance systems, meaning that flows do not cross over pervious areas. The indirectly connected impervious fraction represents impervious areas with runoff that flows over pervious areas before reaching the stormwater conveyance system (rooftops, for example). These fractions were calculated by first estimating the total impervious area for each subwatershed using the National Land Cover Dataset (NLCD) 2011 impervious layer (Xian et al, 2013).

Indirectly connected impervious areas were estimated using roof delineations for the Twin Cities Metropolitan Area produced by the National Geodetic Survey (NGS) in 2008 using LiDAR elevation data. Total roof area coverage located in portions of the watershed with a land use classification consistent with having indirectly connected impervious surfaces (i.e. Park/Recreational/preserve, single family attached, single family detached, and undeveloped) were calculated for each subwatershed. Other impervious area types (roads, sidewalks, driveways and parking lots) were assumed to be directly connected to the storm sewer system. Directly connected impervious areas were calculated by subtracting the indirectly connected impervious areas from the total impervious area for each subwatershed. The impervious factions were determined by dividing each impervious value by the total subwatershed area for each of the subwatersheds in the model.

1.1.1.3 Watershed Width and Slope

The SWMM Runoff Non-linear Reservoir Method was used as the hydrograph generation technique for this project. This method computes outflow as the product of velocity, depth and a watershed width factor. The watershed "width" in XP-SWMM is defined as the subwatershed area divided by the flow path length. This factor is a key parameter in determining the shape of the hydrograph for each subwatershed and is often used as a calibration parameter, when calibration data is available. The main flow path length was calculated in ArcGIS and was used in conjunction with the subwatershed area to calculate the width parameter.

The average slope (ft/ft) for each subwatershed was calculated in ArcGIS (standard ArcGIS Spatial Analyst raster tools) using the MNDNR 2011 LiDAR elevation data set.

1.1.1.4 Rainfall Data

The XP-SWMM model was run for the 1-year, 2-year, 5-year, 10-year, 50-year, and 100-year recurrence, 24-hour precipitation events using the Atlas 14 precipitation frequency estimates. Point-based precipitation frequency estimates for the centroid of the study area were obtained from NOAA's National Weather Service Precipitation Frequency Data Server (PFDS) located at http://dipper.nws.noaa.gov/hdsc/pfds/.

Nested 24-hour rainfall distributions were created for each modeled storm event. Each rainfall distribution was a storm hyetograph derived from the precipitation frequency estimates. A "nested" hyetograph was built, which is a hypothetical precipitation distribution where the precipitation depths for various durations within the storm have identical exceedance probabilities. This distribution maximizes the rainfall intensities by incorporating selected short duration intensities within those needed for longer durations at the same probability level. As a result, the various storm durations are "nested" within a single hypothetical distribution.

1.1.1.5 Infiltration Data

Soils

Soils data for the area was obtained through 2014 Gridded Soil Survey Geographic Database for the state of Minnesota (USDA, 2014) which was imported into ArcGIS. The database included the soil names and the hydrologic soil group (HSG) designation for most of the soil types. The hydrologic soil group designation classifies soils into groups (A, B, C, and D) based on the infiltration capacity of the soil (well drained, sandy soils are classified as “A” soils; poorly drained, clayey soils are classified as “D” soils). When a HSG designation was not included in the soils database, the soil description was used to estimate the HSG. If a soil description was unavailable, the most dominant soil group in the vicinity was assumed.

Horton Infiltration

Infiltration was simulated in the XP-SWMM model using the Horton Infiltration equation. This equation is used to represent the exponential decay of infiltration capacity of the soil that occurs during heavy storm events. The soil infiltration capacity is a function of the following variables: F_c (minimum or ultimate value of infiltration capacity), F_o (maximum or initial value of infiltration capacity), k (decay coefficient), and time.

The actual values of F_c, F_o, and k are dependent upon soil, vegetation, and initial moisture conditions prior to a rainfall event. Because it was not feasible to obtain this detailed information for each subwatershed through field samples, it was necessary to make assumptions based on the various soil types throughout the study area. Table 1 summarizes the Horton infiltration values used for each HSG to calculate composite infiltration parameters for each subwatershed. The values shown in the table are based on suggested values in the *Storm Water Management Model, Version 4: User's Manual* (U.S. EPA, 1988). Composite F_c and F_o values were calculated for each subwatershed based on the fraction of each soil type within the subwatershed. Global databases containing the infiltration parameters for each subwatershed were developed and imported into the XP-SWMM models.

Table D-1-1 Horton Infiltration Parameters

Hydrologic Soil Group	F_o (in/hr)	F_c (in/hr)	k (1/sec)
A	5	0.38	0.0008
B	3	0.23	0.0008
C	2	0.1	0.0008
D	1	0.03	0.0008

1.1.1.6 Depression Storage Data

Depression storage represents the volume (in inches) that must be filled with rainfall prior to the occurrence of runoff in XP-SWMM. It characterizes the loss or "initial abstraction" caused by such phenomena as surface ponding, surface wetting, interception and evaporation. Separate depression storage input values are required in XP-SWMM for pervious and impervious areas.

The depression storage assumptions used for the models were based on the values used in the XP-SWMM model developed for the *Nine Mile Creek Watershed District Bloomington Use Attainability Analysis* (Barr Engineering, 2001). For this reference model, the depression storage was estimated by plotting total precipitation for several measured rainfall events at a Bloomington continuous-recordingprecipitation gage versus runoff from several Bloomington monitoring sites. A regression analysis of the data yielded a y-intercept that was assumed to be the depression storage (in inches). Based on this analysis, the assumed impervious depression storage was 0.06 inches and the pervious depression storage was 0.17 inches. These values are in line with the range of values recommended in literature.

1.2 Hydraulic Modeling

1.2.1 Storm Sewer Network

Data detailing the storm sewer network for the area was provided by the cities of St Paul, Mendota Heights, West St. Paul and the Minnesota Department of Transportation (MN/DOT). The storm sewer data was provided in a GIS format, with the database file containing invert elevations, pipe sizes, pipe lengths, and manhole rim elevations. Where storm sewer information was missing in the GIS data set, "as-built" drawings containing the storm sewer information were provided by the cities. A Manning's roughness value of 0.013 was applied to each storm sewer pipe.

There are three culverts under Cherokee Heights Boulevard that serve as the three main stormwater discharge points into the Brickyard Area of Lilydale Regional Park. The location of the storm sewer pipes and the three culverts under Cherokee Heights Boulevard are shown in Large Figure 4-1 of the main report.

1.2.2 Storage Areas

Three storage areas were included in the model: one located at the upstream end of the 18-inch culvert Freemont Avenue culvert under Cherokee Heights/TH13, one just upstream of the 60-inch culvert under Cherokee Heights Boulevard, and a depression area located to the south of Simard Street and north of Miriam Street. Storage curves describing the elevation/area relationship were developed in GIS for each of these storage areas using the 2011 MNDNR LiDAR elevation data set.

1.2.3 Overland Flow Network

Since there is no known storm sewer pipe system actively conveying water within the Brickyard Area of Lilydale Regional Park, runoff from the Brickyard Area downstream of Cherokee Heights Boulevard generally flows overland following the slope of the land. Runoff from the three main stormwater discharge points (described above) flows into overland channels through the Brickyard Area. The overland channels were modeled as natural channel cross-sections. Channel lengths, upstream and downstream channel elevations, and channel shape were determined using the 2011 MNDNR LiDAR elevation data set. A Manning's roughness value of 0.05 was applied to each of the natural channel cross-sections.

A street overland flow channel network was also added to the upstream portion of the study area served by storm sewer. All street sections are represented in the XP-SWMM model using a trapezoidal channel with a 30-foot bottom width, 1:1 side slopes, and a Manning's roughness value of 0.014. Street elevations were determined using the 2011 MNDNR LiDAR elevation data set. All surface runoff that is surcharged or exceeds the capacity from the Freemont Avenue and Cherokee Heights storm sewer systems is routed through overland flow street channels into the Cherokee Heights basin, through the 60-inch culvert under Cherokee Heights, and into the Cherokee Heights ravine (modeled using a natural channel cross-section).

2.0 References

Barr Engineering, 2001. *Nine Mile Creek Watershed District Bloomington Use Attainability Analysis*

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USDA, 2014. *Gridded Soil Survey Geographic (gSSURGO) Database Users Guide*. Natural Resources Conservation Service, United States Department of Agriculture. April 2014.

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