The University of British Columbia | Okanagan Campus

Integrated Rainwater Management Plan

Final Report | Part 4: Geotechnical Investigation

a place of mind

THE UNIVERSITY OF BRITISH COLUMBIA

Prepared for

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ACKNOWLEDGEMENT

The University respectfully acknowledges the traditions and customs of the Okanagan Nation and its people in whose territory the campus is situated. The Syilx (Okanagan) people have been here since time immemorial. In September 2005, the Okanagan Nation Alliance officially welcomed UBC to traditional Syilx (Okanagan Nation) territory in an official ceremony, Knaqs npi'lsmist, where UBC signed a Memorandum of Understanding with the Okanagan Nation.

As they have been stewards of this traditional territory since time immemorial, UBC works with the Okanagan Nation to ensure they are partners in the pursuit planning at the Okanagan Campus.

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MEMORANDUM

TO:	Glen Shkurhan, Urban Systems Ltd	Our file: 3529-M01 Draft: July 14, 2016 Final: July 29, 2016

FROM: Martin Stewart, P.Geo. and Remi Allard, P.Eng.
Email: mstewart@piteau.com and rallard@piteau.com

RE: Infiltration Capacity Field Assessment at the University of British Columbia - Okanagan Campus, Kelowna B.C.

At the request of Glen Shkurhan of Urban Systems Ltd. (USL), Piteau Associates Engineering Ltd. (Piteau) has prepared this memorandum to document the results of a hydrogeological assessment in support of an Integrated Stormwater Management Plan (ISMP) for the Okanagan Campus of UBC (the Campus) being prepared by USL. The primary objective of this work is to understand the infiltration capacity of the soils below the Campus property to receive storm water flows captured at surface. A preliminary desktop assessment conducted by Piteau determined that much of the Campus is underlain by shallow, low permeability, soils which may inhibit infiltration. However, the deeper, higher permeability, soils (e.g., an aquifer exploited for the Campus open loop geothermal field) may provide a receptor for infiltration via excavated infiltration basins or gravity drainage wells. Historical data from previous geotechnical and hydrogeological work at the Campus did not provide sufficient spatial or depth of coverage to identify soils where infiltration is permissible from a hydrogeological perspective, or to quantify the infiltration capacity of those soils. This memorandum is intended to fill those data gaps and to identify feasible locations to facilitate storm water infiltration as part of the ISMP.

1.0 BACKGROUND

In February 2016, USL was contracted by UBC to provide a comprehensive ISMP to develop a sustainable and low impact design for disposal of wastewater that more closely reflects the natural return of water to ground on the Okanagan Campus. Piteau was contacted to provide input regarding the existing knowledge of subsurface conditions which could inform the ISMP. Piteau's initial assessment of historical drilling and testing of soils around campus indicated that there is potential to put storm water to ground at some locations on campus; however, significant gaps existed in the historical data. Those data gaps included the spatial distribution of soil types, the stratigraphy of soils at depth and measurements of saturated hydraulic conductivity (Ks), or infiltration capacity of the soils.

Subsurface information from the Campus has been derived from a variety of sources including historical investigations for geotechnical assessments of foundation soils for new infrastructure, groundwater exploration, water well construction and testing reports, development and monitoring reports related to the open loop geothermal system which services the Campus. Compiled historical information includes data from: 41 water wells (including exploration, monitoring and production wells), 90 auger holes and 19 test pits. This data includes over 900 soil unit descriptions, and 50 water level measurements from boreholes. Saturated hydraulic conductivity estimates include seven direct measurements of transmissivity from aquifer pumping tests, and indirect estimates of Ks based on 49 grain size analyses.

Soil types encountered during historical drilling and test pitting range from fine grained clay, silt and till to coarser grained sand and gravel deposits. In the eastern half of the Campus, the subsurface stratigraphy is dominated by thick accumulations of sand and gravel associated with a regional aquifer along the west side of the valley. A thin cover of silt to clay and fine sand is irregularly distributed over parts of the aquifer. In contrast, below the western, more developed, half of the Campus, finer grained materials predominate. Evidence suggested that layering related to the valley-bottom aquifer could extend up and underneath the developed portions of campus. However, there was insufficient deeper drilling to confirm its presence.

The depth to water in the coarse grained sediments below the lower elevation east half of campus is well understood based on measurements in existing boreholes. The elevation of the water table is consistent over the area and has not changed significantly over time. In contrast, only two measurements of depth of water are available from previous reports west of Alumni Road and Parking lot F. Western Water Associates (WWA, 2013)[1] reported a water depth of 21.9m below the Campus Central Courtyard and Interior Testing Services Ltd. (ITSL)[2] reported a perched water table at 2.4m depth below the Health Sciences Center. The water table was either not intercepted, or not recorded at any other location investigated for the western half of campus.

2.0 FIELD PROGRAM

Between June 13 and 21, 2016 five boreholes were drilled using a hollow stem auger rig, three tests pits were excavated using a backhoe and one borehole was drilled using a cable tool rig. Figure 1 presents the locations of the test locations around the Campus. Borehole logs are presented in Appendix A. Measured Ks values from the current program and historical drilling are presented in Fig. 2.

Mud Bay Drilling was subcontracted to provide drilling services for the auger holes. A rotary hollow-stem auger was used to drill up to 15m depth. One hole (AH16-4) was completed with a PVC standpipe screened over a sand-packed interval to allow measurement of piezometric levels in the lower formation and to provide for falling head injection tests, if required.

Workman and Sons Enterprises was subcontracted to provide excavation services to excavate three test pits north of Lot H (Fig. 1). Soils retrieved via the excavator bucket were logged up to 3m depth in the test pits. After logging any visible strata, a suitable depth interval was chosen and excavation to that depth at a location next to the original test pit was completed to provide a substrate to conduct infiltration tests using a Guelph Permeameter. Test pit soil logs and permeameter test results are presented in Appendix B.

Selected soil samples from boreholes and test pits were sent to ITSL for dry weight grain-size sieve analysis. Grain size analysis plots are presented in Appendix C.

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[1] WWA, 2013. Monitoring and adaptive management program for the University of British Columbia Okanagan Campus geoexchange project. Report to UBC, 96 pages.

[2] ITSL, 2008. Geotechnical investigation – proposed Health Sciences Center University Way, UBC Okanagan. Report to UBC Properties trust, 11 pages.

Additional shallow testing was conducted using the Guelph Permeameter to assess the capacity of native and landscaped areas to accept recharge from surface water (rainfall and runoff). Test locations included three of the auger test hole sites and two locations in native (undeveloped) terrain surrounding the developed areas of campus (Fig 1). Results of the permeameter testing are presented in Appendix D.

Trinity Valley Drilling was subcontracted to provide drilling services to complete a 150mm diameter, 40m deep borehole (TW16-1) at the corner of University Way and Discovery Avenue (Fig. 1). The borehole was drilled using a cable tool rig. This type of rig allows completion of the borehole to the required depth with minimal soil disturbance and accurate sampling of cuttings, at a reasonable price. It was intended that a 100mm diameter PVC standpipe would be installed with a slotted screen and sand pack at an appropriate depth to construct a test gravity drainage well. However, no permeable strata were intercepted by the target depth. The hole was backfilled and abandoned without completing a test well.

Completion details for the proposed work sites are highlighted in Table I, and results of the field investigations are summarized in the following subsections.

Table I - Field Investigation Locations and Completion Depths

Location	UTM E (m)	UTM N (m)	Surface Elevation (m-elev[a])	Depth Drilled (m-bgs[b])	Comment
AH16-1	328099	5534980	448.4	10.7	completed / backfilled
AH16-2	327910	5534523	451.0	12.2	completed / backfilled
AH16-3	328127	5534807	441.9	13.1	completed / backfilled
AH16-4	328491	5534769	423.3	15.2	completed with 2" standpipe
AH16-5	Not completed				
AH16-6	327782	5535058	468.9	12.2	completed / backfilled
TP16-1	328432	5535069	421.2	3.0	completed / backfilled
TP16-2	328377	5535098	422.2	2.7	completed / backfilled
TP16-3	328437	5535145	421.1	2.7	completed / backfilled
TW16-1	327887	5534728	448.9	38.4	completed / backfilled

a) m-elev = meters elevations as determined by a digital elevation model
b) m-bgs = meters below ground surface

2.1 Auger Hole AH16-1

Auger hole AH16-1 was completed in the University Commons area to explore the thickness of the fine grained silty cap material observed in auger holes identified in geotechnical drill holes for the design of nearby student residence buildings (ITSL, 2009)[3]. Based on the historical logs, shallow silty material grades into coarser material with depth. The deeper soils could provide a receptor for infiltrated storm water.

[3] ITSL, 2009. Geotechnical investigation proposed 4- to 6-storey student residence buildings Mews Road, UBC Okanagan. Report to UBC Properties Trust, 39 pages.

This hole was drilled to a depth of 10.7m (35 ft) and intercepted predominantly silt and fine sand with some clay and gravel-bearing zones. Clayey zones were found to be moist. The water table was not encountered in the hole. High blow counts and difficulty during drilling attest to the densely compacted nature of the soils encountered at this location. Grain size analysis of two samples taken at 7.6m and 9.1m depth confirm the soils contain high proportions of fines.

An infiltration test (GP16-1) was completed with a Guelph Permeameter next to the auger hole at 22 cm depth (see Appendix D). The calculated field Ks at this location is 2.9×10^{-6} m/s. This value may be not be representative of the longer duration infiltration capacity of the area as the test was completed in shallow fill overlying clay. The shallow fill will accept water from short-duration rainfall events, but infiltration from snowmelt and prolonged wet periods could fill up pore space in the fill, limiting the total cumulative volume of water which can infiltrate from surface.

2.2 Auger Hole AH16-2

Auger hole AH16-2 was completed in the parking lot west of the gymnasium in the upper south portion of the Campus to explore the thickness of interpreted cap of fine grained silty material identified in geotechnical drill holes for the design of the gymnasium addition (ITSL, 2011)[4]. Based on the historical logs, the shallow silty material grades into coarser sand and gravel at shallow depths. The deeper soils could provide a receptor for infiltrated storm water.

This hole was drilled to a depth of 12.2m (40 ft) and intercepted predominantly fine sand and clay with some gravel-bearing zones. Clayey zones were found to be damp. The water table was not encountered in the hole. Similar to AH16-1, high blow counts and difficulty during drilling attest to the densely compacted nature of the soils encountered. Grain size analysis of two samples taken at 7.6m and 9.1m depth confirm the soils contain a higher proportion of fines than AH16-1. The high proportion of fines and compact nature of the soils limit the ability of the subsurface to accept significant volumes of water at this location.

An infiltration test (GP16-2) was completed with a Guelph Permeameter next to the auger hole at 25 cm depth (see Appendix D). The calculated field Ks at this location is 1.4×10^{-5} m/s. Soils are heterogeneous and contain clay. The clayey soil can accept higher rates of infiltration than at AH16-1; however, the presence of clay may limit the total cumulative volume of water infiltrated during prolonged wet periods, due to swelling of the clays when wet.

2.3 Auger Hole AH16-3

Auger hole AH16-3 was completed at a location north of the library and along the south median of parking Lot F. This location was chosen to explore the continuity of coarser grained materials identified below the commons area observed in auger holes during geotechnical drilling for new developments (EBA, 2006)[5]. Based on the historical logs, shallow silty material grades into coarser sand and gravel, at increasing depth. The coarser material could provide a receptor for infiltrated storm water.

This hole was drilled to a depth of 13.1m (43 ft). Clay was intercepted to a depth of approximately 5m. The clay was underlain by approximately 4m of damp to dry sand and gravel. This unit is

[4] ITSL, 2011. Geotechnical investigation proposed wellness centre, UBC Okanagan Gymnasium addition. Report to UBC Properties Trust, 14 pages.

[5] EBA, 2006. Geotechnical investigation University Way, UBC Okanagan. Report to HMA Architects, 37 pages.

underlain by clay and gravel, with some sand. Similar to AH16-1, high blow counts and difficulty during drilling of the lower depth interval of this auger hole indicate the deeper formation is densely compacted. The 5m thick clay cap is interpreted to be of low permeability and likely inhibits direct infiltration. However, grain size analyses of two samples taken at 6.1 and 7.6m depth indicate that the intermediate coarser grained sand interval is of a distinctly different character than the dense fine-grained formation intercepted in AH16-1 and AH16-2. This zone, intercepted between 5 and 9m depth, appears to be unsaturated and is more permeable than the more dominant finer grained formations in the area.

2.4 Auger Hole AH16-4

Auger hole AH16-4 was completed at the eastern boundary of campus, south of the main entrance traffic circle (roundabout). This location was chosen to delineate the depth of cover fill and the fine-grained formation observed in boreholes in the area (EBA, 2005; ITSL, 2016; Kala, 1986)[6,7,8]. An extensive coarse-grained alluvial aquifer exists below the eastern margins of campus. This aquifer has been drilled and tested as a source of both drinking water for the Glenmore-Ellison Irrigation District, and as a source and sink of groundwater for the Campus open-loop geothermal system. Despite the extensive historical work completed on the aquifer, the depth of the fine-grained cap at surface and the local water table elevation were unknown in the area south of the traffic circle.

This hole was drilled to a depth of 15.2m (50 ft). Loose fill and refuse were intercepted to a depth of approximately 4.5m. This layer was underlain by an additional 6.5m of moist clay with gravel to a depth of approximately 9.7 m-bgs. Interlayered compact sand and gravel, and clay layers marked the transition zone at 10-12m depth separating the fine-grained cap from the sand and gravel aquifer. The water table appears to be situated within the transition zone.

Grain size analyses of two samples taken at 10.6 and 15.2m depth indicate that the aquifer is of similar character to the coarse-grained lens encountered in AH16-3. The material sampled, which is interpreted to be the upper portion of the aquifer described above, contains a significant amount of fines and is moderately well sorted.

2.5 Auger Hole AH16-5

The location for auger hole AH16-5 was proposed in the central courtyard area, at the centre of the main developed area of the Campus. The intent of this location was to fill a significant data gap for subsurface soil conditions below the main Campus. This location was identified by the utility locator to be within a dense network of subsurface utilities for the Campus. A decision to complete the utilities locate and drill the auger hole was deferred pending results from all other site investigations. Based on drilling results from the first five auger holes and the test well, it is inferred that the dense fine-grained soil material is continuous across the middle and west areas of Campus, extending to significant depth at most locations. Drilling at this location was therefore not completed.

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[6] EBA, 2005. Groundwater heat pump predesign study, UBC Okanagan. Report to UBC, 125 pages.

[7] ITSL, 2016. Geotechnical investigation proposed warehouse site A – UBC Okanagan university Way and Innovation Drive (north of roundabout). Report to UBC Properties Trust, 18 pages.

[8] Kala Groundwater Consulting Ltd., 1986. Glenmore Irrigation District Vector Developments property 16 inch well. Report to GEID, 36 pages.

2.6 Auger Hole AH16-6

Auger hole AH16-6 was completed in the gravel lot northwest of the Upper Cascades residences to explore subsurface hydrogeological conditions in an area where no historical information existed. This hole was drilled to a depth of 12.2m (40 ft) and intercepted predominantly silt to fine sand and gravel. Soils encountered were densely compacted and poorly sorted. Minor clayey zones were found to be moist. The water table was not encountered in the hole. Grain size analysis of one sample taken at 6.1m depth indicates the soils contain high proportions of fines and are of similar character to the soils encountered in AH16-1, AH16-2 and in the upper layer in AH16-3. The high proportion of fines and compact nature of the soils limit the ability of the subsurface in this area to accept significant volumes of water.

2.7 Test Pit TP16-1

Test Pit TP16-1 was completed 40m north of Lot H in a gravel parking lot. Exploration in this area was proposed to delineate the depth of cover fill and the fine-grained cap observed in historical boreholes drilled in the area (ISTL, 2011; EBA, 2005; EBA, 2006). Work in this area was also to test the infiltration capacity of the shallow cover and/or upper aquifer, which is the same aquifer described in AH16-4.

TP16-1 was completed to a depth of 3.0m (10 ft). Soils observed in the test pit are similar in composition to others in the area characterized as fill. No identifiable layering was noted in the excavation, so the location and depth of disturbed material remains undefined in this area. Most or all of the material exposed at surface and in test pits may be fill, which is consistent with anecdotal information from the operator of a gravel pit which was previously in this area. Based on infiltration rates using a Guelph Permeameter, the field Ks of the material at 1.8m depth was calculated to be 2.7×10^{-6} m/s. This value is considered to be high considering the materials observed (fine sand with clay). Low flow rates during the infiltration testing indicate a high relative error in the calculation.

2.8 Test Pit TP16-2

Test Pit TP16-2 was completed 40m north of the northwest corner of Lot H, at the base of the prominent slope in the area. This pit is the second of three test pits excavated to broadly characterize the cover soils in the former gravel pit area and to measure their infiltration capacity. TP16-2 was completed to a depth of 2.7m (9 ft). Asphalt was found to be mixed in with dark brown dense clay and fine sand at approximately 1.4m depth, indicating fill exists to this depth at this location. Similar to TP16-1, no definable layering exists which would indicate the depth where native soils exist. Based on infiltration rates using a Guelph Permeameter, the field Ks of the material at 1.7m depth was calculated to be 1.3×10^{-6} m/s. This value is considered to be high for the materials observed (fine sand with clay). As with TP16-1, low flow rates during the infiltration test indicate a high relative error in the calculation. In addition, the structure of the fill appears to be heterogeneous which could result in preferential infiltration pathways leading to erroneous results.

2.9 Test Pit TP16-3

Test Pit TP16-3 was completed 100m north of Lot H, close to a train of concrete barriers dividing the empty lot. This pit is the third of three pits excavated to broadly characterize the cover soils in the gravel pit and to measure their capacity. TP16-3 was completed to a depth of 2.7m (9 ft). The upper 1.2m of the excavation encountered similar soils to those in the first two test pits, which are dominated by fine sand and clay. This material transitioned through fine sand to 2.3m depth where very well sorted fine sand was encountered. This sharp transition could indicate the lower portion of the hole was completed in native material. Sieve analysis of a sample from this hole indicates the grain size distribution of the cover fill is of similar character to the fine grained material observed in the upper campus area.

Based on infiltration rates using a Guelph Permeameter, the field Ks of the material at 1.8m depth was calculated to be 9.6 x 10^{-6} m/s, which is significantly higher than values from the preceding test pits.

2.10 Test Well TW16-1

Test well TW16-1 was drilled at the corner of University Way and Discovery Ave. This location was drilled to explore the potential for infiltration of storm water via gravity drainage to a deep sand and gravel formation inferred from historical borehole logs (EBA, 2006). The test hole was drilled to a depth of 38.4m (126 ft) using a cable tool drilling rig. Drilling was stopping prior to the proposed completion depth (45m) based on the low probability of finding suitable formation to accept storm water below that depth. The soil profile encountered in the test hole was similar to the soil profile observed in shallow auger holes across the middle and west areas of Campus. Soils at this location include compact gritty silt and fine sand, with significant clay intervals including the upper 5.5m and lower 20.7m of the hole. A small 1m thick interval of brown water-bearing sand was encountered at 28.0 m-bgs, but is not considered suitable for infiltration of storm water. This interval is believed to be an isolated lense within a relatively continuous fine-grained formation. Based on the lack of favourable materials encountered, no samples were sent for sieve analysis and the proposed PVC test well was not installed. After drilling was completed, the hole was backfilled and sealed at surface.

An infiltration test (GP16-3) was completed with a Guelph Permeameter next to the test hole location at 25 cm depth (see Appendix D). The permeameter was unable to infiltrate any measureable quantity of water. Observations during drilling of TW16-1 indicate a high content of clay in the upper 5m of soil. It was also noted that significant water was retained by the shallow soils, either from irrigation or precipitation, despite the area not having received significant rainfall in the week prior to this observation. This indicates that there is no available space for water to infiltrate at this location.

2.11 Native Ground, GP16-4 and GP16-5

Two permeameter tests (GP16-4 and GP16-5) were conducted at less than 20 cm depths in native ground on slopes north of the Cascades residences (Fig. 1; Appendix D). The infiltration capacity of soils below native undeveloped land on Campus has not been measured in previous studies, and presented a significant data gap in understanding the expected runoff versus infiltration rate across the Campus. Finding suitable locations for testing was complicated by the diverse nature of vegetative cover in the area. Significant networks of groundhog burrows, variable vegetation cover, varying slope angle and heterogeneous soil cover infer that infiltration rates may change dramatically over short distances. Test GP16-4 was invalid due to transient wicking effects of the shallow soils. The calculated field Ks for test GP16-5 was 1.0 x 10^{-4} m/s.

The native ground test locations are on moderately sloping terrain. Vegetation growth and surface features indicate transient groundwater seepage can emerge at the local toe of the slope. Soils in hole AH16-6 to the south of the test locations indicate deeper soils are dominantly finer grained with significant silt and clay. These observations suggest that infiltration over native ground, which is predominantly on steeper slopes on the Campus, is characterized by rapid infiltration into surficial coarse-grained soils or permeable soil structures (burrows), but quickly re-emerges locally as seepage where significant slope changes occur. An example of this is groundwater seepage and slope instability east of the University Commons. Regional infiltration for the purpose of regional surface water budgets is therefore likely to be dominated by the infiltration capacity of the fine-grained soils. Peak flow rates from runoff over native ground are likely attenuated by local recharge to slopes and re-emergence of shallow groundwater at the base of those slopes.

3.0 ANALYSIS AND DISCUSSION

Three critical hydrogeological factors which can limit the potential for infiltration of storm water to ground include:

1. the characteristic infiltration rate of the soil;
2. the depth to a limiting condition; and

Over short durations, the infiltration rate will limit how fast water can be accepted by the ground over a unit surface area within an infiltration basin. The contact surface area in the base of any infiltration ditch or basin must be scaled to infiltrate the desired volumes of storm water for a given duration. A value for infiltration rate may be roughly correlated to the Ks of the formation receiving the water. Measured Ks values were provided above in units of m/s and are summarized in Fig. 2. Although infiltration rate is of the same dimension (length/time), interpreted infiltration rate/capacity is expressed in units of m/day in the following sections to differentiate the two variables. A more detailed description of infiltration rate is provided in Section 3.1 below.

The depth to a limiting condition is the available room for mounding of water in unsaturated soils above either the natural water table, or an impermeable geologic boundary. The depth to limiting condition can be a significant factor in determining how much water can be accepted over longer periods. As water is infiltrated, a groundwater mound will accumulate on top of the limiting condition below the infiltration receptor. The mound height is a function of the rate of infiltration, the permeability of the formation and the depth of the underlying saturated portion of the formation. If the mound height exceeds the height of ground, water will seep at surface.

3.1 Definition of Infiltration Rate

Characteristic infiltration rates for the Campus can be defined by two specific values:

1. maximum infiltrative capacity (MIC) of a soil type; and
2. natural discharge capacity (NDC) of a soil formation.

The MIC has units of velocity (m/day) and describes the estimated maximum rate at which water seeps into the ground over a unit area. The MIC generally approximates the Ks of the soil, and assumes that the hydraulic gradient in the vertical direction is unity (1 m/m). The NDC provides an estimate of volumetric groundwater flow rate from a point of infiltration to an area of natural groundwater discharge. The NDC is estimated as the groundwater flow that can be accommodated within currently unsaturated soils in the proposed infiltration area and down-gradient flow path. Determination of the NDC can be complicated by factors outside the local area of infiltration which control the ability of the bulk formation to transmit water away from the infiltration site.

3.2 General Hydrogeological Conditions Observed on Campus

Soils observed across Campus appear to fall broadly into two groups, based on sieve analysis (Fig. 3) and hence relative Ks. The dominant soil type below the western half of the Campus is a fine-grained unstructured soil, comprised of 20-50% fines less than 0.1mm in size (silt and clay) and 20-50% fine sand. The second group of soils are poorly sorted sand and gravel deposits intercepted in boreholes at two locations on Campus (AH16-3 and AH16-4).

The water table was intercepted in only one hole on Campus (AH16-4) during the current field investigation. Previous work had indicated the water table is well defined below the eastern half of the Campus and is controlled by regional groundwater levels within the extensive aquifer that exists in the base of the valley. Water below the western half of the Campus may be present at significant depth, perched on shallow soil layers, or held in tension in pore space within surficial clay or silt-rich soils. Most auger holes in this study intercepted moist to wet intervals, but no sign of a discrete water table was noted. Furthermore, there was no geological formation encountered that would represent a discrete limiting condition. Based on soil descriptions and sieve analyses, it appears the grain size of soils and local heterogeneity will be the primary factors limiting the ability to infiltrate storm water on Campus.

Figure 4 outlines the boundaries of areas of the Campus where storm water infiltration may be feasible and where there is limited potential. Two regions were not analysed in detail, including the area where the existing storm water pond is present immediately east of the Engineering Building, and the area further east and south of the pond where existing infiltration fields exist for the disposal of geothermal wastewater and septic effluent. The three zones available to explore infiltration potential include the lower elevation region to the northeast of Lot H (Northeast Campus), the eastern lower elevation region (Eastern Campus), and the middle to upper elevation regions of Campus (Upper Campus). These three regions are discussed in the following subsections.

3.3 Northeast Campus

Based on recent test pit analysis, soils in the shallow subsurface (<3m) below the gravel lot north of Lot H are predominantly fine sand with clay and minor gravel. While these soils tend to be dense, they contain evidence of random fill and waste (e.g., asphalt). Previous geotechnical investigations (ITSL, 2012)[9] indicate the area is dominated by a heterogeneous mix of unstructured sand with variable silt and gravel content, the saturated lower portions of which compose a highly productive aquifer.

Permeameter testing indicates field Ks values of between 1.3×10^{-6} to 9.6×10^{-6} m/s for relatively shallow soils in this area which are characterized as fill. The soils observed are poorly compacted and thus characterized by relatively higher bulk Ks. Inconsistent infiltration test results support the non-homogeneous nature of shallow soils, or fill in this area.

In 2005, EBA conducted a rapid infiltration basin (RIB) test at a location 50m north of the University Way traffic circle (EBA, 2005). Based on grain size analysis, EBA estimated the Ks value of the formation in this area is 2×10^{-4} m/s. During the infiltration test they were able to infiltrate water at a rate of 0.032 m^3/s, equivalent to 13.9 m/day, over the base of the RIB. Utilizing a method

[9] ITSL, 2012. Geotechnical investigation, university reserve lands – study area, University of British Columbia Okanagan Campus. Report to UBC Campus and Community Planning, 19 pages.

developed by Hantush (1967)[10], the design inputs for the RIB, and resultant groundwater mounding measurements, a Ks value of 4.5×10^{-5} m/s was calculated for the receiving soils.

The calculated infiltration rate from the testing of the RIB and the Ks values appear to be more representative of the native material, in comparison to the fill. Based on the uncertainty regarding the distribution of fill and native material, a conservative value of half the measured infiltration rate for the EBA RIB test, or 7m/day, is assumed to be representative of the MIC for the lower elevation, Northeast Campus. This value is recommended in the absence of additional infiltration basin testing for the purpose of basin design. Because this area is underlain by a highly productive aquifer whose transmissivity exceeds the MIC, the NDC of the region is assumed to exceed the MIC and thus is not a limiting factor for engineering design of an infiltration basin in the Northeast Campus.

The measured depth to water below the Northeast Campus varies from 8 to 10 m-bgs near the University Way traffic circle, to deeper than 20 m-bgs farther to the west (Fig. 5). This depth range corresponds to approximately 412 m-elev across the area (+/- 2m). This relatively flat water table over a broad area indicates that the deeper soils are highly conductive, confirming the presence of the high yield aquifer. These elevations appear consistent over time as well, supported by the depth to water in AH16-4 being the same as that measured in the area in 2007.

Using the Hantush (1967) solution, a range of mounding heights were estimated based on a variety of hypothetical RIB basin designs. Assuming a reasonable range of basin geometries and soil conditions, the calculated mounding height of water from an infiltration basin should not rise above the ground surface in the Northeast Campus area. The primary limiting factor to disposal of storm water to ground appears to be the infiltration capacity of the soils receiving that water. The infiltration rate could be significantly enhanced if the aquifer is daylighted in the base of an infiltration facility. Although best estimates suggest that the depth to the top of the aquifer may be less than 3m in places, field investigations are recommended in order to verify the depth prior to detailed design.

A significant amount of drilling and testing has been completed for groundwater production to service water supply systems (Kala, 1986) and the Campus's geothermal system (EBA, 2007)[11]. This testing has provided a high degree of confidence in estimates for the Ks and thickness of the aquifer. Saturated hydraulic conductivity estimates range from 1×10^{-4} m/s to as high as 2.9×10^{-3} m/s.

The expected achievable rate of infiltration via gravity drainage to a well completed in the aquifer below the Northeast Campus can be calculated using the Thiem Equation for steady state flow to/from a well (Thiem, 1906)[12]. Inputs to this calculation are based on information from the nearby Glenmore Ellison Improvement District (GEID) water supply wells and hole AH16-4. A gravity drainage well is estimated to be capable of receiving greater than 0.035 m^3/s (560 USgpm). The actual flow that a completed well will accept can be highly dependent on other factors including:

- Interference from nearby injection/pumping wells;
- Flow under transient head conditions; and

[10] Hantush, M.S., 1967. Growth and decay of groundwater mounds in response to uniform percolation. Water resources research, 3:1, pp. 227-234.
[11] EBA, 2007. Supplementary investigations for geoexchange system, UBC Okanagan Campus. Report to UBCO, 157 pages.
[12] Thiem, G., 1906. "Hydrologische methoden". Leipzig, Gebhardt, 56.

- Changes over time to the efficiency of the well from biofouling and degradation of the formation around the well.

Completion and testing of a trial gravity drainage well is required to confirm the infiltration potential of the aquifer.

A gravity drainage well circumvents the infiltration of water through shallow soil cover. Below the Northeast Campus, the highest permeability formation is the aquifer found at depth. The aquifer has the potential to accommodate the highest instantaneous rates of disposal, with a minimal surface footprint. The actual NDC for the aquifer is greater than the discharge capacity for a single gravity drainage well. If multiple drainage wells are utilized, optimal well spacing will be critical in order to limit mounding in the aquifer.

3.4 Eastern Campus

Fieldwork conducted in this area is limited to drilling of AH16-4. However, information provided by Campus staff indicates that fine-grained soil, dominated by fill, likely caps a significant portion of the soils below Eastern Campus (Fig. 4). Much of this area lies at a higher elevation than the Northeast Campus. It appears that at elevations above the floor of the valley, fine-grained soils are more likely to be present in the shallow subsurface, overlying the deeper, coarser grained aquifer. Retention of water in the pond near the engineering building is due to accumulation of water above the low permeability soil cap in this area. The water level in the pond does not fluctuate significantly, which suggests that evapotranspiration and seepage losses through the base of the pond are roughly equivalent to direct precipitation plus the current volume of storm water received by the pond. Additional storm water directed to the pond may therefore cause the footprint to expand, most likely to the south. There is some evidence that suggests this is already occurring.

Assuming the upper contact of the aquifer is at the same elevation as observed in AH16-4, the relative depth of this material from surface could be greater than 20m below ground in the Eastern Campus area. The possible presence of fine-grained fill cover and the considerable depth to the coarser-grained aquifer limit the potential for storm water disposal via infiltration basins in the Eastern Campus. Assuming the fill cover is comparable to other fine-grained soils present on campus, an infiltration rate of 0.1 m/day is appropriate for surface water modelling in this area. The NDC in the aquifer below the Eastern and Northeast Campus is several orders of magnitude higher than the assigned infiltration rate of the shallow soils. Therefore gravity drainage wells are expected to be a more efficient storm water disposal method as compared to near-surface infiltration facilities.

Potential to dispose of water using gravity drainage wells may be comparable to the Northeast Campus area; however, higher uncertainty exists with respect to the local hydraulic characteristics of the aquifer. A significant gap in drilling coverage exists below the Eastern Campus. The continuity, thickness and hydraulic conductivity of the aquifer below this area remains untested and would require additional exploratory drilling to confirm the potential for storm water disposal.

Furthermore, the Eastern Campus area is up-gradient of the geothermal disposal field. Gravity drainage wells installed in the Eastern Campus could interfere with the existing geothermal system. In contrast, the Northeast area of the Campus is in the area of extraction wells for the geothermal system. Extraction wells in close proximity to gravity drainage wells could be of mutual benefit from a water balance perspective. The higher geological certainty and lower risk of interference with the geothermal disposal field suggests that storm water disposal is preferable in the Northeast Campus area as opposed to the Eastern Campus area.

3.5 Upper Campus

Soils in the Upper Campus area are dominated by poorly sorted, densely packed silt, fine sand and clay with some gravel and cobbles. The soils appear dominantly massive and unstructured. The lack of layering encountered precludes the presence of any geological limiting condition in the area. While some soils were found to be moist to wet, no discrete water table was observed in the auger holes. Hole TW16-1 encountered a thin water bearing sandy to pebbly lens at 28m depth (421 m-elev), although no discrete water table was identified. Therefore it appears that there is no discrete limiting condition in the Upper Campus area, but rather the subsurface is dominated by fine-grained soils that limit the ability to inject significant volumes of storm water for disposal.

Based on observations of soil types, grain size distributions, and Guelph Permeameter test results, the Ks of soil in the Upper Campus area is estimated to range from $1x10^{-7}$ to $1x10^{-4}$ m/s. In some cases, the saturated clay-rich soils encountered were below the resolution of the measurement techniques used to determine Ks. Hydraulic conductivity values in such cases are likely significantly less than 1×10^{-7} m/s. The higher end of the Ks range is interpreted to be a local anomaly and is not reflective of the larger scale Ks of the soil formation in Upper Campus.

Groundwater recharge in the Upper Campus is dominated by vertical infiltration from precipitation. Groundwater flow paths are interpreted to follow topography, and hence, groundwater flow will mimic surface water flow on the Upper Campus. The risk of infiltrating water to the subsurface on hillside slopes, particularly in low permeability soils such as observed in TW16-1 and AH16-3, is that soils could convey flow horizontally which then emerges at lower elevations along the same slope. This issue can be exacerbated by the installation of multiple infiltration basins or other point sources of groundwater recharge along a single groundwater flowpath. Figure 6 depicts areas of higher slope angle across the Campus to illustrate the locations where groundwater seepage is a potential issue if excess storm water is put to ground upslope of these locations. This process is demonstrated by seepage at the base of native treed slopes, and development of instability due to seepage, to the east of the University Commons, as described in Section 2.11.

The MIC for the Upper Campus, based on the range of soil Ks highlighted above, is expected to be between 1.0 and 0.01 m/day. However, due to the heterogeneity of soil permeability and saturation, the NDC of the soils is assumed to range from near zero to 0.1 m/day.

The risk of seepage along slopes and the inability to infiltrate water during permeameter testing indicate there is limited opportunity to develop infiltration basins in landscaped areas of the Campus. In areas of natural cover where irrigation is not present, soils will have sufficient storage and transmissivity to accommodate some infiltration. Natural disturbance of soils from burrowing or vegetation can locally enhance infiltration from precipitation. In native tree covered areas of Upper Campus, a unit NDC of 0.1 m/day can be used as the average infiltration capacity for storm water modelling. In heavily irrigated and landscaped areas, an infiltration rate of 0.04 m/d is recommended to reflect the lower infiltration capacity.

In the Upper Campus area, shallow swales or basins may accept relatively small volumes of infiltration to ground; however, the design of swales should be primarily to generate evapotranspirative losses from small amounts of accumulated precipitation. It is important to recognize that groundwater will travel along flow paths through the soil which mimic surface water flow. Recharge to the ground is cumulative along these flow paths. Enhancing recharge through the construction of multiple infiltration features along a single flow path will increase the risk of groundwater seepage at inflections in the slope which can lead to geotechnical concerns for lower elevation areas of the Campus.

3.6 Summary of Storm Water Infiltration Options

Based on the findings of the hydrogeological assessment presented above, several options exist to dispose of storm water to ground on the Campus. The infiltration capacity of the Upper Campus area is limited and it is not feasible to dispose significant quantities of captured storm water to ground in this area. Small scale infiltration via rain gardens, swales, or similar features is feasible. . Soils in the Northeast area of campus have a significant natural discharge capacity and can dispose of significant volumes of storm water. Options for disposal include shallow infiltration basins constructed in the upper soil horizons, or deeper gravity drainage wells installed in the deeper sand and gravel aquifer. In the East Campus area, fine grained soils limit the ability to dispose of water via infiltration basins; however, the same aquifer is interpreted to be present below this area and may be able to accept water via gravity drainage wells. Uncertainty remains without further testing and analysis of risks to water quality and interference with the geothermal disposal field. Hydrogeological considerations for the storm water disposal options highlighted are summarized below.

Significant volumes of water may be disposed of via rapid infiltration basins or other features constructed in the Northeast Campus. Data suggest that the deeper the foundation of the basin is excavated, the higher the infiltration rate and basin performance will be. One caveat to construction is that, based on previous geotechnical analysis, there appears to be clay present in the relative shallow soils in the area. Some clays have a propensity to absorb significant volumes of water and swell in the process. This can have serious implications for existing and proposed building foundations or other infrastructure in the area. If shallow infiltration is to be considered for the ISMP, additional analysis is recommended to determine the composition of clays present to assess if geotechnical risk exists.

Based on field testing and analysis, a gravity drainage well installed in the aquifer below the Northeast and East campus areas will be capable of accommodating a significant volume and rate of storm water flow. Figure 7 presents a schematic drawing of a conceptual design for treatment and disposal via a gravity drainage well. Additional gravity drainage wells would provide significantly higher capacity than that outlined above, however the maximum achievable capacity must consider optimal spacing of wells. Generally, as with water well exploration, a more reasonable approach would be to determine the desired flow rate first, then drill and test one or more wells until the desired capacity is reached, or the limits of the aquifer are determined.

Gravity drainage wells used to dispose of storm water may require a pre-injection reservoir for transient storage. The reservoir may also be used for chemical treatment of effluent (if needed) and settlement of suspended sediment. Based on the Thiem analysis, the diameter of the borehole is less critical as opposed to screen length and infiltration rate of the well. However, the volume inside the well casing above the water table can provide additional transient storage during disposal.

Infiltration basins and gravity drainage wells require regular maintenance for optimal infiltration capacity. Biofouling and accumulation of sediment will degrade the ability to infiltrate over time. A system should be designed to allow periodic cleaning to maintain efficiency. Infiltration basins or other surficial features need to remain exposed or accessible to allow periodic scarification. The top of casing for gravity drainage wells should remain accessible to allow for sediment removal, cleaning of well screens and periodic re-development of the well. Gravity drainage wells should incorporate PVC casing and screens. The screened interval must be entirely below the water table to promote anaerobic conditions and hence limit bio-fouling. Alternately, an interval of the aquifer equivalent to the twice the screen length can be back filled with high sphericity, ceramic (inert) media.

3.7 Aquifer Water Quality Risks

In 2014 the BC Ministry of Environment prepared a document summarizing best management practices for the protection of groundwater for underground disposal of storm water[13] . The document includes recommendations for the siting and design of storm water infiltration facilities along with the characterization of the type of pollutants potentially generated by the project, the risks they pose to groundwater and measures to reduce their input into storm water quality. The primary objectives of the document are to provide a framework for evaluating the feasibility of storm water infiltration facilities based on proximity to existing infrastructure, to determine treatment required and to consider design elements that will minimize impacts to water supply aquifers.

Currently the aquifer which underlies the eastern and northeast portions of Campus hosts 3 water supply wells operated by GEID that are used for potable supply, including the two Vector Wells located immediately west of the main entrance traffic circle and the Lochrem Road Well located 2.3 km north of the traffic circle. As the Lochrem Road well is located up-gradient and at considerable distance away from areas being considered for storm water disposal, this well is considered to be at low risk.

GEID has not operated the Vector Wells for several years as they have several source water locations. The water quality in these wells is relatively high in iron and manganese as compared to the other source locations. We understand they are currently considering options for future use or abandonment of the wells. The larger, 400mm diameter Vector well was tested in 2010[14] and the total manganese concentration in the well was 0.35 mg/L. Health Canada currently has a draft document in circulation for public consultation with the intent of revising the drinking water guideline for manganese[15] to a maximum acceptable concentration (MAC) of 0.1 mg/L and an aesthetic objective (AO) of 0.02 mg/L. Future use of the larger vector well, and presumably the nearby smaller well, will therefore require treatment. It is probable that the treatment requirements will render these wells as economically non-usable.as compared to other water sources available to GEID. If these wells are decommissioned, the aquifer underneath the eastern and northeastern portions of the Campus will no longer be used for potable water supply.

Determination if the aquifer is used for public water supply is important as any facility specifically designed to convey storm water to the saturated zone of a drinking water aquifer requires a higher level of design and in some instances regulatory approval.

Literature information indicates that for most pollutants, surface infiltration facilities do not pose a high risk to groundwater resources when the facilities are properly sited and designed. This is because many storm water pollutants are present at low levels, and because many common pollutants are subject to adsorption, degradation and filtration in the infiltration systems.

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[13] BC Ministry of Environment. 2014. Underground Stormwater Infiltration: Best Practices for the Protection of Groundwater in British Columbia.

[14] Golder, 2010. Vector 2 well, Glenmore-Ellison Improvement District, Kelowna, B.C.. Report to GEID, 57 pages.

[15] Health Canada, 2016. Manganese in drinking water. Document for public consultation by the Federal-Provincial-Territorial Committee on Drinking Water, 116 pages.

Common pollutants of concern in storm water runoff are:

- Suspended sediments from numerous sources including un-stabilized soils, human activities and atmospheric deposition;
- Trace metals, primarily copper, lead, zinc, and cadmium. The sources include exposed metals (e.g., galvanized metals for roofing, pipe and guard rails) or metals associated with compounds exposed to the environment, such as paints and wood preservatives;
- Nutrients, primarily nitrogen and phosphorus, from landscaping activities, automobile exhaust and atmospheric fallout;
- A wide variety of petroleum hydrocarbons associated with vehicles and other human activities;
- Pesticides, herbicides and fungicides used in residential, commercial and municipal landscaping activities;
- Salts used for roadway de-icing; and
- Pathogens and pathogen indicators associated with human waste, animal waste and natural watershed sources.

Suspended sediments are a principal pollutant of concern for all sites because many other pollutants tend to adhere to particulates, and because they can clog infiltration facilities, diminishing their performance.

Table 2 - Potential source control measures for areas that drain to underground infiltration systems

Pollutant	Potential source controls
Sediment	• Limit disturbance of native soils • Actively implement effective erosion and sediment control measures at construction sites
Trace metals	• Limit use of exposed metals such as copper flashing and galvanized roofing materials • Use alternatives to treated lumber
Nutrients (nitrogen and phosphorus)	• Diligent nutrient management, including proper application and storage to limit runoff and leaching • Reduce turf areas and consider alternative landscaping with native plants
Petroleum hydrocarbons	• Develop and implement spill prevention plans • Properly store and dispose of all hazardous materials, lubricants and

	solvents
Pesticides	• Properly store and apply all pesticides according to manufacturer instructions • Use integrated pest management practices • Use alternative landscaping with native plants
Salts	• Properly store and limit use of salts for de-icing • Use alternative de-icing practices

Options for pre-treatment facilities can range from no treatment to high levels of treatment targeting soluble and high-risk pollutants. Table 3 shows three categories of treatment objectives and associated types of treatment facilities that can be used to achieve those objectives.

Table 3 - Pre-treatment options for underground infiltration systems

Treatment category	Target Pollutants	Representative treatment facilities
Pre-settling	Trash and debris Coarse sediments	Sumped catch basins, sedimentation manholes Oil/water separators
Solids removal	Treatment exceeding pre-settling Coarse and fine sediments A portion of the metals, indicator bacteria and particulate nutrients that are associated with sediments	Catch basin devices such as tree-well filter, catch basin media filtration systems Hydrodynamic devices Media filtration systems
Oil removal	Treatment exceeding solids removal Oils and grease A portion of the more soluble hydrocarbons and pesticides	Storm water filtration systems using engineered media Biofilters: swales, rain gardens

3.8 Storm Water Disposal Regulations

Storm water disposal to ground via drain fields, infiltration basins and other surface features is controlled under the Environmental Management Act through the Municipal Wastewater

Regulations (MWR)[16]. Water quality, setback distances and guidelines for design are specified in those regulations. A minimum setback distance of 60m is recommended, consistent with the MWR. In general, a protective setback distance will depend on site-specific conditions including the direction and rate of groundwater flow and the vulnerability of the drinking water wells to contamination. Therefore, local municipalities may require greater setback distances based on established bylaws or to address site-specific hydrogeologic conditions.

Disposal of storm water to injection/recharge wells is governed under the Groundwater Protection Regulations (GWPR)[17] of the BC Water Act. The GWPR are not specific in outlining discharge quality, setback distances and water quality guidelines, instead transferring the responsibility for design onto a qualified professional. It is recommended that adoption of the MWR guidelines as a minimum standard for water quality and locating storm water wells should address risk to groundwater quality in the aquifer. These standards must also include consideration for the unique risks from injecting storm water directly to a highly permeable semi-confined aquifer. The regulations state that the design must ensure "the point of infiltration of the proposed well is and will remain above the water table at all times" (Part 3, Section 19, ii-B[18]), however, a well owner may apply for an exemption on the advice of a professional assessment. Based on recent discussions with the regulator, the primary issues to consider are the potential pollutants associated with runoff from the tributary watershed, what is the formation receiving the storm water, and does the formation provide some attenuation of pollutants associated with the runoff.

The distance from the GEID wells to the empty lot immediately north of the main entrance traffic circle is 90m and to the area north of Parking Lot H is 300m. If GEID decommissions the Vector Wells, then the area immediately north of the traffic circle is the preferred location. If GEID continues to use the Vector Wells, the area north of Parking Lot H is more appropriate in terms of maximizing the distance from the wells and providing the most attenuation of potential storm water pollutants.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Analysis of historical data and information collected from fieldwork associated with this program indicate the following with respect to storm water disposal to ground below the Okanagan Campus of UBC:

- The measured and inferred Ks of soils below the Upper Campus varies between 1×10^{-7} and 1×10^{-4} m/s;
- For the purpose of surface water modelling, the average infiltration capacity of developed ground below the Upper Campus area is estimated to be 0.04 m/day, which is relatively low;
- The combination of relatively low infiltrative capacity and low natural discharge capacity (shallow limiting condition) indicates that large scale storm water disposal to ground in the Upper Campus area is not feasible;

[16] Municipal Wastewater Regulation (MWR) under the Environmental Management Act, effective February 29, 2016. B.C. Reg. 87/2012. http://www2.gov.bc.ca/gov/content/environment/waste-management/sewage/municipal-wastewater-regulation [accessed July 2016]
[17] Groundwater Protection Regulation (GWPR) under the Water Act, effective February 29, 2016, 2005 (remainder). B.C. Reg. 39/2016. http://www2.gov.bc.ca/gov/content/environment/air-land-water/water [accessed July 2016].
[18] GWPR, ibid

- Small scale or localized disposal may be possible in the Upper Campus area at locations where surface water does not accumulate (i.e. away from roadside drainage swales and convergent slopes, such as the intersection between the Critical Studies and Arts buildings), or where the ground is not saturated due to irrigation. However, due to low infiltration capacity, these systems should be designed to optimize evapo-transpirative losses and not exceed the natural discharge capacity which could result in seepage downstream;
- For the purpose of surface water modelling, the average infiltration capacity of native ground is estimated to be 0.1 m/day;
- Infiltration rates for native soils may be significantly higher due to natural disturbance and variation in soil composition. Evidence of daylighting seepage along these slopes indicates the infiltrative capacity is high and the natural discharge capacity is low;
- Gravity drainage wells to greater depth in the Upper Campus area are also not feasible as no suitable receiving formation exists below this portion of Campus;
- The infiltration potential near the existing pond and near the existing infiltration fields in the southeast portion of the Campus were not assessed due to concerns of mounding interference with these two systems;
- The potential to infiltrate storm water using shallow basins in the Eastern Campus area is relatively low due to the inferred thickness and low permeability of soils at ground surface;
- The Ks of fine-grained shallow fill/soils in the Northeast Campus area is estimated to range from 1×10^{-6} to 5×10^{-5} m/s;
- The infiltration capacity of shallow soils is estimated to be 1 m/day in the Northeast Campus and approximately 0.1 m/day in the Eastern Campus for the purpose of surface water modelling;
- The estimated infiltration capacity of soils for the purpose of analyzing the feasibility of infiltration basin design is estimated to be 7 m/day in the Northeast Campus. Previous RIB basin tests have demonstrated rates of up to 14 m/day are possible; however, actual infiltration rates could vary significantly. The conservative rate accounts for heterogeneity in soil type;
- Soils in the northeast should be analyzed for the presence of swelling clays if those soils are to be used for infiltration of storm water;
- The Ks of the thick and extensive sand and gravel aquifer underlying the Northeast and East Campus areas is estimated to range from 1×10^{-4} to 3×10^{-3} m/s;
- The depth to the top of the aquifer ranges from 3 m-bgs to possibly greater than 12 m-bgs in the Northeast and East Campus areas. The depth to water in the aquifer is between 8 and 20 m-bgs;
- The infiltration rate for a single gravity drainage well installed in this aquifer is estimated to be 0.035 m^3/s (560 USgpm), or more. The natural discharge capacity of the aquifer will allow for additional wells to increase the cumulative infiltration rate; however, additional analysis is required to determine the location and spacing if more than one infiltration well is needed. This rate assumes groundwater infiltration and mounding has reached a steady state over a longer period. Transient mounding height over the short term could be higher;
- Infiltration of storm water using conventional methods such as infiltration beds and swales is feasible in the Northeast Campus, however the low Ks of surficial soils will require substantial footprint areas for effective disposal. Gravity drainage wells installed in the aquifer will provide the most efficient means of storm water disposal, in terms of providing the highest rates and volumes of disposal, combined with the smallest infrastructure footprint;

- Disposal of storm water to ground via near surface conventional methods or gravity drainage wells in the Northeast and East areas of Campus will require treatment prior to disposal;

5.0 LIMITATIONS

This investigation has been conducted using a standard of care consistent with that expected of scientific and engineering professionals undertaking similar work under similar conditions in B.C. No warranty is expressed or implied.

This memorandum is prepared for the sole use of the Okanagan Campus of UBC and Urban Systems Ltd. Any use, interpretation, or reliance on this information by any third party, is at the sole risk of that party, and Piteau accepts no liability for such unauthorized use.

Yours truly,

PITEAU ASSOCIATES ENGIN TD.

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GEOSCIENTIST
July 29, 2016

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Senior Hydrogeologist

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Principa(Hydrogeologist

MLS/RA/dls

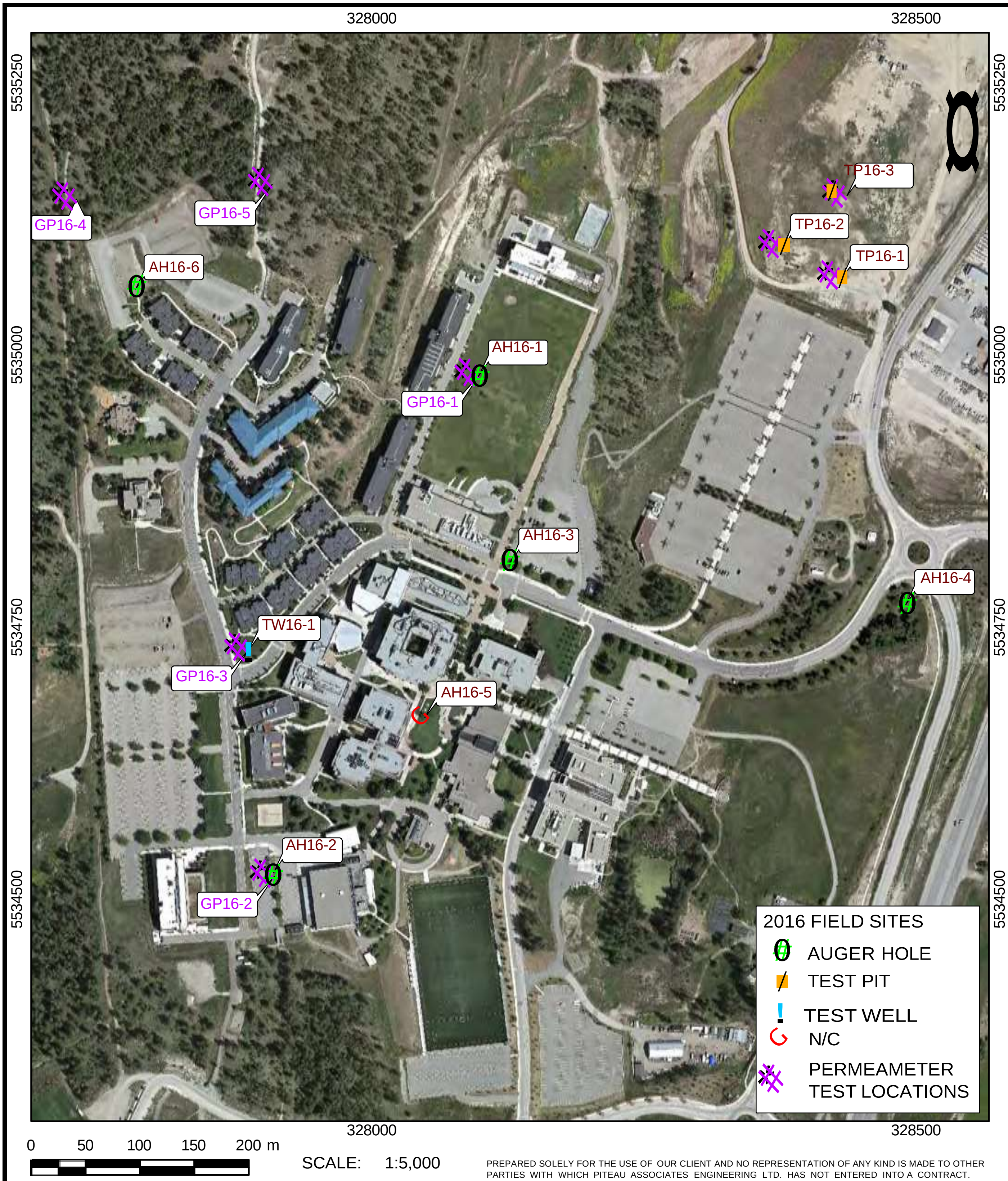
Att.

6.0 INDEX

6.1 Figures

FIGURES

H:\Project\3529\ArcGIS\ArcMaps\2016 Memo\Fig 1 Location Plan.mxd



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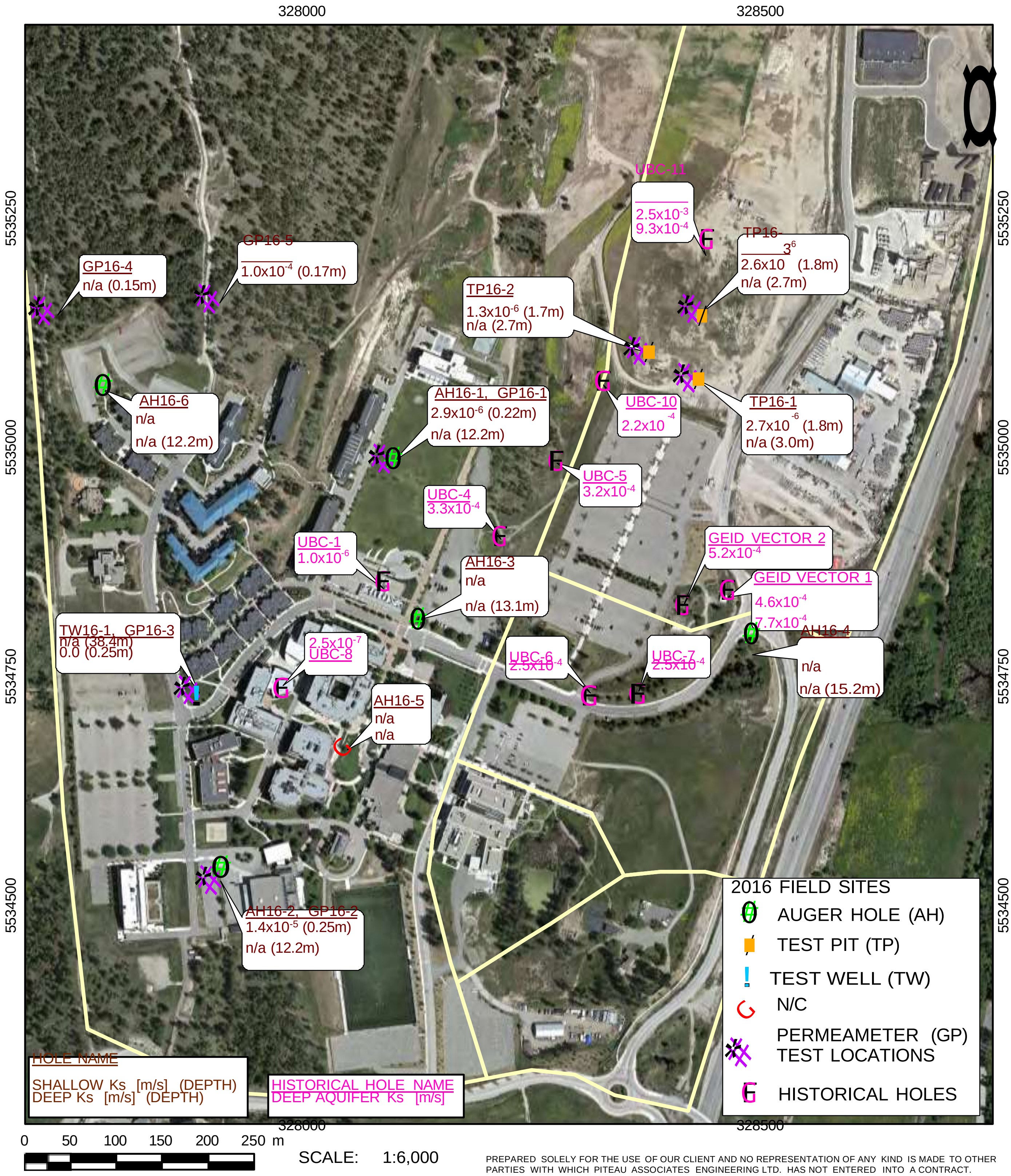
TEST HOLE, TEST PIT AND PERMEAMETER TEST LOCATIONS- UBC OKANAGAN CAMPUS

BY:	DATE:
MLS	JUL 16
APPROVED: MLS	FIG: 1

H:\Project\3529\ArcGIS\ArcMaps\2016 Memo\Fig 2 Ks values.mxd



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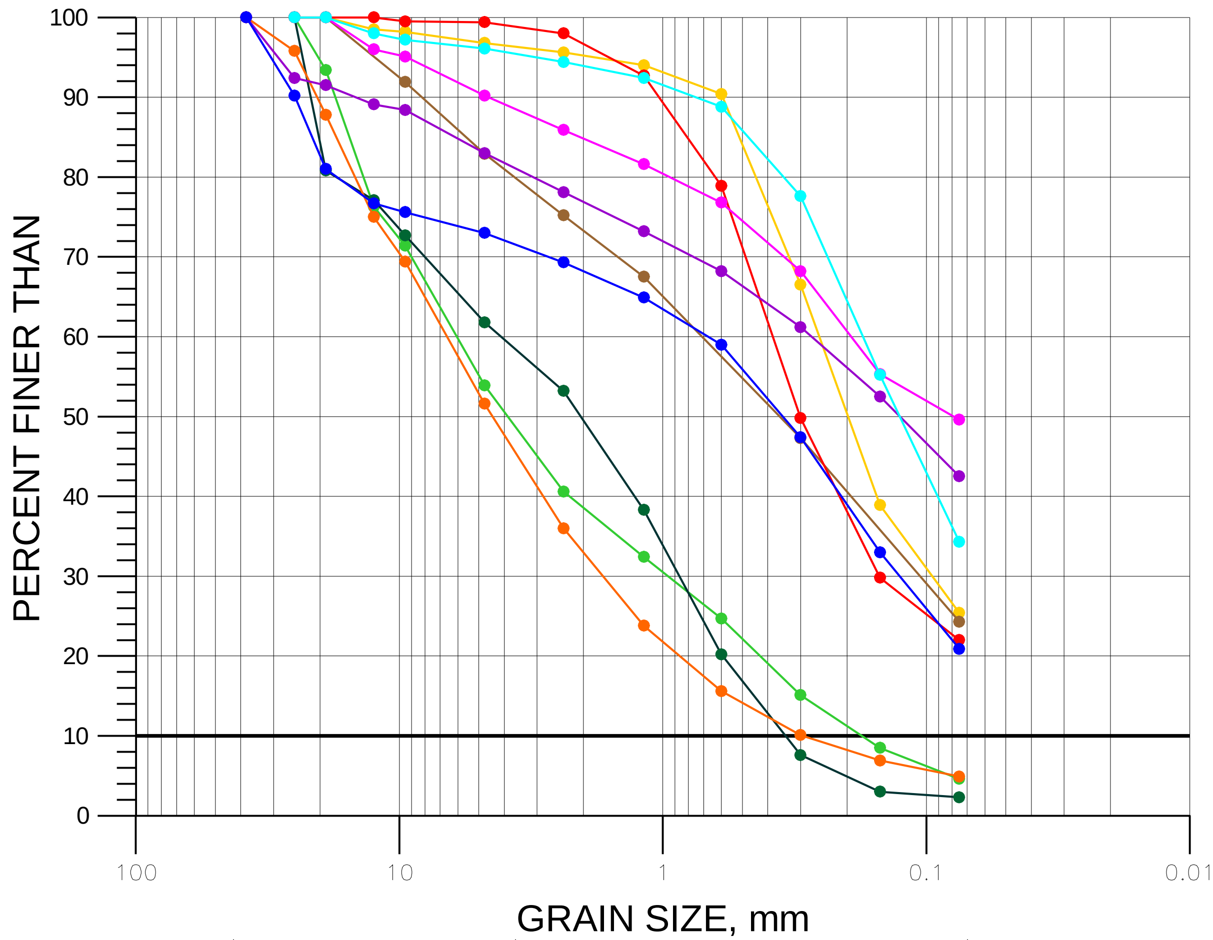
MEASURED FIELD SATURATED HYDRAULIC CONDUCTIVITY

BY:	DATE:
MLS	JUL 16
APPROVED:	FIG:
MLS	2

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

- AH16-1 (7.6m)
- AH16-1 (9.1m)
- AH16-2 (7.6m)
- AH16-2 (9.1m)
- AH16-3 (6.1m)
- AH16-3 (7.6m)
- AH16-4 (10.6m)
- AH16-4 (15.2m)
- AH16-6 (6.1m)
- TP16-3 (2.7m)

HAZEN EQUATION

AH16-3 (7.6m) = 0.0009
AH16-4 (10.6m) = 0.0012
AH16-4 (15.2m) = 0.00032

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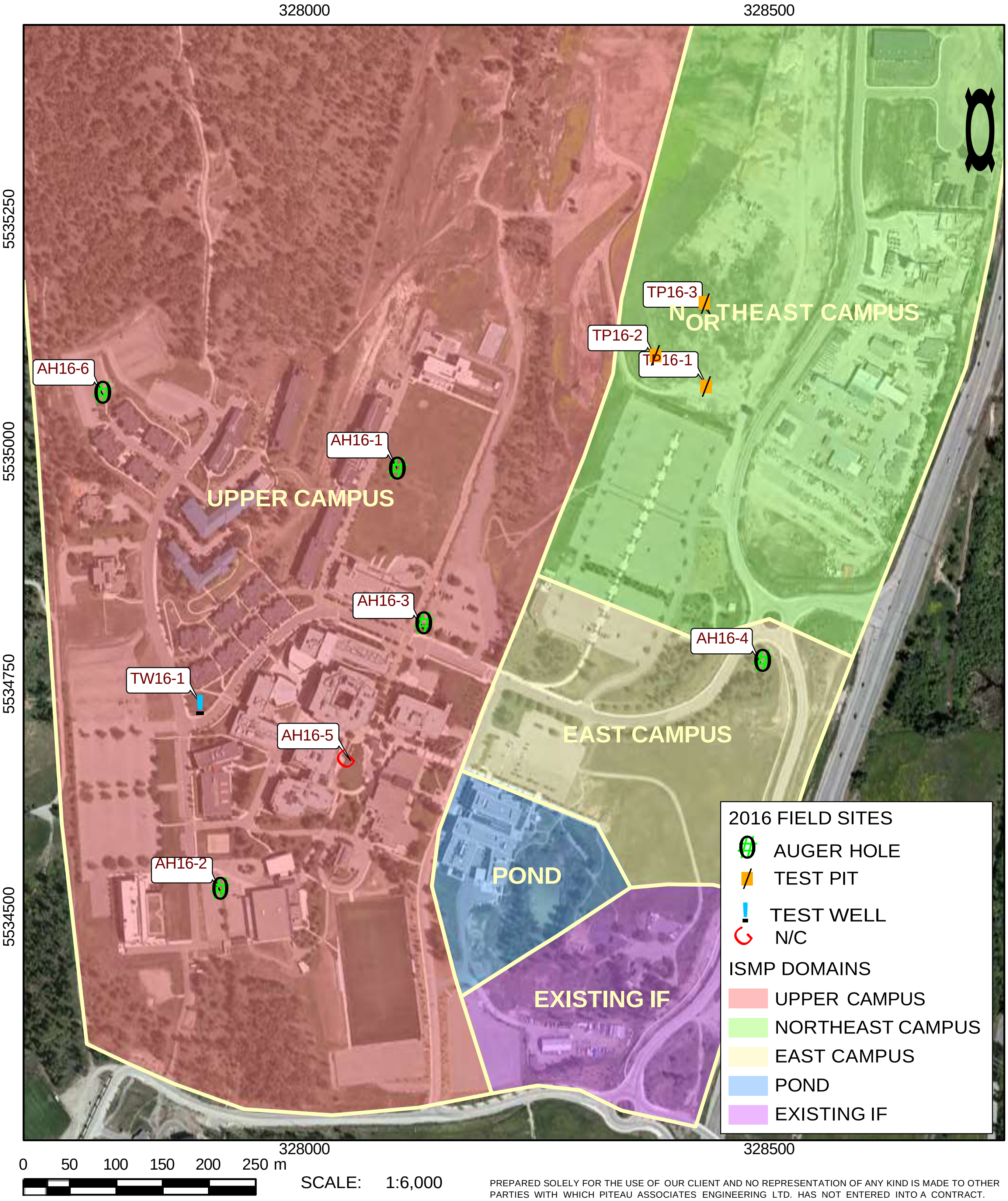
GRAIN SIZE ANALYSIS FOR UBCO

BY:	DATE:
GJL	JUL 16
APPROVED: MS	FIG: 3

H:\Project\3529\ArcGIS\ArcMaps\2016 Memo\Fig 4 ISMP Domains.mxd



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DOMAINS DEFINING PROSPECTIVE AREAS FOR STORM WATER INFILTRATION AND AREAS OF LIMITED POTENTIAL

BY: MLS	DATE: JUL 16
APPROVED: MLS	FIG: 4

H:\Project\3529\ArcGIS\ArcMaps\2016 Memo\Fig 5 Depth to Water.mxd

SCALE: 1:4,000

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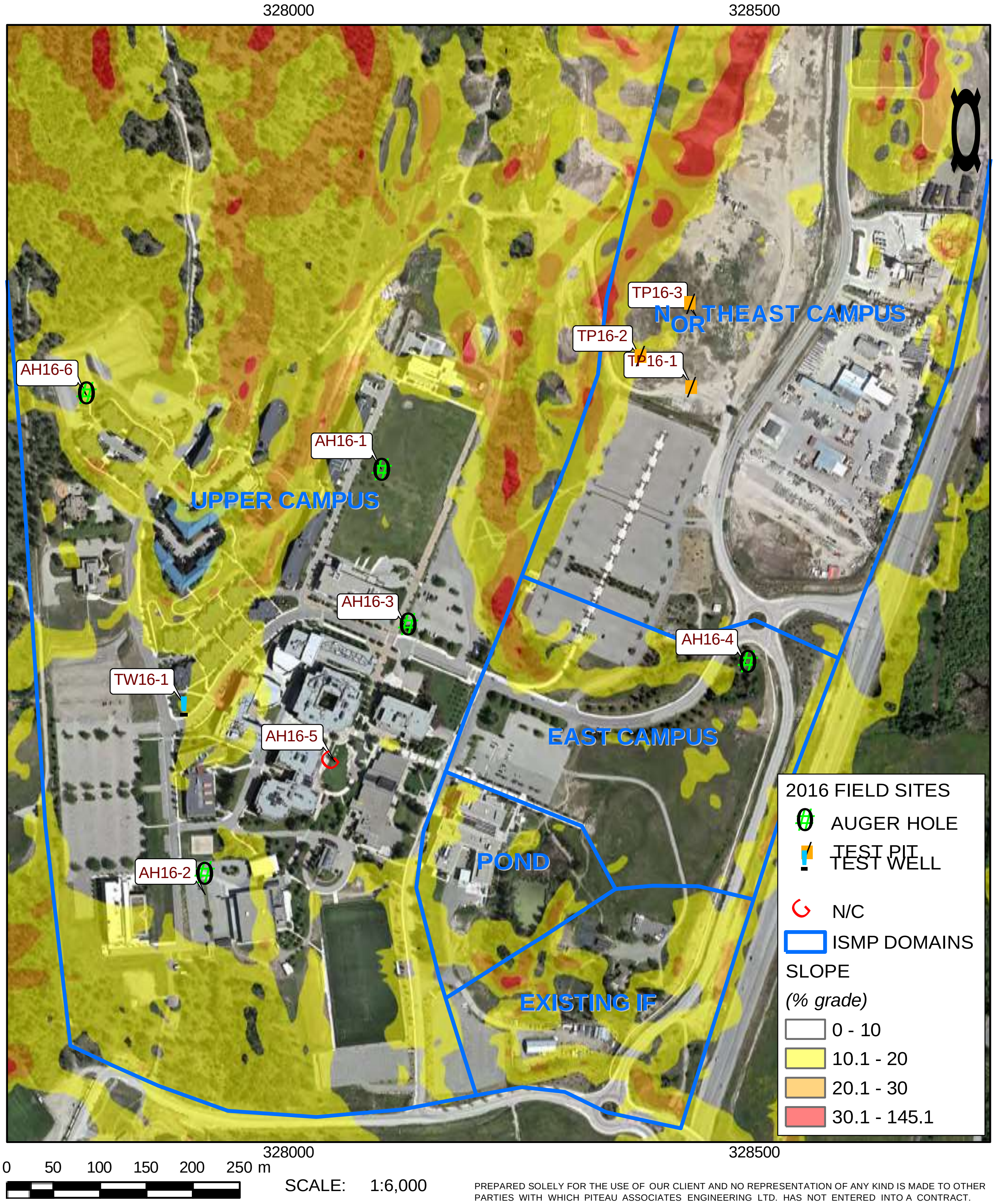
MEASURED DEPTH TO WATER IN BOREHOLES
IN NORTHEAST AND EAST CAMPUS

BY:	DATE:
MLS	JUL 16
APPROVED: MLS	FIG: 5



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TOPOGRAPHIC SURFACE SLOPE GRADE

BY:	DATE:
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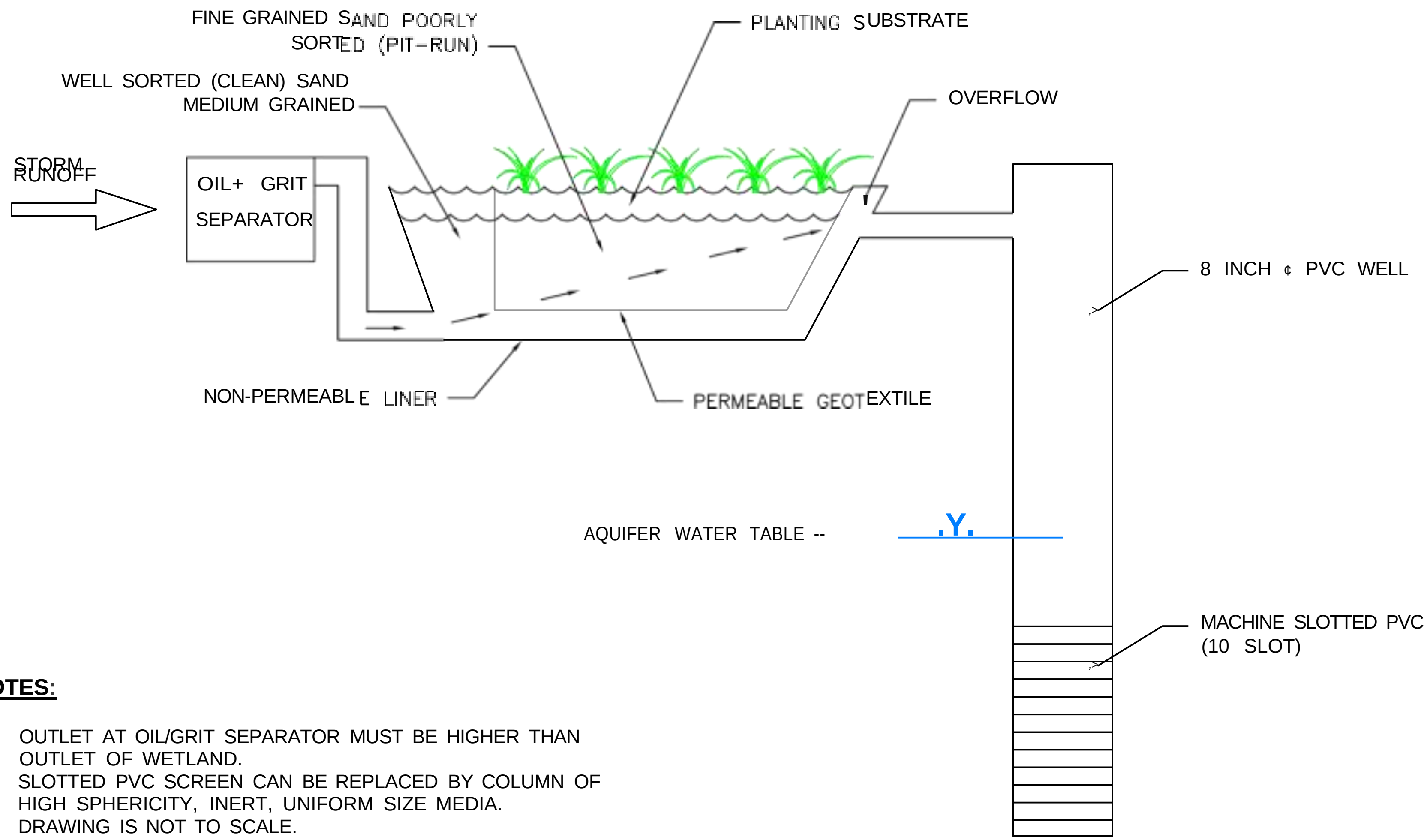
APPROVED: MLS	FIG: 6



NOTES:

1. OUTLET AT OIL/GRIT SEPARATOR MUST BE HIGHER THAN OUTLET OF WETLAND.
2. SLOTTED PVC SCREEN CAN BE REPLACED BY COLUMN OF HIGH SPHERICITY, INERT, UNIFORM SIZE MEDIA.
3. DRAWING IS NOT TO SCALE.

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SCHEMATIC OF PRE-INJECTION TREATMENT AND DISPOSAL VIA GRAVITY DRAINING

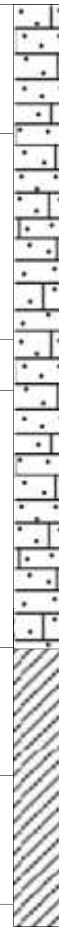
BY:	DATE:
MS/lf	JUL 16
APPROVED:	FIG: 7

APPENDIX A

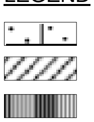
BOREHOLE HYDROGEOLOGICAL LOGS

H:\Project\3529\Field\AH16-1 LOG.grf

ELEV. (m-ASL)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION		COMMENTS
	0	Soft SILT to fine SAND fill		
448				
	2	Soft grey CLAY w. SILTY fine SAND and trace GRAVEL		
446				
	4	Harder material		Grinding bit - COBBLE at 15'
444				
	6	Increasing in SILT content over CLAY brown SILT to fine SAND, CLAY - MOIST w. trace GRAVEL		
442				
	8	Fine brown SAND well sorted w. trace rounded GRAVEL - DRY	SAMPLE AH16-1 (7.6m)	Blow Count 48 per 6" 50 per 1"
440				
	10	Fine brown very well sorted SAND - DRY	SAMPLE AH16-1 (9.1m)	Blow Count 49 per 6" 50 per 1"
438		Fine brown well sorted SAND w. trace GRAVEL - DRY		Blow Count 50 per 5"
		End of Hole @ 10.7 m-bgs (35 ft)		
	12			
436				
	14			
434				



LEGEND



MIX OF FINES AND COARSE

SAND / GRAVEL

CLAY / SILT

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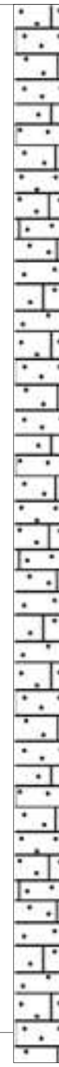
HYDROGEOLOGICAL LOG FOR AUGER HOLE AH16-1

BY	DATE
GJL	JUL 16
APPROVED	**FIG.**
MLS	A-1

ELEV. (m-ASL)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION	COMMENTS
	0		
450			
	2		Very large rock
448			
	4		Really slow drilling due to hardness of soil
446			
	6		
444			
	8	Fine brown SAND / CLAY (clumps), trace rounded GRAVEL - DAMP SAMPLE AH16-2 (7.6m)	Blow Count 50 per 6" 50 per 3"
442		CLAY with trace fine SAND and rounded GRAVEL - GREY SAMPLE AH16-2 (9.1m)	Blow Count 45 per 6" 50 per 6"
	10		
440		Hard Pack moderately sorted CLAY / fine SAND grey - DAMP	Blow Count 45 per 6" 50 per 6"
	12	Hard Pack moderately sorted CLAY / fine SAND grey - DAMP End of Hole @ 12.2 m-bgs (40 ft)	Blow Count 50 per 6"
438			
	14		
436			



LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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HYDROGEOLOGICAL LOG FOR AUGER HOLE AH16-2

BY	DATE
GJL	JUL 16
APPROVED	**FIG.**
MLS	A-2

\\10.0.25.4\project\Project\3529\Field\AH16-3

ELEV. (m-ASL)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION		COMMENTS
442 – 437.5	0 – 4.6	Very well sorted grey CLAY		unsure of exact point of change from the clay to sand
		Very well sorted medium grey-brown SAND - DAMP	SAMPLE AH16-3 (6.1m)	Blow Count 7 per 6" 11 per 3" 13 per 6" 21 per 6" — Started to hit some rocks
		Poorly sorted brown SAND w. round GRAVEL and COBBLES - DRY (rock dust in sample)	SAMPLE AH16-3 (7.6m)	Blow Count 20 per 6" 25 per 3" 30 per 6" 35 per 6"
		Moderately sorted hardpack CLAY / GRAVEL w. fine to medium SAND grey - MOIST		Blow Count (rock stuck in bit) 18 per 6" 26 per 6" 56 per 6" 54 per 6"
		Poorly sorted CLAY / GRAVEL w. fine to medium SAND grey MOIST		Blow Count 50 per 3"
		Poorly sorted hard park Clay w. angular fine to medium SAND and rounded GRAVEL		Blow Count 56 per 6" 55 per 6" Blow Count 26 per 6" 50 per 6"
		End of Hole @ 13.1 m-bgs (43 ft)		

Elevation scale (m-ASL): 442, 440, 438, 436, 434, 432, 430, 428
Depth scale (m-BGS): 0, 2, 4, 6, 8, 10, 12, 14

LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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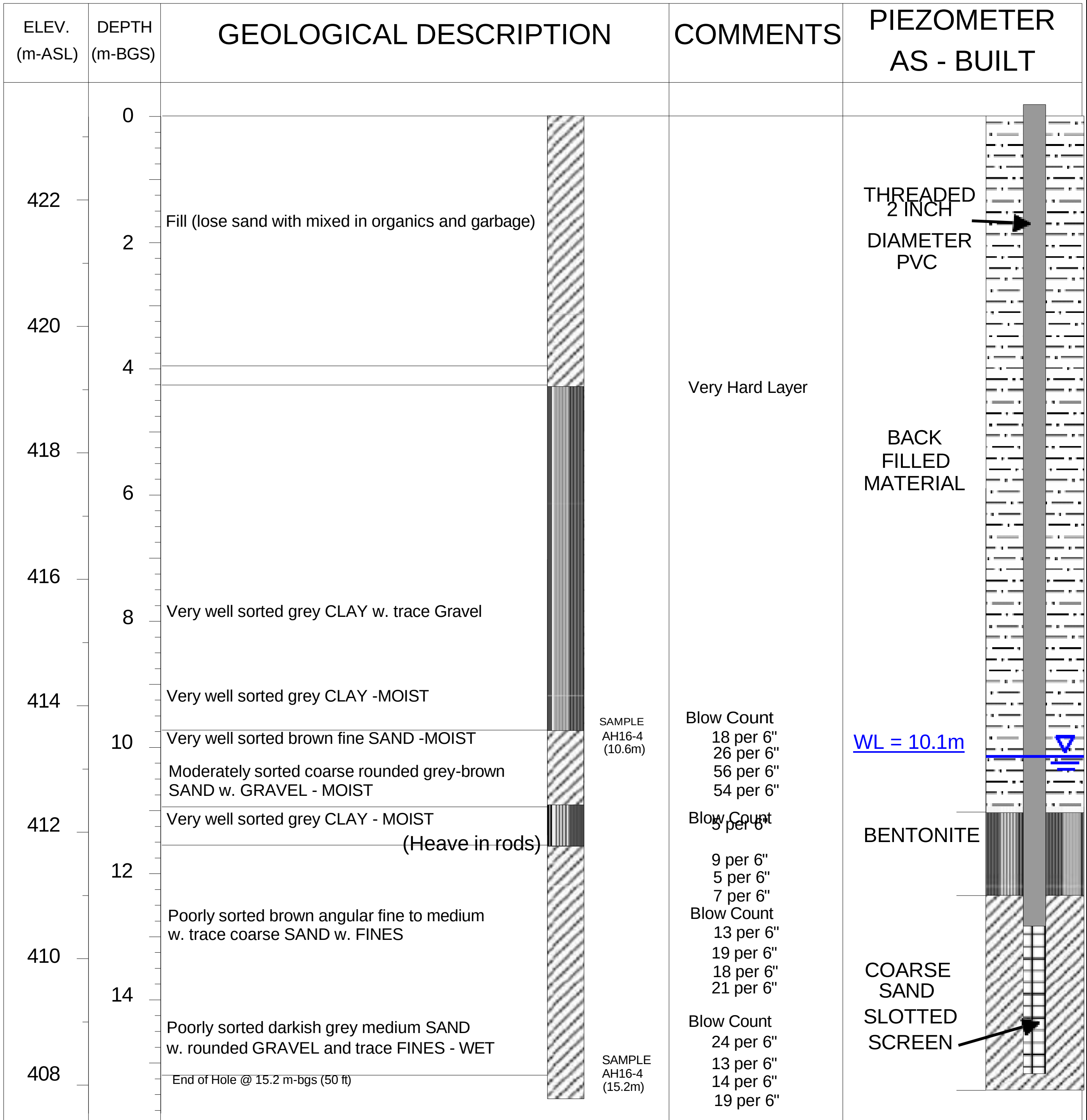
HYDROGEOLOGICAL LOG FOR AUGER HOLE AH16-3

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	A-3

\\10.0.25.4\project\Project\3529\Field\AH16-4 LOG 160628.grf



LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT
- WATER TABLE

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HYDROGEOLOGICAL LOG FOR AUGER HOLE AH16-4

BY	DATE
GJL	JUL 16
APPROVED MLS	FIG. A-4

\\10.0.25.4\project\Project\3529\Field\AH16-6 LOG.grf

ELEV. (m-ASL)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION	COMMENTS
	0		
468		Soft SILT / GRAVEL fill	
	2	Natural compact soil	
466		Hard SILT, GRAVEL, COBBLES, fine SAND	
	4	More GRAVEL and SILT content	
464		More GRAVEL and SILT content	
	6	Poorly sorted compact yellow-brown oxidized rounded SILTY fine SAND to GRAVEL - WET	SAMPLE AH16-6 (6.1m)
462			
	8		
460		Fine well sorted SILTY SAND	
	10		Blow Count >50 per 6"
458		Very hard till, compact CLAY w. GRAVEL and COBBLES 1" seam of fine to medium grained well sorted clean SAND	
	12	End of Hole @ 12.2 m-bgs (40 ft)	
456			
	14		
454			

LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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HYDROGEOLOGICAL LOG FOR AUGER HOLE AH16-6

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	A-5

H:\Project\3529\Field\TW16-1 LOG.grf

DEPTH (m-BGS)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION	COMMENTS
	0	CLAY, top soil and small stones soft	
		CLAY brown soft	
445	5	Grey CLAY and GRAVEL soft	
440		Grey cemented GRAVEL very hard	
435	10, 15	Brown cemented GRAVEL hard	
430	20	Brown CLAY and SAND with scattered PEBBLES hard	
425	25	Brown CLAY w. SAND lenses and PEBBLES medium hardness	
		Grey CLAY w. lenses of SAND and PEBBLES soft	Broken ROCK medium hardness
420		SAND PEBBLES water bearing dirty brown	
415	30, 35	Grey CLAY SAND PEBBLES dry soft	
410	40	End of Hole @ 38.4 m-bgs (126 ft)	

LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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HYDROGEOLOGICAL LOG FOR TEST WELL TW16-1

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	A-6

APPENDIX B

TEST PIT LOGS AND PERMEAMETER TEST RESULTS

H:\Project\3529\Field\TPSE GP LOG.grf

ELEV. (m-ASL)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION
	0	Very well sorted yellowish grey fine SAND - DRY
421		Poorly Sorted Clay w. fine SAND rounded GRAVEL and COBBLES dark yellowish brown - DRY
	1	
420		Well sorted yellowish brown CLAY and fine SAND w. trace rounded gravel - MOIST
	2	
419		Poorly sorted yellowish brown CLAY and SAND
		End of Hole @ 2.7 m-bgs (9 ft)
	3	
418		

INFILTRATION TEST RESULTS (GUELPH PERMEAMETER)

TEST DEPTH: 1.8m (6ft)

<u>Reservoir used: Inner</u> <u>Y = 2.14 cm^2</u>

First Set of Readings (H_1 = 5 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	64.0	-	-
2	2	2	64.9	0.90	0.45
3	3	1	65.2	0.30	0.30
4	4	1	65.3	0.10	0.10
5	6	2	65.5	0.20	0.10
6	8	2	65.6	0.10	0.05

<u>Reservoir used: Inner</u> <u>Y = 2.14 cm^2</u>

First Set of Readings (H_2 = 10 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	66.1	-	-
2	2	2	66.4	0.30	0.15
3	4	2	66.9	0.50	0.25
4	7	3	72.1	5.20	1.73
5	8	1	73.5	1.40	1.40
6	9	1	76.0	2.50	2.50

R_1= (0.1) / 60 = 0.00167 cm/sec

R_2= (2.0) / 60 = 0.0333 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.0333)]-[(0.0054)(2.14)(0.00167)]

K_{fs} = 0.000273 cm/sec

LEGEND

MIX OF FINES AND COARSE

SAND / GRAVEL

CLAY / SILT

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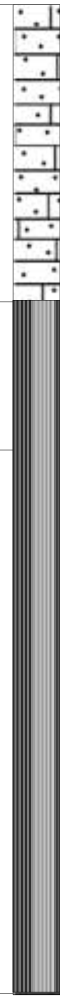
HYDROGEOLOGICAL LOG FOR TEST PIT TP16-1

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	B-1

H:\Project\3529\Field\TPSW GP LOG.grf

DEPTH (m-BGS)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION
	0	
422		Yellowish grey CLAY w. COBBLES and BOULDERS
421	1	Dark yellowish brown CLAY and ASPHALT
420	2	Poorly sorted grey CLAY and fine SAND w. trace well rounded GRAVEL
419	3	End of Hole @ 3.0 m-bgs (10 ft)



INFILTRATION TEST RESULTS (GUELPH PERMEAMETER)

TEST DEPTH: 1.7m (5½ft)

Reservoir used: Inner Y = 2.14 cm^2

First Set of Readings (H_1 = 5 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	54.8	-	-
2	2	2	55.2	0.40	0.20
3	4	2	55.6	0.40	0.20
4	6	2	55.9	0.30	0.15
5	8	2	56.2	0.30	0.15
6	10	2	56.4	0.20	0.10

Reservoir used: Inner Y = 2.14 cm^2

First Set of Readings (H_2 = 10 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	59.8	-	-
2	2	2	60.7	0.90	0.45
3	4	2	61.9	1.20	0.60
4	6	2	63.1	1.20	0.60
6	8	2	65.5	2.40	1.20

R_1= (0.2) / 60 = 0.00333 cm/sec

R_2= (1.1) / 60 = 0.0183 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.00333)]-[(0.0054)(2.14)(0.0183)]

K_{fs} = 0.000126 cm/sec

LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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HYDROGEOLOGICAL LOG FOR TEST PIT TP16-2

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	B-2

H:\Project\3529\Field\TPN GP LOG.grf

DEPTH (m-BGS)	DEPTH (m-BGS)	GEOLOGICAL DESCRIPTION
	0	Hard pack fine brown SAND - DRY
421		Hard pack CLAY - DRY
		CLAY w. rounded GRAVEL
	1	Layers of: Yellowish grey fine poorly sorted SAND, Dark yellowish brown CLAY w. coarse SAND
420		Hard pack fine SAND w. trace rounded GRAVEL
	2	NATIVE SOIL
419		Very well sorted fine brown SAND SAMPLE TP16-3 (2.7m)
		End of Hole @ 2.7 m-bgs (9 ft)
	3	
418		

INFILTRATION TEST RESULTS (GUELPH PERMEAMETER)

TEST DEPTH: 1.8m (6ft)

Reservoir used: Inner $Y = 2.14\ cm^2$

First Set of Readings (H_1 = 5 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	39.0	-	-
2	1	1	43.4	4.40	4.40
3	2	1	46.6	3.20	3.20
4	3	1	51.5	4.90	4.90
5	4	1	54.3	2.80	2.80
6	5	1	58.4	4.10	4.10
7	6	1	62.8	4.40	4.40
8	8	2	71.9	9.10	4.55

Reservoir used: Inner $Y = 2.14\ cm^2$

First Set of Readings (H_2 = 10 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	21.5	-	-
2	1	1	32.4	10.90	10.90
3	2	1	40.9	8.50	8.50
4	3	1	54.1	13.20	13.20
5	4	1	69.3	15.20	15.20

R_1= (4.11) / 60 = 0.0685 cm/sec

R_2= (11.95) / 60 = 0.199 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.199)]-[(0.0054)(2.14)(0.0685)]

K_{fs} = 0.000956 cm/sec

LEGEND

- MIX OF FINES AND COARSE
- SAND / GRAVEL
- CLAY / SILT

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HYDROGEOLOGICAL LOG FOR TEST PIT TP16-3

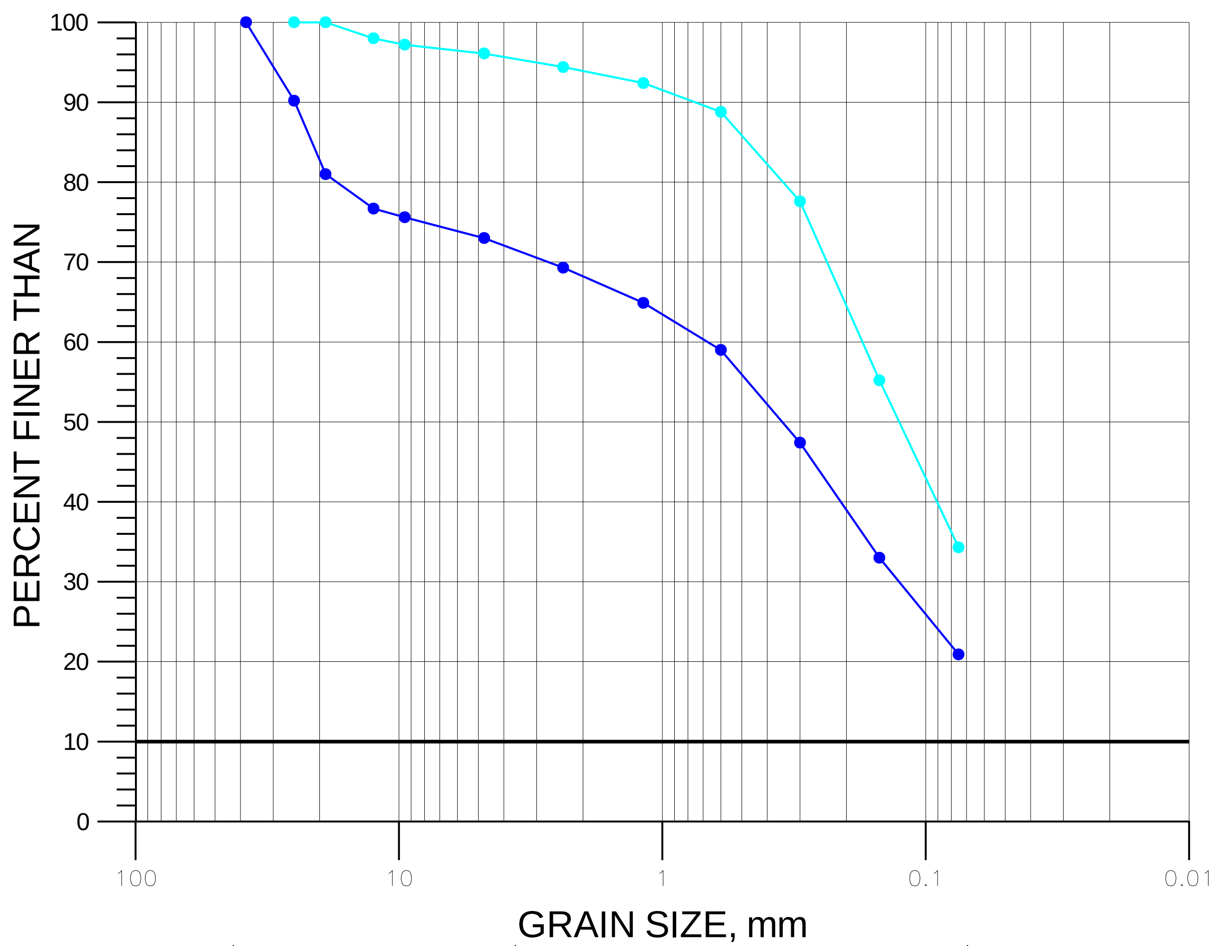
BY: GJL | DATE: JUL 16
APPROVED: MLS | FIG. B-3

APPENDIX C

GRAINS SIZE ANALYSES FROM SIEVE SAMPLES

H:\Project\3529\Sieves\AH16-1.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

AH16-1 (7.6m)
AH16-1 (9.1m)

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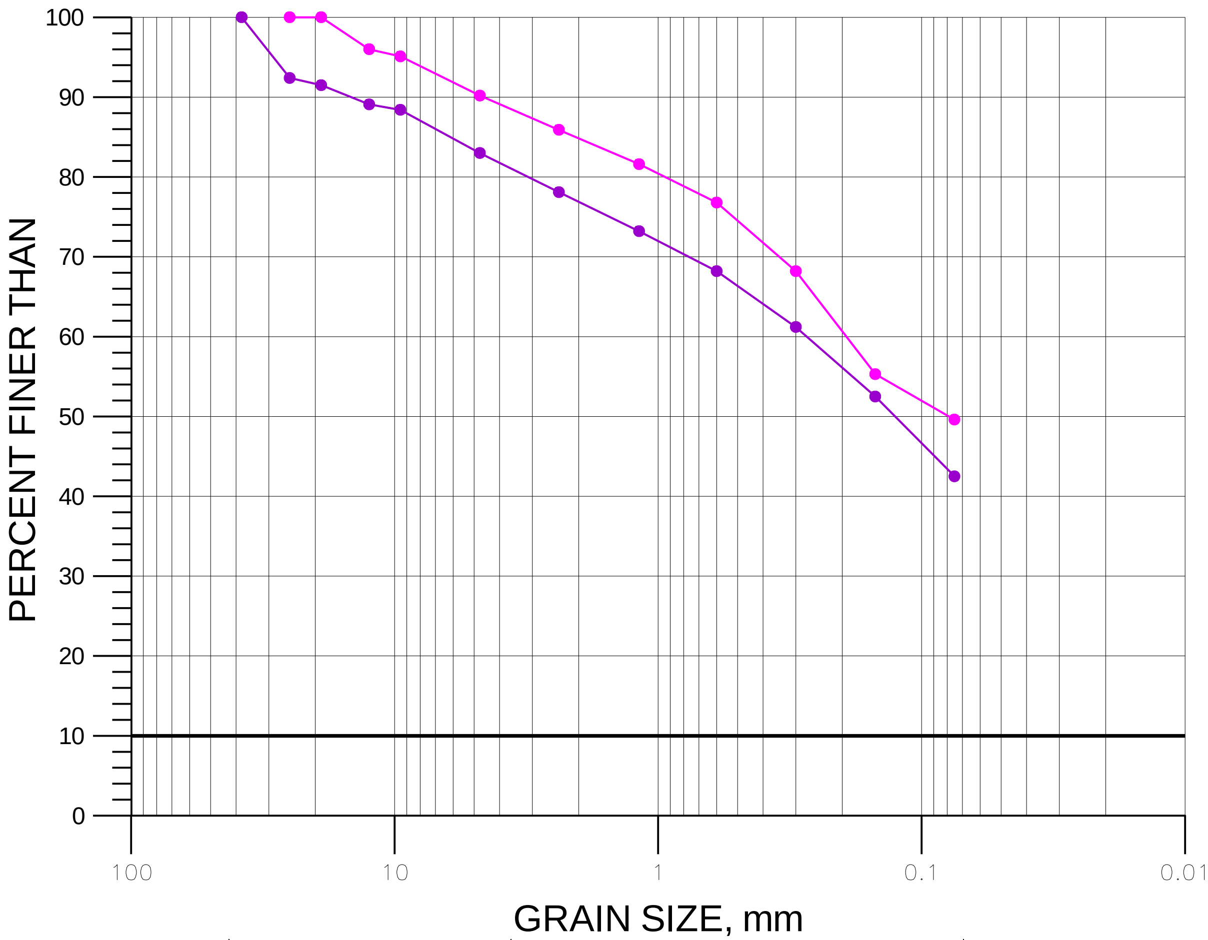
GRAIN SIZE ANALYSIS FOR AUGER HOLE AH16-1

BY:	DATE:
GJL	JUL 16
APPROVED:	FIG:
MLS	C-1

H:\Project\3529\Sieves\AH16-2.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

AH16-2 (7.6m)
AH16-2 (9.1m)

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GRAIN SIZE ANALYSIS FOR AUGER HOLE AH16-2

BY: GJL	DATE: JUL 16
APPROVED: MLS	FIG: C-2

H:\Project\3529\Sieves\AH16-3.grf

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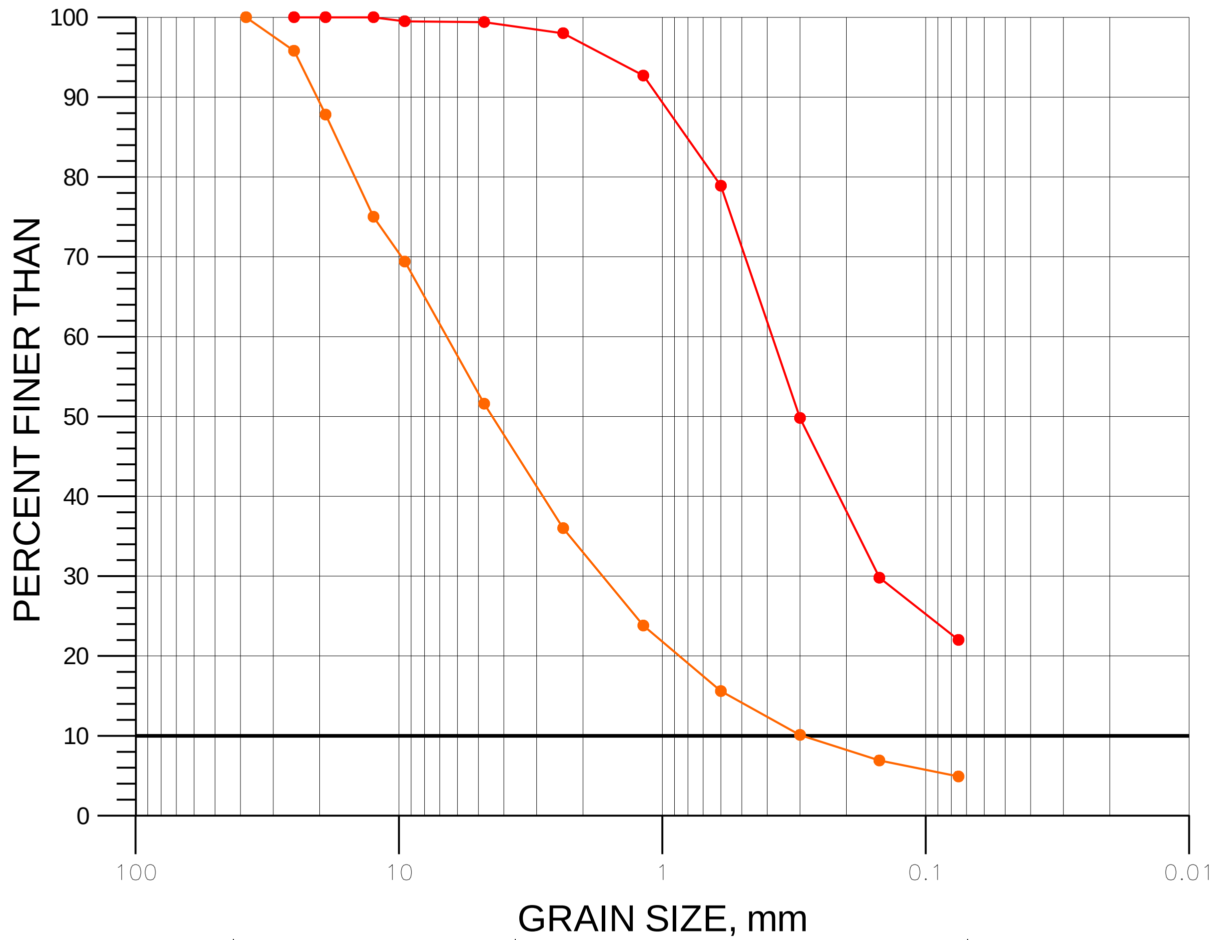

USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

AH16-3 (6.1m)
AH16-3 (7.6m)

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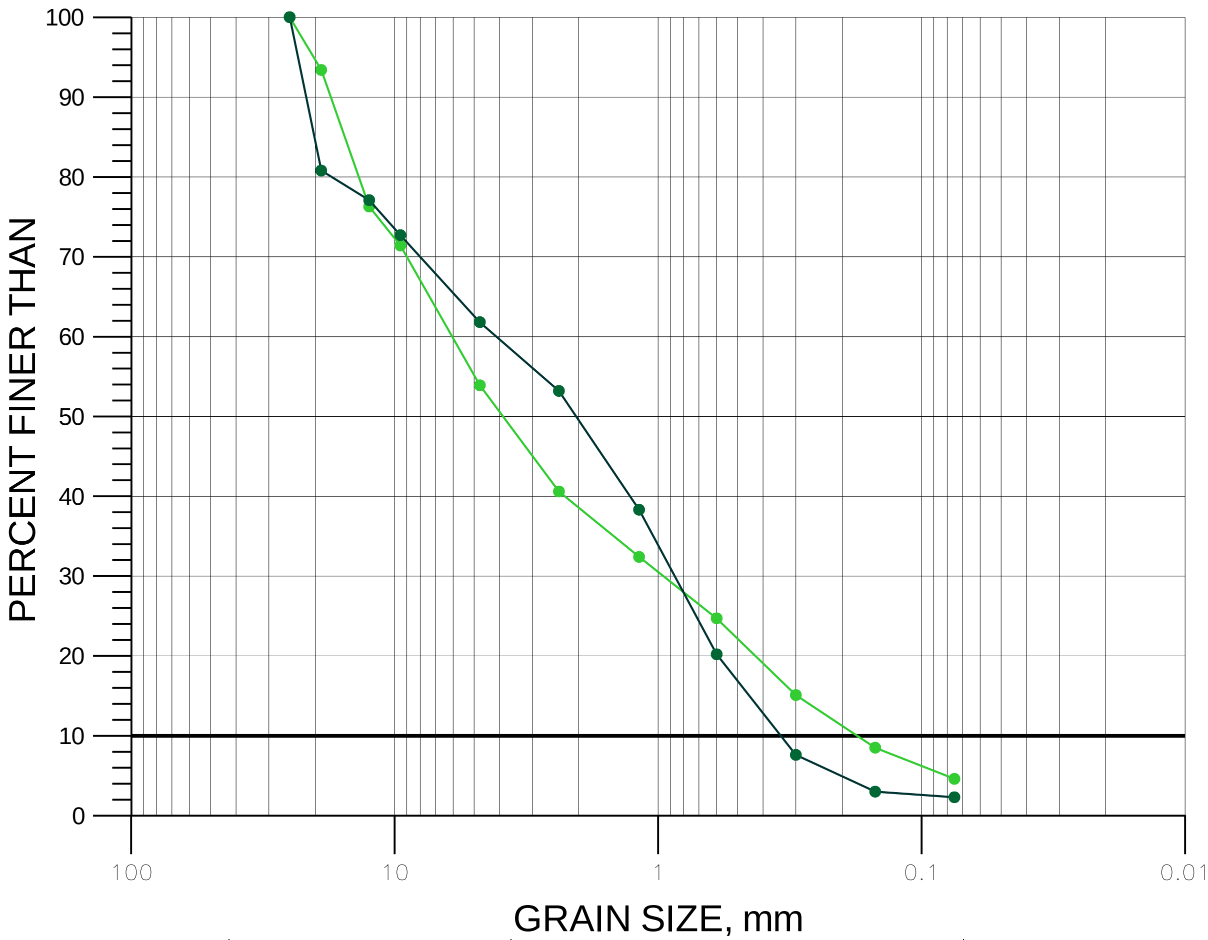
GRAIN SIZE ANALYSIS FOR AUGER HOLE AH16-3

BY:	DATE:
GJL	JUL 16
APPROVED:	FIG:
MLS	C-3

H:\Project\3529\Sieves\AH16-4.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

AH16-4 (10.6m)
AH16-4 (15.2m)

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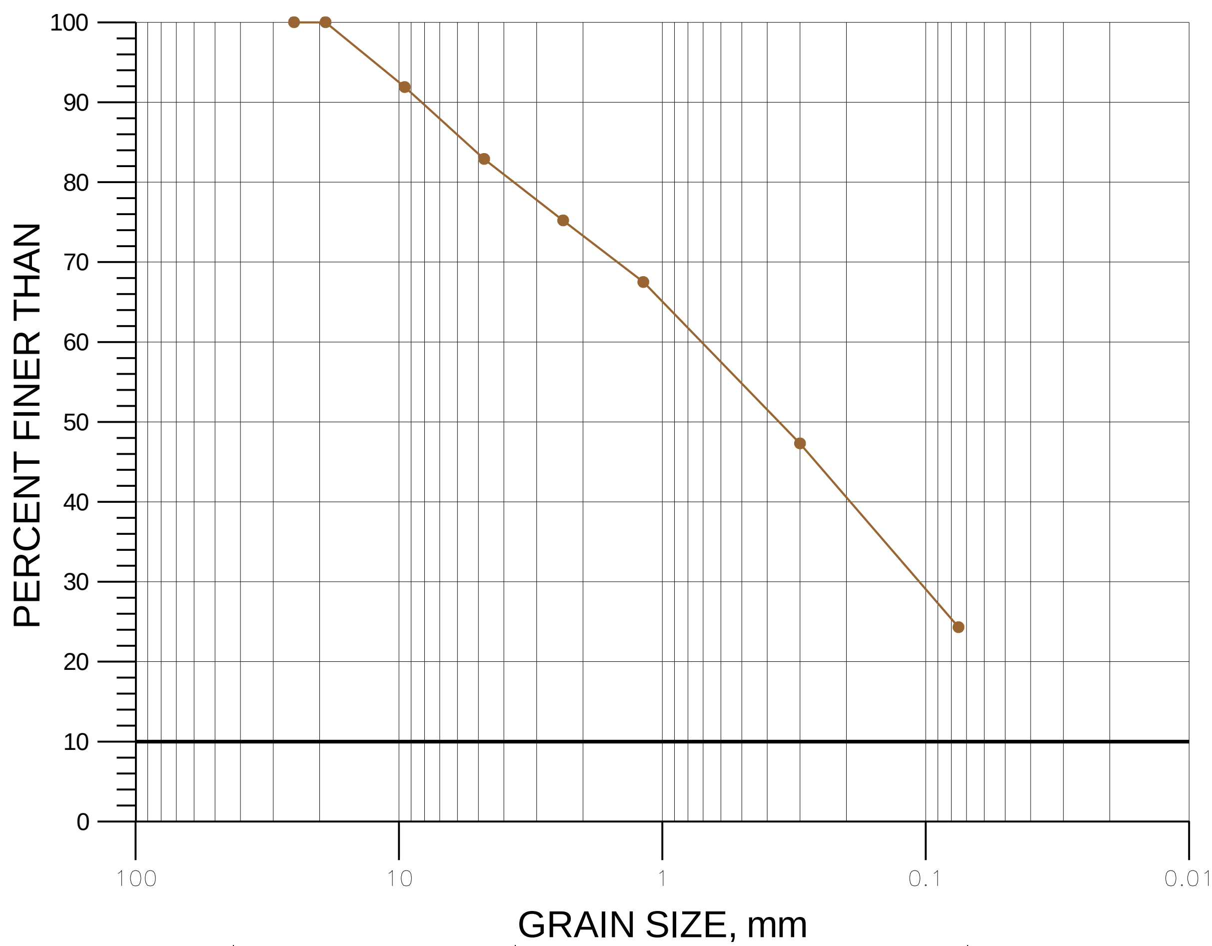
GRAIN SIZE ANALYSIS FOR AUGER HOLE AH16-4

BY:	DATE:
GJL	JUL 16
APPROVED:	FIG:
MLS	C-4

H:\Project\3529\Sieves\AH16-6.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

AH16-6 (6.1m)

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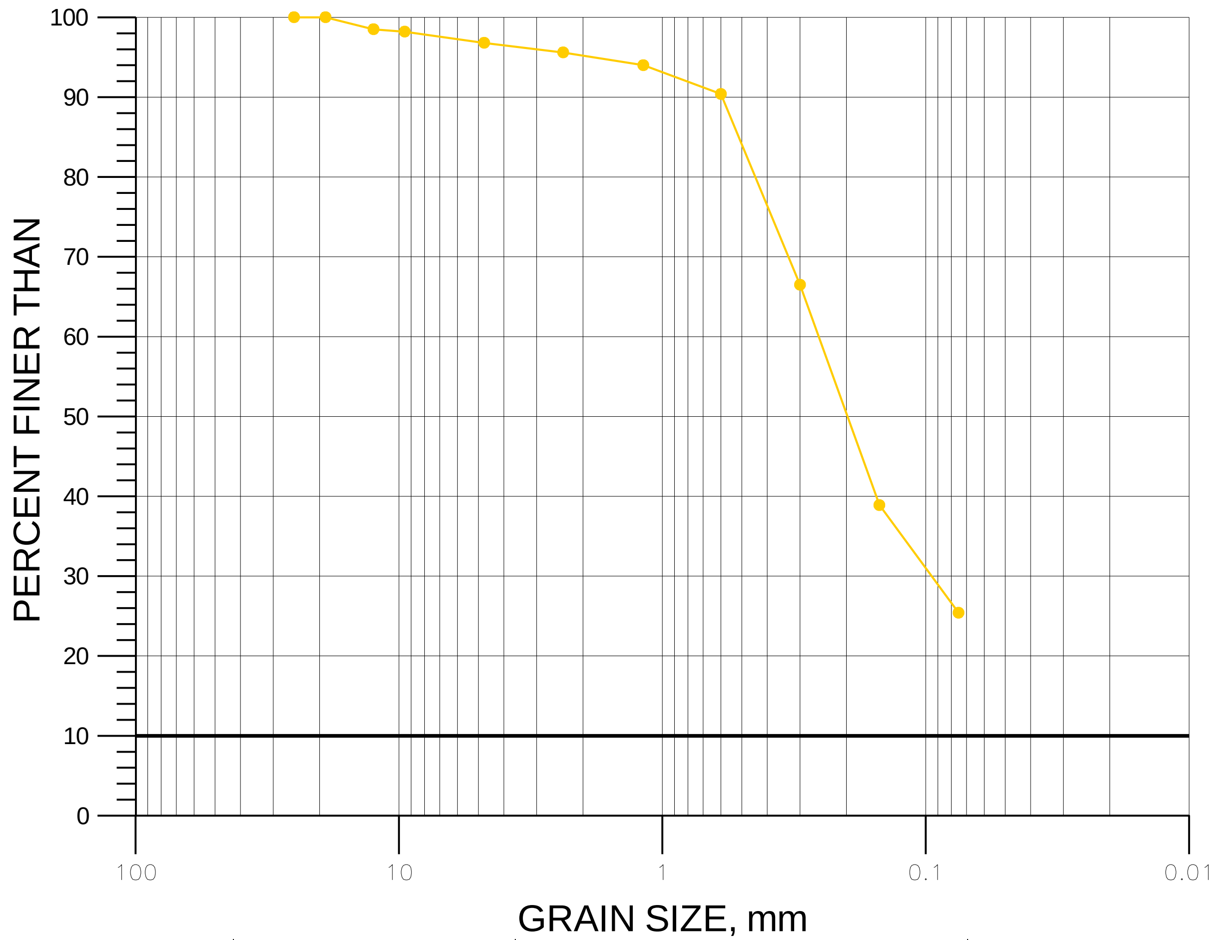
GRAIN SIZE ANALYSIS FOR AUGER HOLE AH16-6

BY:	DATE:
GJL	JUL 16
APPROVED: MLS	FIG: C-5

H:\Project\3529\Sieves\TP16-3.grf

UNIFIED SOIL CLASSIFICATION SYSTEM 1992



USCS	Coarse	Fine	Coarse	Medium	Fine	
COBBLE SIZE	GRAVEL SIZE		SAND SIZE			SILT or CLAY SIZE

TP16-3 (2.7m)

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GRAIN SIZE ANALYSIS FOR TEST PIT TP16-3

BY:	DATE:
GJL	JUL 16
APPROVED:	FIG:
MLS	C-6

APPENDIX D

PERMEAMETER TEST RESULTS

H:\Project\3529\Field\GP16-1.grf

LANDSCAPED SOIL

Date: July 12th, 2016 — Field Engineer: GJL

Hole ID: GP16-1 — Depth of Hole: 0.22M

Reservoir used: Inner — $Y = 2.14\ cm^2$

First Set of Readings (H_1 = 5 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	47.0	-	-
2	3	3	48.4	1.40	0.47
3	6	3	49.3	0.90	0.30
4	10	4	50.3	1.00	0.25
5	12	2	50.7	0.40	0.20
6	14	2	51.0	0.30	0.15
7	16	2	51.3	0.30	0.15

Reservoir used: Inner — $Y = 2.14\ cm^2$

First Set of Readings (H_2 = 10 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	50.0	-	-
2	5	5	51.3	1.30	0.26
3	8	3	55.1	3.80	1.27
4	10	2	59.0	3.90	1.95
5	11	1	61.2	2.20	2.20
6	12	1	63.8	2.60	2.60
6	13	1	66.3	2.50	2.50
4	14	1	68.4	2.10	2.10
5	15	1	70.6	2.20	2.20

R_1= (.15) / 60 = 0.0025 cm/sec

R_2= (2.15) / 60 = 0.036 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.0358)]-[(0.0054)(2.14)(0.00250)]

K_{fs} = 0.000286 cm/sec

GEOLOGICAL DESCRIPTION COMMENTS

Medium SAND w. CLAY sorted grey - MOIST

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PERMEAMETER TEST DATA AND CALCULATIONS FOR GP16-1

BY: GJL | DATE: JUL 16
APPROVED: MLS | FIG. D-1

H:\Project\3529\Field\GP16-2.grf

LANDSCAPED SOIL

Date: July 12th, 2016 | Field Engineer: GJL
Hole ID: GP16-2 | Depth of Hole: 0.25M
Reservoir used: Combined | $Y = 35.22 cm^2$

First Set of Readings (H_1 = 5 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	41.5	-	-
2	5	5	46.5	5.00	1.00
3	9	4	47.0	0.50	0.13
5	13	4	47.1	0.10	0.03

Reservoir used: Inner | $Y = 2.14 cm^2$

First Set of Readings (H_2 = 10 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	48.6	-	-
2	3	3	51.4	2.80	0.93
3	5	2	53.6	2.20	1.10
4	8	3	55.2	1.60	0.53
5	13	5	58.7	3.50	0.70
6	15	2	59.8	1.10	0.55

R_1= (.03) / 60 = 0.0005 cm/sec

R_2= (.6) / 60 = 0.01 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(35.22)(0.01)]-[(0.0054)(2.14)(0.0005)]

K_{fs} = 0.00144 cm/sec

GEOLOGICAL DESCRIPTION COMMENTS

CLAY w. fine SAND brown hard - MOIST

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PERMEAMETER TEST DATA AND CALCULATIONS FOR GP16-2

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	D-2

H:\Project\3529\Field\GP16-3.grf

LANDSCAPED SOIL

Date: July 12th, 2016 Field Engineer: GJL

Hole ID: GP16-3 Depth of Hole: 0.25m

Reservoir used: Inner $Y = 2.14\ cm^2$

First Set of Readings (H_1 = 5 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	28.6	-	-
2	9	9	29.2	0.60	0.07
3	14	5	29.2	0.00	0.00

Reservoir used: Inner $Y = 2.14\ cm^2$

First Set of Readings (H_2 = 10 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	33.8	-	-
2	4	4	33.8	0.00	0.00
3	7	3	33.8	0.00	0.00

R_1= (0) / 60 = 0 cm/sec

R_2= (0) / 60 = 0 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0)]-[(0.0054)(2.14)(0)]

K_{fs} = No Flow

GEOLOGICAL DESCRIPTION COMMENTS

Hard CLAY w. dark brown w. trace medium SAND and organics

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PERMEAMETER TEST DATA AND CALCULATIONS FOR GP16-3

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	D-3

H:\Project\3529\Field\GP16-4.grf

NATIVE SOIL

Date: July 12th, 2016 — Field Engineer: GJL

Hole ID: GP16-4 — Depth of Hole: 0.19m

Reservoir used: Inner — $Y = 2.14\ cm^2$

First Set of Readings (H_1 = 5 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	39.5	-	-
2	4	4	44.9	5.40	1.35
3	5	1	46.1	1.20	1.20
4	6	1	47.2	1.10	1.10
5	8	2	49.3	2.10	1.05
6	10	2	51.3	2.00	1.00
7	11	1	52.3	1.00	1.00
8	12	1	53.3	1.00	1.00

Reservoir used: Inner — $Y = 2.14\ cm^2$

First Set of Readings (H_2 = 10 cm)

Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	54.5	-	-
2	1	1	55.5	1.00	1.00
3	3	2	57.3	1.80	0.90
4	5	2	59.1	1.80	0.90
5	8	3	61.9	2.80	0.93
6	11	3	64.8	2.90	0.97

R_1= (1.00) / 60 = 0.0167 cm/sec

R_2= (0.93) / 60 = 0.0155 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.0155)]-[(0.0054)(2.14)(0.016667)]

K_{fs} = Did not work, Soil wicking water upwards

GEOLOGICAL DESCRIPTION COMMENTS

fine SAND well sorted w. trace medium SAND and SILT
brown - DRY

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PERMEAMETER TEST DATA AND CALCULATIONS FOR GP16-4

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	D-4

H:\Project\3529\Field\GP16-5.grf

NATIVE SOIL

Date: July 12th, 2016 — Field Engineer: GJL

Hole ID: GP16-5 — Depth of Hole: 0.17m

Reservoir used: Combined — $Y = 35.22\ cm^2$

First Set of Readings (H_1 = 5 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	40.1	-	-
2	4	4	47.9	7.80	1.95
3	5	1	49.6	1.70	1.70
4	7	2	53.2	3.60	1.80
5	9	2	56.8	3.60	1.80
6	11	2	60.2	3.40	1.70

Reservoir used: Combined — $Y = 35.22\ cm^2$

First Set of Readings (H_2 = 10 cm)					
Reading Number	Time (min)	Time Interval (min)	Water Level (cm)	Δ Water Level (cm)	Rate of Change (cm/min)
1	0	-	29.0	-	-
2	1	1	38.4	9.40	9.40
3	2	1	46.6	8.20	8.20
4	3	1	54.1	7.50	7.50
5	4	1	66.2	12.10	12.10
6	5	1	71.1	4.90	4.90
7	6	1	15.0	Refill	
8	7	1	28.0	13.00	13.00
9	8	1	48.0	20.00	20.00
10	9	1	55.0	7.00	7.00
11	10	1	61.8	6.80	6.80
12	11	1	68.5	6.70	6.70

R_1= (1.75) / 60 = 0.0292 cm/sec

R_2= (6.5) / 60 = 0.108 cm/sec

K_{fs} = [(0.0041) (Y) (R_2)] - [(0.0054) (Y) (R_1)]

K_{fs} = [(0.0041)(2.14)(0.199)]-[(0.0054)(2.14)(0.0685)]

K_{fs} = 0.0101 cm/sec

GEOLOGICAL DESCRIPTION COMMENTS

fine SAND well sorted w. trace medium sand - DAMP

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PERMEAMETER TEST DATA AND CALCULATIONS FOR GP16-5

BY	DATE
GJL	JUL 16
APPROVED	FIG.
MLS	D-5

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The University of British Columbia would like to acknowledge the work carried out by the UBCO Leadership Team, Technical Working Group and Urban Systems' consultant team, in the development of the *UBC Okanagan Integrated Rainwater Management Plan (IRMP, 2017)*.

The *IRMP* was developed from 2016-2017 by Urban Systems' interdisciplinary consultant team in collaboration with UBC. It was developed to support the *UBC Okanagan Campus Plan (2015)* and *UBC Okanagan Whole Systems Infrastructure Plan (2016)* by providing an update to the 2*011 Stormwater Master Plan*. The *IRMP* responsibly manages the rainwater that falls on campus in a way that respects natural hydrological processes, protects existing environmental values, and manages risk.

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