Appendix F

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Memorandum

Date: December 19, 2014

Project: East Urban Community

To: Heather Wilson - JFSA

From: Jason Cole, M.Sc., P.Geo.
Rob Frizzell, M.Sc., P.Geo.

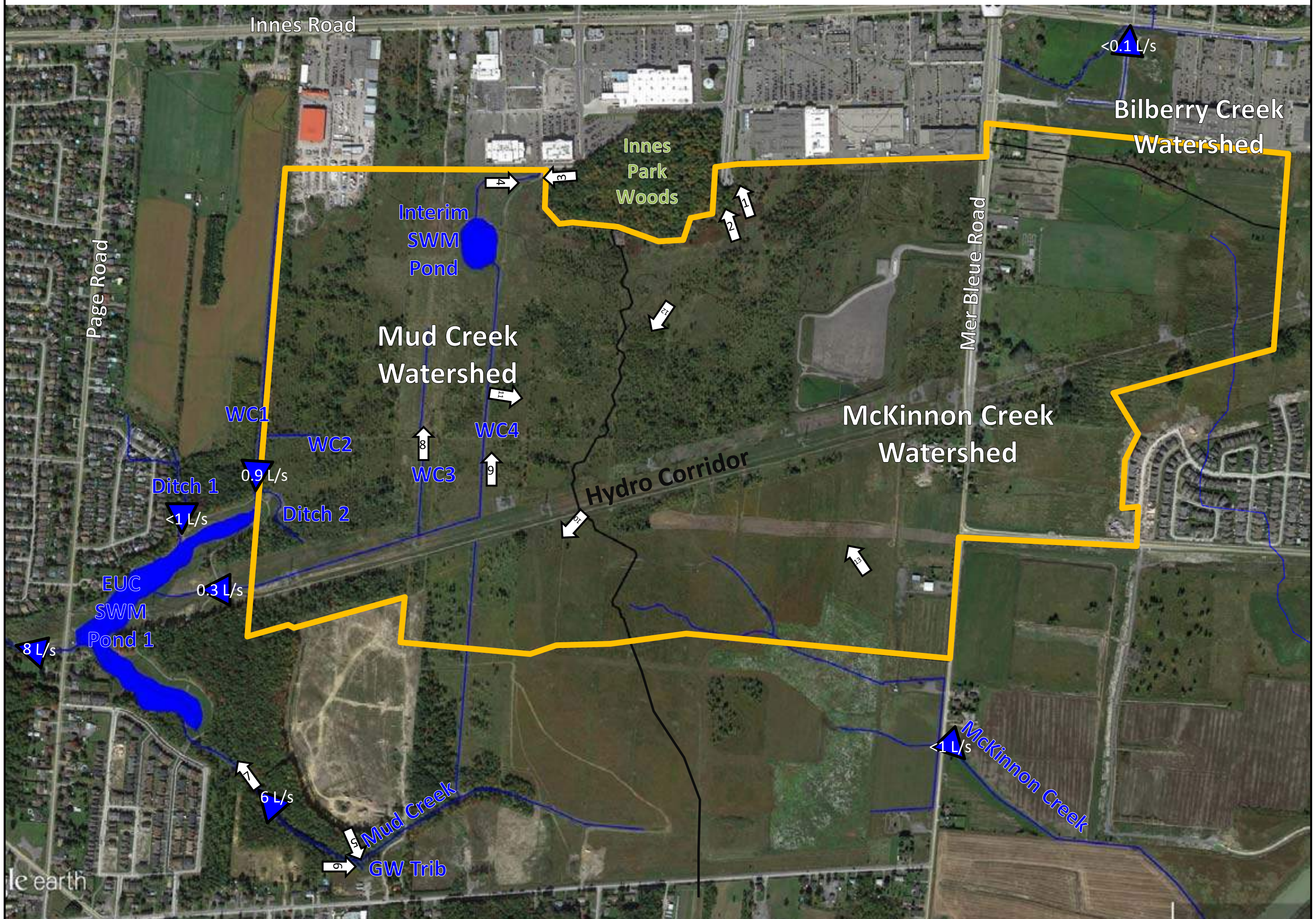
cc Steve Pichette - DSEL

Subject: Pre-Development Hydrogeological and Water Budget Assessment, East Urban Community Mixed Use Centre Development – Preliminary Findings

1 Introduction

Palmer Environmental Consulting Group Inc. (PECG) is pleased to present the preliminary results of our Pre-Development Hydrogeological and Water Budget Assessment for the East Urban Community Mixed Use Centre (EUC MUC) in Ottawa, Ontario (the "site"). The site is located within the Mud Creek, McKinnon Creek and Bilberry Creek watersheds (**Figure 1**). Mud Creek and Bilberry Creek watersheds are within the regulatory limits of the Rideau Valley Conservation Authority (RVCA) and McKinnon Creek is within the regulatory limits of South Nation Conservation (SNC). The study area is dominated by active and remnant agricultural land-use, with isolated areas of deciduous forest and thicket swamp communities (EUC MUC Existing Conditions Report, August 2014). The proposed development plan for the site includes a mixed use urban community consisting of residential, employment, industrial and supporting land-uses.

This memorandum provides an assessment of site-specific geological and hydrogeological conditions, groundwater supported ecosystems, and the pre-development water budget for the site and for each sub-watershed within the site boundary. Based on the results of this assessment, a series of Hydrogeological Considerations are presented to support the preparation of Concept Plan Alternatives for the site that take into account the existing site water budget, the function of natural environment features, and that are consistent with the Source Water Protection Planning Policies for the watersheds. Additional supporting details to this memorandum and a post-development water budget assessment will be included in a future final report submission.



Legend

- Site Boundary
- Watershed Drainage Area
- Drainage Feature
- Surface Water Flow Measurement (Nov 17/18)
- Photograph Location and Direction (Appendix B)

Base mapping from Google Earth (2014).

Drainage Features modified from OBM Mapping based on site specific observations.

N

600 m

Site Map

Eastern Urban Community Hydrogeology Study
December 2014
PN# 14151

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Figure 1

2 Site Visit

On November 17 and 18, 2014, Mr. Jason Cole from PECG conducted a site visit with staff from J.F. Sabourin and Associates Ltd. (JFSA) to better understand site geology/hydrogeology and identify ecological and surface water features that may be affected by changes in the water budget post-development. Based on data from the Ottawa International Airport Meteorological Station, less than 5 mm of total precipitation fell the week prior to the site visit. No rainfall occurred during the field visit, however, 10.8 cm of snow fell on November 17 and 0.4 cm fell on November 18, with the majority accumulating on the site.

Stream flow, and water temperature and conductivity measurements were made by JFSA at each identified surface water feature to understand the volume of water leaving the site under baseflow conditions. These results are presented in **Appendix A**. Shallow soil augering was conducted across the site and within each geological unit as identified from regional Ontario Geological Survey (OGS) mapping. This was completed to support a re-interpretation of the site-specific surficial geology to be used for the water budget assessment. Each woodlot/wetland community type and surface water feature was visited to provide insight into how each feature functions (i.e., groundwater supported or surface water supported). A photo log is provided in **Appendix B**.

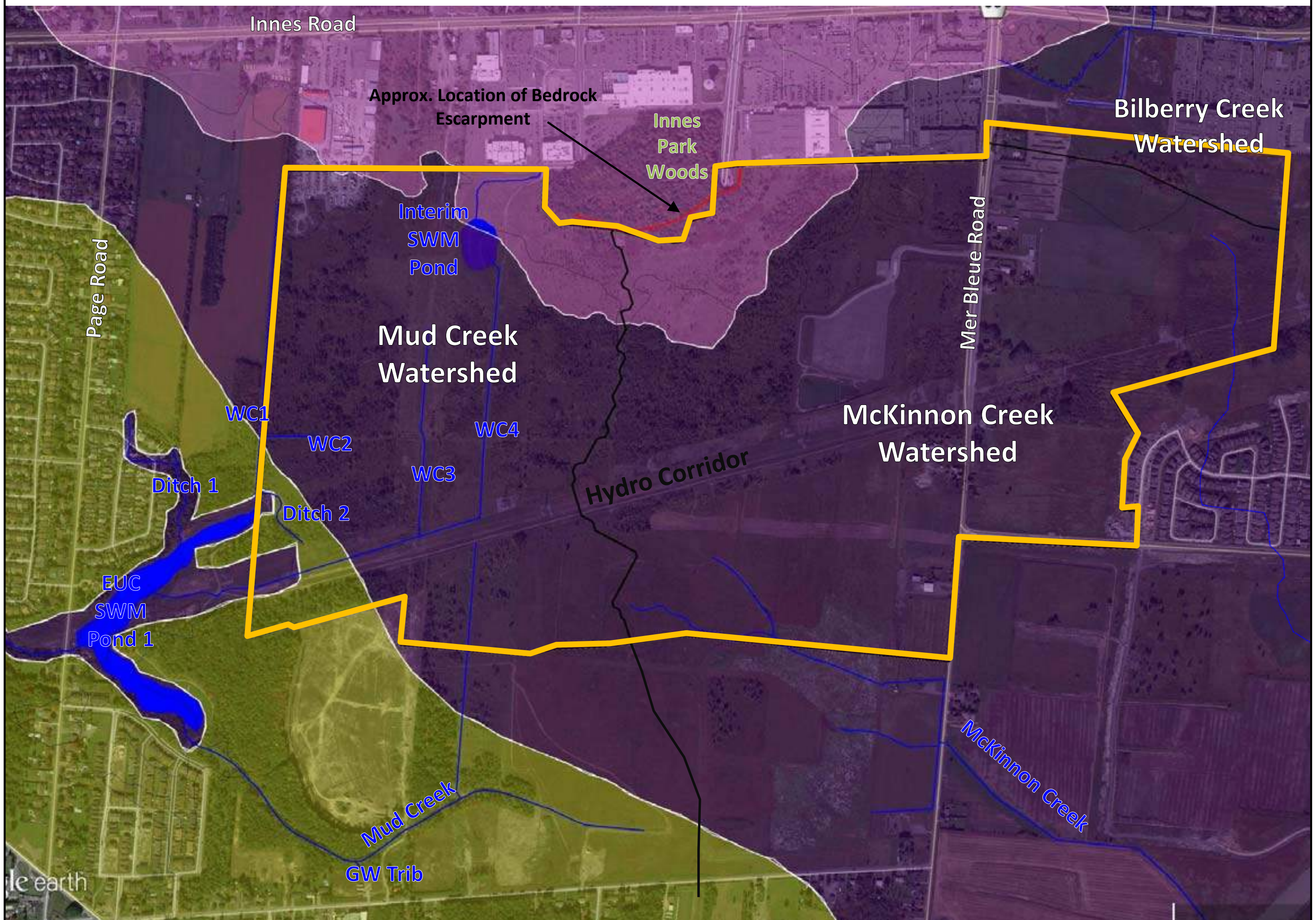
3 Site Conditions

3.1 Geology

In order to accurately complete a water budget for the site, a detailed site-specific understanding of the geology and hydrogeological conditions is required. PECG reviewed borehole logs from Patterson Group (2014), MOE well records, collected shallow geology data using a 1 m long hand auger, and completed an interpretation of the landforms and soils based on aerial orthophotography interpretations. **Figure 2** presents the revised surficial geology for the EUC MUC site. The revised geology map is similar to the regional OGS mapping, with a few noticeable changes. These changes include an extension of shallow bedrock conditions southwards, increase in the extent of glaciomarine clay within the valleylands of Mud Creek, and minor changes to the edge of the surficial sand unit.

The surficial geology across the site is primarily glaciomarine clay (**Figure 2**), which is comprised of laminated marine silt and clay layers, deposited within the post-glacial Champlain Sea (Chapman and Putnam, 1984). These clay deposits range in thickness from approximately 1 m to greater than 10 m within the site boundary.

Deposits of coarse-texture glaciomarine sand are present southwest of the site, with a small portion of this unit located within the site boundary near the EUC SWM Pond 1 (**Figure 2**). These deposits were formed along the edge of the post-glacial Champlain Sea. Based on borehole drilling results (Patterson, 2014) and hand augering, this unit is estimated to be about 1 m in thickness and overlies the glaciomarine clay.



Legend

- Site Boundary
- Watershed Drainage Area
- Drainage Feature
- Coarse Textured Glaciomarine (sand)
- Fine Textured Glaciolacustrine (silt , clay)
- Bedrock

Geology map modified from OGS Mapping based on site specific observations.

N

600 m

Surficial Geology

Eastern Urban Community Hydrogeology Study
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Figure 2

Paleozoic bedrock outcrops from the Middle Ordovician Bobcaygeon and Lindsay Formations are present in the northern portion of the study area (**Figure 2**). A noticeable bedrock escarpment is present (**Figure 2** and Photo 1), and based on OGS mapping, is interpreted to form along a fault separating the two bedrock units. The Bobcaygeon Formation is described as a crystalline, brown to grey-brown fossiliferous limestone (Williams and Telford, 1986). The Lindsay Formation is described as a light to dark grey to greyish brown, crystalline fossiliferous limestone with shaley partings and nodules (Williams, 1991). Both of these units are susceptible to chemical weathering along joints and fractures (i.e., solution enhanced porosity and permeability). Solution enhanced fractures and more competent bedrock outcrops are shown in photos 1 – 4 in **Appendix B**.

3.2 Hydrogeology

The glaciomarine clay forms a regional aquitard limiting infiltration and groundwater flow at the site. Groundwater flow through these soils is predominantly downwards (vertical), providing recharge (albeit limited) to deeper aquifers. Shallow groundwater flow is expected to closely mimic site topography and follow watershed boundaries. The water table is expected to be shallow and perched water table conditions may form due to very poor drainage through the soils.

The surficial sands to the southwest of the site (**Figure 2**) have been identified as a Highly Vulnerable Aquifer (HVA) and a Significant Groundwater Recharge Area (SGRA) in the Mississippi-Rideau Source Protection Plan (2013). This unit is generally between 0.1 and 1 m in thickness and is comprised of well sorted fine sand (photo 5 in **Appendix B)**. The water table is predicted to be shallow and perched within this sand aquifer unit, with horizontal groundwater flow dominating over vertical flow. Groundwater flow within the sand unit is towards Mud Creek, where discharge areas are expected. A groundwater supported channel draining to Mud Creek was identified during the site visit (photo 6) and is shown on **Figure 1** (GW Trib). Surface water monitoring results for flow, stream temperature and conductivity (**Appendix A**), and field observations (visible discharge) were used to confirm that this feature is supported by groundwater discharge from the surficial sand aquifer. These observations support this unit being classified as a SGRA.

The fractured bedrock found at surface (**Figure 2**), is classified as an HVA. Owing to the level of solution enhanced fractures observed, this unit should also be classified as an SGRA. Groundwater flow in this unit is controlled by the direction and orientation of joints and fractures and the hydraulic gradients across the site. Regional groundwater flow is expected to be north towards the Ottawa River.

3.3 Natural Environment

The vegetation communities within the study area consist of wet meadows (photo 10), thicket swamps photos 11 and 12), open field meadows (photo 12), and deciduous forests (Niblett Environmental Associates Inc., 2014). Niblett (2014) describes the formation of the standing water within wetland communities as a result of “pooling water”. This description matches what was observed during the November 2014 site visit by PECG and JFSA staff. None of the identified vegetation communities on the site are designated natural heritage features, and based on our understanding, are not protected under provincial policy. We also understand that the Innes Park Woodlot is not within the site boundary.

The formation of these natural features is directly related to the geology and topography of the site. Areas with low permeability clay soils and flat topography, such as the EUC MUC site, have progressively developed small depressions. These microtopographic features increase the retention of surface water, create shallow seasonal ponds, and promote infiltration. These wetlands lack a well-developed organic soil layer (as confirmed through soil augering results) due to the fact that they are subject to seasonal water level fluctuations that leave them dry for substantial parts of the year.

Based on our understanding of wetland formation and site observations, the wetlands on the EUC MUC site are not supported by groundwater discharge. Direct precipitation and limited runoff provide the water to support the wetland communities. The hydrology of these features is directly related to seasonal precipitation patterns.

3.4 Surface Water

The EUC MUC site is situated within three watersheds, Mud Creek on the west side, McKinnon Creek on the east side, and Bilberry Creek on the northeast portion of the site (**Figure 1**).

The Mud Creek watershed within the site is drained by a series of shallow artificial drainage channels (photo 8). These channels were created to remove surface water and are not groundwater supported, although some very localized minor seepage from the perched water table may occur. South of the study area, the headwaters of Mud Creek are found within a well-defined channel, originating from groundwater discharge from the surficial sand aquifer (photo 7). At the time of the field visit, Mud Creek had a flow of approximately 8 L/s on the west side of Page Road, where it leaves the EUC MUC site (**Figure 1** and **Appendix A**). The site itself contributed about 2 L/s combined from the various artificial drainage features (WCs and Ditches). The main branch of Mud Creek (south of the site) before the EUC SWM Pong 1 was measured at approximately 6 L/s, with much of this flow interpreted to be directly from the surficial sand aquifer.

On the McKinnon Creek watershed, the site is drained by two separate branches of McKinnon Creek (**Figure 1**). The first is found on the southern middle portion of the site and the second is from the far north east side of the site (**Figure 1**). Less than 1 L/s was measured entering McKinnon Creek at the southeast corner of the site (**Figure 1**). No measurements were collected from the second branch to the north east. At the time of the field visit, no distinct channel could be seen.

The Bilberry Creek watershed begins at the northeast corner of the site and drains to the north (**Appendix A**). The flow was too low to measure, which is not unexpected given the small catchment area.

All surface water features at the site are characterized as surface water fed drainage features. Baseflow in Mud Creek is supported through groundwater discharge from the surficial sands, which are located to the south of the site. Therefore, changes to infiltration within the EUC MUC site boundary will not impact baseflow to Mud Creek.

4 Pre-Development Water Budget

4.1 EUC MUC Site

A pre-development water budget was calculated over the site area using a monthly soil-moisture balance approach as described in Thornthwaite and Mather (1957) to determine the average annual ET and surplus under a pre- and post-development condition (**Table 1**).

The 1981 – 2010 Climate Normals from the McDonald Cartier Ottawa International Airport Meteorological Station were used to obtain monthly precipitation and temperature data. An average soil moisture storage value of 200 mm was used for the site based on the Ministry of the Environment (MOE) Stormwater Management Planning and Design Manual (MOE, 2003) and site specific knowledge of soil and vegetation conditions.

The calculated actual evapotranspiration (ET) based on the Thornthwaite and Mather monthly water balance model is approximately 586 mm/year, or about 62% of the total precipitation (**Table 1**). The actual evapotranspiration is calculated based on a potential evapotranspiration (PET) and soil-moisture storage withdrawal. Monthly PET is estimated using monthly temperature data and is defined as a water loss from a homogeneous vegetation-covered area that never lacks water (Thornthwaite, 1948; Mather, 1978). The calculated PET for the study area is 611 mm/year, or about 65% of the total precipitation. In general, there is a total soil moisture deficit of 87 mm/year or about 9% in the study area.

The estimated water surplus for the site is about 358 mm/year (38% of total precipitation). The water surplus has two components: a runoff component which is the overland flow that occurs when soil moisture capacity is exceeded, and an infiltration component. Using the method in the MOE SWM manual and MOEE (1995) for guidance, it is estimated that about 67% (240 mm/year) of the surplus runs off with the remaining 33% (118 mm/year) infiltrating. These values are based on the relatively flat topography with micotopographic features, the dominant glaciomarine clay surficial soils, and presence of successional forest/wetland communities. Using a total site area of 225.43 ha, it is estimated that about 266,032 m^3/yr infiltrates and 540,125 m^3/yr runs off the site.

Given the abundance of standing water on the site during the site visit, it is clear that infiltration of groundwater is greatly limited by the site geology. Rather than recharging deeper aquifer units, it is likely that infiltration within the clay soils forms a perched water table on the site that supports water tolerant vegetation communities (Photos 9, 10, and 11 in **Appendix B).** . Only precipitation that falls on the area of exposed or shallow bedrock contributes significant recharge to deeper aquifer units. Precipitation that falls on the area of surficial sands supports a shallow water table and baseflow to Mud Creek.

Site wetland features as identified by Niblett (2014) are not supported by groundwater discharge. These features are supported by direct precipitation and localized surface water runoff. A final Concept Plan showing the proposed land-uses surrounding the vegetation communities would be required to assess the impact of site development on these features, if considerations are being made to maintain any of these features.

Table 1. EUC MUC Site: Pre-Development Water Budget

PRE-DEVELOPMENT WATER BALANCE (mm)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**YEAR**
Precipitation (P)	65.4	54.3	64.4	74.5	80.3	92.8	91.9	85.5	90.1	86.1	81.9	76.4	943.6
Temperature (T)	-10.3	-8.1	-2.3	6.3	13.3	18.5	21.0	19.8	15.0	8.0	1.5	-6.2	6.4
Potential Evapotranspiration (PET)	0	0	0	32	83	120	139	121	77	35	5	0	611
P minus PET	65	54	64	42	-2	-27	-47	-35	14	51	77	76	333
Change in Soil Moisture Storage	0	0	0	0	-2	-25	-38	-22	87	0	0	0	0
Soil Moisture Storage	200	200	200	200	198	173	135	113	200	200	200	200	-
Actual Evapotranspiration (AET)	0	0	0	32	82	118	130	108	77	35	5	0	586
Soil Moisture Deficit (mm)	0	0	0	0	-2	-25	-38	-22	0	0	0	0	-87
Surplus (P-AET)	**65**	**54**	**64**	**42**	**-2**	**-25**	**-38**	**-22**	**14**	**51**	**77**	**76**	**358**
PARTITIONING BETWEEN INFILTRATION AND RUNOFF													
Soil Factor	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Slope Factor	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Vegetation Factor	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Infiltration Coefficient	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**	**0.33**
Runoff Coefficient	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**	**0.67**
WATER BUDGET													
Potential Infiltration (mm)	**22**	**18**	**21**	**14**	**-1**	**-8**	**-13**	**-7**	**4**	**17**	**25**	**25**	**118**
Potential Runoff (mm)	**44**	**36**	**43**	**28**	**-1**	**-17**	**-25**	**-15**	**9**	**34**	**52**	**51**	**240**
Eastern Urban Community Site Area (m^2)	**2,254,300**												
Potential Infiltration (m^3)	**48,652**	**40,395**	**47,908**	**31,350**	**-1,488**	**-18,598**	**-28,269**	**-16,366**	**10,075**	**38,132**	**56,835**	**56,835**	**266,032**
Potential Runoff (m^3)	**98,779**	**82,014**	**97,269**	**63,650**	**-3,021**	**-37,760**	**-57,394**	**-33,228**	**20,455**	**77,420**	**116,548**	**115,393**	**540,125**

4.2 Mud Creek Watershed

The pre-development water budget for the Mud Creek watershed is presented in **Table 2**. Under the pre-development condition, the average annual infiltration rate within the watershed is 127 mm/a and the average annual runoff is 237 mm/a. It is estimated that 105,011 m^3/a infiltrates and 196,137 m^3/a becomes runoff within the Mud Creek watershed.

As previously discussed, the area of exposed bedrock (including areas with thin drift) is considered a SGRA and HVA. The water budget assessment estimates that 18,984 m^3/yr infiltrates within this area (**Table 2**). While this infiltration does not directly support the function of a natural feature or significant aquifer on the site, it does support the overall water balance for the watershed. Consideration should be given to maintaining the pre-development infiltration rate in this area post-development through the placement of less impactful land-uses (i.e., parkland, schools, buffers) or through the use of Low Impact Development (LID) measures (**Figure 3**). The quality of infiltrating water must be considered when designing infiltration measures on exposed bedrock or areas of thin overburden.

The small area of surficial sand at the southwest corner of the site is estimated to infiltrate 11,384 m^3/yr of precipitation. Within the site boundary, groundwater flow within this sand aquifer is expected to follow topography and flow westwards towards the EUC SWM Pond 1. These surficial sands may provide some groundwater discharge to the EUC SWM Pond 1 and the drainage channels leading into it (Ditch 2 – **Figure 2**). Baseflow to Mud Creek is supported by infiltration that occurs on the property to the south of the site.

The site, within the Mud Creek watershed, is characterized by surface water runoff and a perched water table. Changes in infiltration are therefore not considered to have an adverse impact to the water budget or natural features within the watershed (outside of the SGRA). Changes to surface hydrology and runoff, however, will need to be assessed under a post-development scenario.

4.3 McKinnon Creek Watershed

The pre-development water budget for the McKinnon Creek watershed is presented in **Table 3**. Under the pre-development condition, the average annual infiltration rate within the watershed is 119 mm/a and the average annual runoff is 243 mm/a. It is estimated that 161,446 m^3/a infiltrates and 330,306 m^3/a becomes runoff within the McKinnon Creek watershed.

Similar to Mud Creek, the area of exposed bedrock within the McKinnon Creek watershed is considered a SGRA and HVA. The water budget assessment estimates that 27,840 m^3/yr infiltrates within this area (**Table 3**). While this infiltration does not directly support the function of a natural feature or significant aquifer on the site, it does support the overall water balance for the watershed. Consideration should be given to maintaining the pre-development infiltration rate in this area post-development through the placement of less impactful land-uses in this area (i.e., parkland, schools, buffers) or through the use of LID measures (**Figure 3**). The quality of the infiltrating water must also be considered when designing infiltration measures.

Table 2. Mud Creek Pre-Development Water Budget

Unit	Geology	Vegetation	Area (m^2)	Surplus (mm/a)	Topography Factor	Soil Factor	Vegetation Factor	Recharge Coefficient	Runoff Coefficient	Infiltration Total (mm/a)	Runoff Total (mm/a)	Infiltration Total (m^3/a)	Runoff Total (m^3/a)
1	Clay	Field/ Shrub	695,000	358	0.15	0.05	0.10	0.30	0.70	107	251	74,643	174,167
2	Sand	Field/ Shrub	54,900	377	0.15	0.30	0.10	0.55	0.45	207	170	11,384	9,314
3	Bedrock	Shrub /Tree	79,100	400	0.20	0.30	0.10	0.60	0.40	240	160	18,984	12,656
	Totals		829,000	363	0.15	0.09	0.10	0.35	0.65	127	237	105,011	196,137

Table 3. McKinnon Creek Pre-Development Water Budget

Unit	Geology	Vegetation	Area (m^2)	Surplus (mm/a)	Topography Factor	Soil Factor	Vegetation Factor	Recharge Coefficient	Runoff Coefficient	Infiltration Total (mm/a)	Runoff Total (mm/a)	Infiltration Total (m^3/a)	Runoff Total (m^3/a)
1	Clay	Field/ Shrub	1,244,000	358	0.15	0.05	0.10	0.30	0.70	107	251	133,606	311,746
2	Bedrock	Shrub /Tree	116,000	400	0.20	0.30	0.10	0.60	0.40	240	160	27,840	18,560
	Totals		1,360,000	362	0.15	0.07	0.10	0.33	0.67	119	243	161,446	330,306

Table 4. Bilberry Creek Pre-Development Water Budget

Unit	Geology	Vegetation	Area (m^2)	Surplus (mm/a)	Topography Factor	Soil Factor	Vegetation Factor	Recharge Coefficient	Runoff Coefficient	Infiltration Total (mm/a)	Runoff Total (mm/a)	Infiltration Total (m^3/a)	Runoff Total (m^3/a)
1	Clay	Field/ Shrub	65,300	358	0.15	0.05	0.10	0.30	0.70	107	251	7,013	16,364
	Totals		65,300	358	0.15	0.05	0.10	0.30	0.70	107	251	7,013	16,364

Based on surface water flow and temperature data collected by JFSA, McKinnon Creek does not appear to be supported by groundwater discharge. This feature is supported by surface water runoff from the site and from lands to the south and east of the site.

The site, within the McKinnon Creek watershed, is characterized by surface water runoff and a perched water table, and changes in infiltration are therefore not considered to have an adverse impact (outside of the SGRA). Changes to surface hydrology and runoff, however, will need to be assessed under a post-development scenario.

4.4 Bilberry Creek Watershed

The pre-development water budget for the Bilberry Creek watershed is presented in **Table 4**. Under the pre-development condition, the average annual infiltration rate within the watershed is 107 mm/a and the average annual runoff is 251 mm/a. It is estimated that 7,013 m^3/a infiltrates and 16,364 m^3/a becomes runoff within the Bilberry Creek watershed.

Within the site boundary, the Bilberry Creek watershed does not host any significant recharge areas or natural features that would rely on infiltration or runoff. Based on surface water flow and temperature data collected by JFSA, Bilberry Creek does not appear to be supported by groundwater discharge. This feature is supported by surface water runoff from the site and from lands to the south and east of the site.

5 Hydrogeological Considerations for Concept Plans

The results of this assessment can be used to provide input into Concept Plan Alternatives for the site that take into account the pre-development distribution of infiltration and runoff. The objective of this is to identify the contributing drainage areas and volumes for natural features, SGRAs and watercourses, and consider the possibility of placing less impactful land uses (such as parks, greenspaces, schools, and stormwater management facilities) near natural features. Alternatively, the use of LID mitigation measures, where practical, can be used to balance the pre-to-post water budget.

Figure 3 summarizes the hydrogeological considerations based on the results of this water budget assessment. The development considerations (with matching numbers shown on **Figure 3**) are as follows:

1. The area of shallow drift over bedrock is considered a SGRA and HVA, as the surficial sediments do not significantly inhibit infiltration. While infiltration in this area does not directly support the function of a natural feature or significant aquifer on the site, it does support the overall water balance for the Mud Creek and McKinnon Creek watersheds. The quality of infiltrating water must be considered if future infiltration measures are proposed.

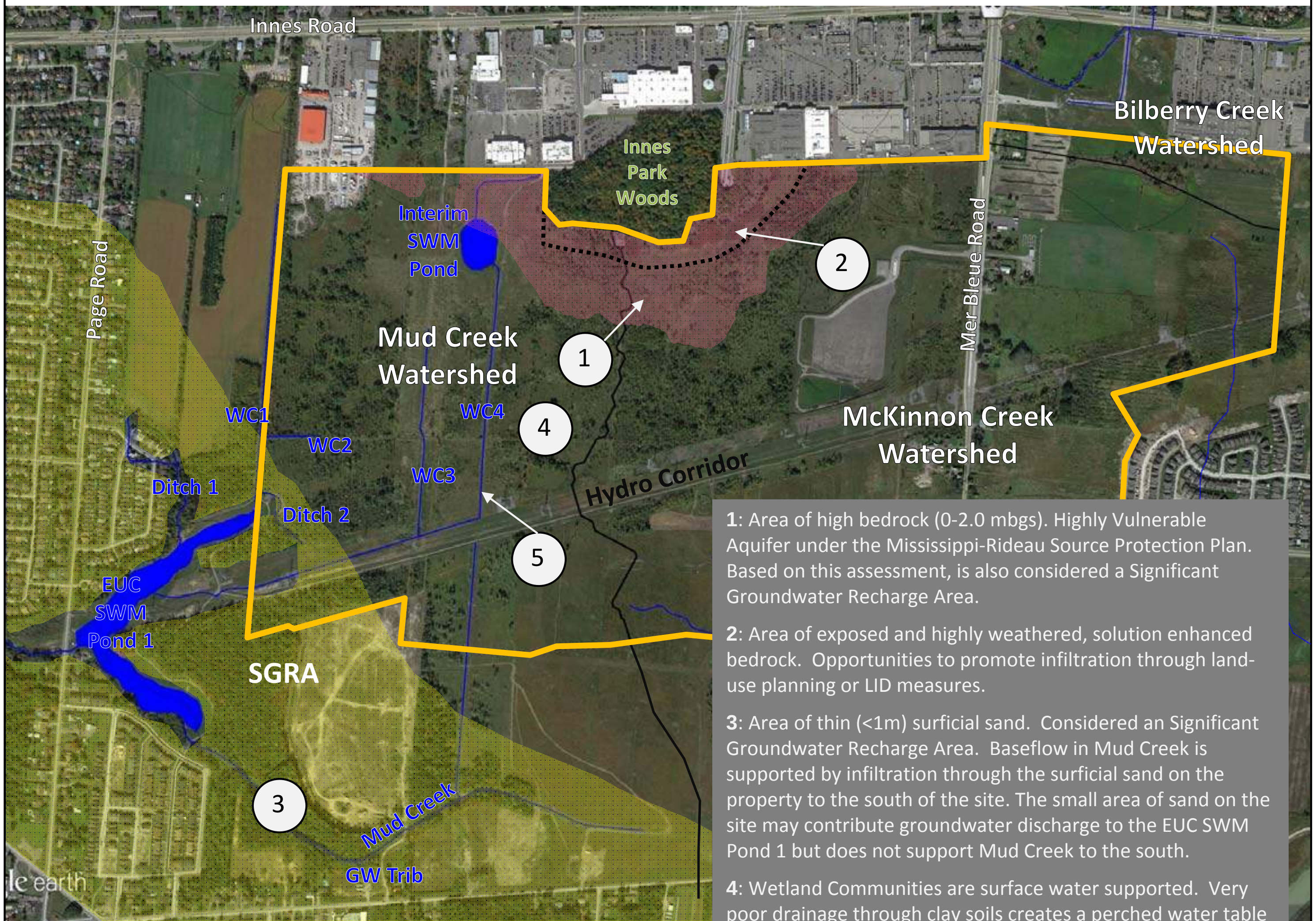
2. The exposed bedrock areas immediately south and east of the Innes Park Woods demonstrates considerable solution enhanced weathering. Consideration should be given to maintaining the pre-development infiltration rate in this area post-development though the placement of less

impactful land-uses (i.e., parks, schools, buffers) or through the use of LID measures. The quality of infiltrating water must be considered if future infiltration measures are proposed.

3. The area of surficial sand, located primarily south of the site, is considered a SGRA. Baseflow in Mud Creek is supported by infiltration through this sand aquifer on the property to the south of the EUC MUC site. The small area of sand on the EUC MUC site may provide some groundwater discharge to the EUC SWM Pond 1, but does not contribute to baseflow in Mud Creek. No mitigation for changes to infiltration are recommended for this area.

4. Wetland communities on the site are supported by direct precipitation and localized surface water runoff. These features are not supported by groundwater discharge. Poor drainage through the clay soils creates a perched water table condition that holds water and has allowed for the development of water tolerant vegetation communities. These wetland communities are not designated natural heritage features.

5. Flow within the drainage features on site is supported by surface water runoff and not by groundwater discharge. The majority of these features were artificially created to remove standing water from the site. Baseflow in Mud Creek is supported through groundwater discharge from the surficial sands located to the south of the site and will not be affected from site development.



1: Area of high bedrock (0-2.0 mbgs). Highly Vulnerable Aquifer under the Mississippi-Rideau Source Protection Plan. Based on this assessment, is also considered a Significant Groundwater Recharge Area.

2: Area of exposed and highly weathered, solution enhanced bedrock. Opportunities to promote infiltration through land-use planning or LID measures.

3: Area of thin (<1m) surficial sand. Considered an Significant Groundwater Recharge Area. Baseflow in Mud Creek is supported by infiltration through the surficial sand on the property to the south of the site. The small area of sand on the site may contribute groundwater discharge to the EUC SWM Pond 1 but does not support Mud Creek to the south.

4: Wetland Communities are surface water supported. Very poor drainage through clay soils creates a perched water table and standing water conditions.

5: Flow in agricultural drains is supported by surface water runoff.

Legend

- Site Boundary
- Watershed Drainage Area
- Drainage Feature

Base mapping from Google Earth (2014).

Drainage Features modified from OBM Mapping based on site specific observations.

N

600 m

Hydrogeological Considerations

Eastern Urban Community Hydrogeology Study
December 2014
PN# 14151

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

Figure 3

Appendix A

Surface Water Field Measurements

(November 17 and 18, 2014)

(from J.F. Sabourin and Associates Ltd.)

LEGEND :

- - - - EUC MUC SITE BOUNDARY

—— DITCHES WHERE MEASUREMENTS WERE TAKEN

SCALE :

0 150 300 450 600 m

N

J.F. Sabourin & Associates Inc.
WATER RESOURCES AND ENVIRONMENTAL CONSULTANTS
OTTAWA (613) 836-3884
GATINEAU (819) 243-6858

CLIENT :

DSEL
david schaeffer engineering ltd
SMART SUBDIVISIONS™

PROJECT :

East Urban Community
Water Balance

CB	Dec 11, 2014	PRELIMINARY	0
BY	DATE	DESCRIPTION	REV.

NOVEMBER 17 + 18, 2014 FIELD MEASUREMENTS CHEMISTRY, FLOW & DEPTH

FIGURE 2

DESIGNED:	
DRAWN:	CB
VERIFIED:	
APPROVED:	

DRAWING REF.	DATE	PROJECT No.
1247-14\Design\CAD\ JFSA Field Work.dwg	Dec/14	1247-14

Appendix B

Photograph Log

Photograph 1 ↑. Lindsay Formation Bedrock. Solution enhanced fracture at the end of Belcourt Blvd. Note the elevation drop from the parking lot. This is believed to correspond to a bedrock escarpment.

Photograph 2 ↑
Lindsay Formation Bedrock. Solution enhanced fracture.

Photograph 3 ↑
Lindsay Formation Bedrock.

Photograph 4 ↑
Lindsay Formation Bedrock within the drainage channel leading into the Interim SWM Pond.

Photograph 5 ↑
Close up of side wall in groundwater fed channel. Note the 1m thick layer of fine sand over clay.

Photograph 6 ↑
GW Trib (Figure 1) Mud Creek. Groundwater fed cut channel flowing towards Mud Creek.

Photograph 7 ↑
Mud Creek looking west.

Photograph 8 ↑
WC3 surface water flow station.

Photograph 9 ↑
Ponded water on the road leading north towards the Interim SWM Pond. WC4 is on the left.

Photograph 10 ↑
Typical Cattail Shallow Marsh Community. Water is ponded at the base of the grasses.

Photograph 11 ↑
Ponded water at the base of a dog wood tree.

Photograph 12 ↑
Typical Ash Mineral Thicket Swamp Community. Water is ponded around the low shrubs.

Photograph 13 ↑
Ponded surface water condition within the McKinnon Creek watershed

1. Introduction

Palmer Environmental Consulting Group Inc. (PECG) and J.F. Sabourin and Associates Inc. (JFSA) were retained by the Richcraft Group of Companies to conduct infiltration and percolation testing at the Eastern Urban Community (EUC) site. Infiltration testing characterizes the rate at which water enters the ground surface, and percolation testing characterizes the rate of water movement beneath the ground surface, but above the water table.

The infiltration and percolation testing were planned and conducted with consideration of: the October 30, 2017 EUC Land Use Plan; the Low Impact Development Stormwater Management Planning and Design Guide, Appendix C – Site Evaluation and Soil Testing Protocol for Stormwater Infiltration (TRCA/CVC, 2010); and the site specific surficial geology conditions as described in PECG (2014). At present, the site is dominated by active and remnant agricultural land-use, with isolated areas of deciduous forest and thicket swamp communities. The proposed development plan for the site includes a mixed use urban community consisting of residential, employment, industrial and supporting land-uses.

2. Site Geology

The EUC site is located within the Ottawa Valley Clay Plain physiographic region (Chapman and Putman, 1984). This region is characterized by relatively thick surficial deposits of marine derived clay, silt, and silty clay deposited within the former Champlain Sea basin. Locally, these deposits are known as the Champlain Sea clay or Leda clay.

Consistent with regional conditions, the surficial materials at the EUC site largely consist of low permeability marine derived clay and silt, and small areas of thin surficial marine sand, overlying Paleozoic bedrock. The surficial materials were confirmed through shallow hand auguring completed as part of the infiltration testing, which generally indicated fine textured marine deposits of silt and clay, with minor sand and gravel. While Ontario Geological Survey (OGS) mapping indicates the presence of coarse textured glaciomarine deposits of sand, gravel, and minor silt and clay along the southwestern edge of the site, these soils were not encountered at the EUC infiltration testing sites.

Where present, it is expected that the overburden thickness at the site ranges from 1 m to 10 m. Regions of shallow or exposed Paleozoic bedrock outcrops from the Middle Ordovician Bobcaygeon and Lindsay Formations are present in the northern portion of the study area. This bedrock is characterized as argillaceous, nodular, very fossiliferous, fine to coarse grained limestone of the Lindsay Formation (Johnson et al., 1992). A noticeable bedrock escarpment is present at the contact between the two formations, as are areas of solution enhanced porosity.

3. Testing equipment, dates and locations

The infiltration testing sites were selected to obtain infiltration and percolation information focused on the different soil types (sand, marine clay and silty clay, and thin clay over bedrock), within both watersheds (Mud Creek and McKinnon's Creek), and to provide a good spatial distribution across the site. The 12 potential testing locations are shown on **Figure 1**.

Infiltration testing was conducted using a Dual-Head Infiltrometer at the surface, which measures field saturated hydraulic conductivity (k_{fs}). Deeper percolation testing was conducted in the shallow sub-surface (maximum depth 0.8 metres below ground surface (mbgs)), using a Guelph Permeameter (GP), which can be used to calculate field saturated hydraulic conductivity (K_{fs}). The TRCA/CVC infiltration testing guidance lists the Guelph Permeameter explicitly and recommends that infiltration tests be carried out with a permeameter or infiltrometer to determine the K_{fs}, rather than using percolation tests or grain-size analyses.

3.1 Infiltration testing (at surface)

Infiltration testing was conducted to quantify the pre-development (existing conditions) surface infiltration rates. This information can be used to quantify the proportion of effective precipitation that could soak into the soils versus running off directly to nearby watercourses. Effective precipitation is the portion of precipitation that reaches the ground surface, i.e. the portion that is not intercepted. Therefore, these surface infiltration measurements and observations could inform hydrologic modelling and water budget calculations for the existing conditions.

Infiltration testing was conducted at the ground surface using a Dual-Head infiltrometer (DHI), shown on **Figures 2 and 3**. The DHI was developed by Meter Environment, following theory described in Reynolds and Elrick (1990). The DHI setup consists of a ring inserted into the soil and a closed chamber connected to a water supply, wherein water is ponded on the soil and air pressure is used to create two different pressure heads. The instrument maintains water levels, measures inflow rate and performs the calculations to determine field saturated hydraulic conductivity (K_{fs}).

Due to field constraints, infiltration measurements using the DHI were collected at 7 sites (sites 1, 2, 3, 5, 6, 7, and 9), and field observations and/or a falling head infiltration test were conducted at the remaining sites (sites 4, 8, 10, 11 and 12). The breadth of the surface infiltration and subsurface percolation testing, combined with the field observations, are sufficient to characterize the runoff response and surface water/groundwater interactions at the EUC site despite the site conditions and limitations observed at some locations at the time of the testing.

Figure 1: Infiltration and percolation measurement site locations and EUC site boundary

The falling head tests were conducted using a 20 cm high, 11 cm diameter steel cylinder, Single Ring (SR) that was inserted into the soil, see **Figure 4**. Water was poured into the cylinder and the rate of fall of the water level in the cylinder over time was recorded to provide an infiltration rate estimate.

Figure 2: Dual-Head Infiltrometer Setup, control unit shown on the left, flexible water reservoir near the bottom and DHI unit setup on the right side of the image.

Figure 3: DHI cylinder installed at the ground surface (cylinder penetrates to 5 cm deep), prior to attaching the top of the unit and starting a test.

Figure 4: Single Ring Infiltrometer Setup, 11 cm diameter steel ring shown on the left of the image, failing head test in progress with water near the ring top.

3.2 Percolation testing (shallow sub-surface)

In addition to infiltration testing, percolation testing was completed to test the permeability of subsurface soils up to 0.8 mbgs to determine field saturated hydraulic conductivity (k_{fs}). Combined with the results from infiltration testing, this information provides data to support the site hydrologic modelling, water budget calculations for the existing conditions, and to provide guidance on the use of LID measures at the site.

Percolation testing was conducted between depths of 0.1 mbgs and 0.8 mbgs using a Guelph Permeameter (GP), shown on **Figure 5**. This method involves measuring the steady state rate of percolation within a 2-3/8" diameter auger hole, through maintaining a constant hydraulic head pressure (H) within the GP water reservoir (Reynolds and Elrick, 1986). Once the head pressure is applied, the rate of fall within the reservoir is monitored until a steady state of change (r) is achieved. This value is used to determine the field saturated hydraulic conductivity (K_{fs}) by applying it to the Reynolds and Elrick (1985) equations.

Similar to the DHI infiltration testing, site conditions and limitations restricted the GP testing that could be completed. GP percolation measurements were collected at 10 sites (sites 1, 2, 3, 5, 6, 7, 8, 9, 10, and 12), although the results obtained at site 10 were not usable due to site conditions (i.e. high water table). The testing that was completed allows for a useful characterization of the percolation rates at varying depths on the EUC site.

Figure 5: Guelph Permeameter setup in the field.
Flexible water reservoir and hand auger in the foreground.

3.3 Test locations

Twelve sites were identified for infiltration/percolation testing. The overall goal of the field testing program was to collect sufficient surface infiltration and sub-surface percolation rates to describe the overall behaviour of the infiltration of effective precipitation on-site. That is, to develop a quantitative model of the overall soil-water interactions describing how rainfall that reaches that ground would be partitioned into runoff or infiltration, and to estimate the extent to which infiltration contributes to the baseflow of natural surface water features and/or recharge of deeper aquifers.

The field work was conducted over six dates; a JFSA field crew conducted DHI tests on November 21, a joint JFSA and PECG field crew conducted DHI and GP tests on November 28 and 29 and a JFSA field crew conducted GP and SR tests on November 30 and December 1 and 4, 2017. In total, GP readings were taken at 10 sites, DHI readings were taken at 7 sites and SR readings were taken at 3 sites. At some sites, multiple GP readings were collected at different depths to quantify the percolation rates through both the upper topsoil unit and the underlying marine clay soils.

The sites where field observations were made, and infiltration and percolation measurements were collected are shown in **Figure 1**. The sites are numbered 1 through 12, and subscript letters (ex. Site 11A) are used to indicate cases where tests were not conducted immediately adjacent to one another due to field conditions. Typically, all tests at a given site were conducted within a few metres of each other.

4. Test Results

Tables 1 and 2 below present the infiltration and percolation rates measured at the EUC sites. The results have been split into two tables based on the underlying geologic material. Table 1 presents the measurement results for the sites underlain by thicker marine clay deposits, and Table 2 presents the results where the marine clay is thinner and bedrock is interpreted to be within approximately 1 m of surface.

The testing results have also been subdivided based on soil stratigraphy and testing method. Based on hand augering results, the upper 20 cm generally consisted of unsaturated silty clay topsoil, underlain by marine clay, which was variably saturated based on site specific conditions. Table 1 and Table 2 summarize the stratigraphic unit tested (i.e., Topsoil or Marine Clay), depth, field saturated hydraulic conductivity (k_{fs}), rate of infiltration or percolation, and the date of testing. In total, GP readings were taken at 10 sites, DHI readings were taken at 7 sites and SR readings were taken at 3 sites.

The collection of percolation data below 0.2 m was limited on the site due to the presence of a high perched water table, estimated to be found between 0.15 and 0.30 m across the site. Field testing methods cannot collect infiltration or percolation data from below the water table, and many percolation tests within the grey marine clay yielded percolation rates of zero (unmeasurable). To achieve measurable results, percolation measurements were generally collected in the soil unit above the grey marine clay and above the perched water table. Deeper auger holes were dug at each location to identify the perched water table depth to plan testing locations. The estimated depth of the perched water table at each site is presented on Tables 1 and 2.

Table 1: Infiltration and percolation test results for sites underlain by the marine clay unit

Site #	Test depth and parameter measured	Topsoil infiltration (DHI or SR)	Topsoil percolation (~0-20 cm) (GP)	Deeper Percolation (~ 20 - 80 cm) (GP)	Date of tests (dd/mm/yyyy)
Site 1	Depth (cm)	0	20	water table at 30	28/11/2017
	K_{fs} (m/sec)	$1.78x10^{-5}$	$6.24x10^{-6}$	0	
	Infiltration / Percolation (mm/hr)	100	76	0	
Site 2	Depth (cm)	0	-	20 / 30 / 47	28/11/2017
	K_{fs} (m/sec)	$2.85x10^{-4}$	-	$1.63x10^{-9}$ / $8.04x10^{-10}$ /0	
	Infiltration / Percolation (mm/hr)	210	-	8/ 7 / 0	
Site 3	Depth (cm)	0	10	water table at 20	28/11/2017
	K_{fs} (m/sec)	$1.32x10^{-4}$	$5.74x10^{-8}$	0	
	Infiltration / Percolation (mm/hr)	171	22	0	
Site 6	Depth (cm)	0	15	water table at 20	29/11/2017
	K_{fs} (m/sec)	$1.55x10^{-4}$	$8.20x10^{-8}$	0	
	Infiltration / Percolation (mm/hr)	178	24	0	
Site 7 ***	Depth (cm)	0	10	water table at 15	01/12/2017 21/11/2017
	K_{fs} (m/sec)	$4.61x10^{-5}$	$9.23x10^{-9}$	0	
	Infiltration / Percolation (mm/hr)	129	13	0	
Site 8 ****	Depth (cm)	0	-	30 / 35	30/11/2017
	K_{fs} (m/sec)	$1x10^{-4}$	-	$1.53x10^{-7}$ / $2.83x10^{-7}$	
	Infiltration / Percolation (mm/hr)	159*	-	28 / 33	
Site 10	Depth (cm)	N/A	-	water table at 20	29/11/2017
	K_{fs} (m/sec)	N/A	-	0	
	Infiltration / Percolation (mm/hr)	N/A	-	0	
Site 11	Depth (cm)	0	-	Water table at 10	04/12/2017
	K_{fs} (m/sec)	$1x10^{-9}$	-	0	
	Infiltration / Percolation (mm/hr)	7**	-	0	
Site 12 *****	Depth (cm)	N/A	20	80	30/11/2017
	K_{fs} (m/sec)	N/A	$3.42x10^{-8}$	$2.82x10^{-9}$	
	Infiltration / Percolation (mm/hr)	N/A	19	10	
	Mean Infiltration/ Percolation (mm/hr) *high and low sites removed*	147	21.7	2.8	

**Infiltration rate measured with single ring falling head test, conditions did not allow for DHI.*

***Infiltration rate measured with single ring falling head test, the water table was at or near surface and may have influenced the measurement.*

****Infiltration rate also measured with single ring falling head test, SR test yielded a constant falling head rate of 66 mm/hr, which equates approximately to K_{fs} = 1x10^{-5} m/sec and an infiltration rate of 86 mm/hr (CVC/TRCA, 2011).*

*****GP tests completed at Site 8 are within more permeable sandy clay material, not marine clay.*

******The water table at Site 12 was observed lower than typically found across the site due to the presence of overlying fill material.*

N/A - The specific test was not performed due to time constraints and/or field conditions. Measurements from surrounding sites can be extrapolated to describe the soil-water interactions at the site.

Note that no tests were performed at Site 4 as the site had been cleared prior to the field work. The surface conditions were therefore not representative of the 'existing' conditions. Measurements from surrounding sites can be extrapolated to describe the soil-water interactions in the northwest portion of the EUC site.

Infiltration and percolation rates were estimated from the field saturated hydraulic conductivity (k_{fs}) using the relationship from Figure C1 (TRCA/CVC, 2010).

Table 2: Infiltration and percolation test results for sites with near surface paleozoic bedrock (< 1 mbgs)

Site #	Test depth and parameter measured	Topsoil infiltration (DHI or SR)	Topsoil percolation (GP)	Deeper Percolation (GP)	Date of tests (dd/mm/yyyy)
Site 5	Depth (cm)	0	10	water table @ 15	29/11/2017
	K_{fs} (m/sec)	High*	5.39x10^{-8}	0	
	Infiltration / Percolation (mm/hr)		21	0	
Site 9	Depth (cm)	0	20	water table @ 35	29/11/2017
	K_{fs} (m/sec)	High*	7.52x10^{-8}	0	
	Infiltration / Percolation (mm/hr)		23	0	
Mean Infiltration/ Percolation (mm/hr)		High*	22	-	

**The infiltration rate out of the DHI ring was too high to maintain a steady pressure head.*

Observations at sites 4, 10 and 12, in combination with infiltration measurements from surrounding sites provide context for expected surface infiltration behavior at those locations. The area around site 4 had been cleared prior to the field work, so infiltration testing would not have been representative of existing conditions. The topsoil texture and infiltration rates measured at sites 1 and 3 in particular, and across the EUC site in general, suggest that the existing conditions infiltration rate at site 4 would have been relatively high. Field constraints prevented DHI measurements at site 12, however the topsoil material was a silty clay with visible pores. Visually, the topsoil in this area had fewer pores than some other sites and may have an infiltration rate closer to the low end of the measurement range from other sites. At Site 10, the auger results indicated low permeability, saturated marine clay soils within the upper 40 cm, as well as high water table conditions which was observed at approximately 0.05 to 0.10 mbgs. An infiltration measurement was collected with the SR at site 11, though that site was characterized by a very shallow or at surface water table during the field visit. During lower water table conditions, the surface infiltration rate is likely higher than the measured 7 mm/hr value.

5. Discussion and Conclusions

Surface infiltration and shallow subsurface (0.1 mbgs to 0.8 mbgs) percolation rates were collected in the fall of 2017 within the EUC site boundary. Overall the EUC site has two major geologic distinctions, a zone of shallow bedrock in the north comprising about 3% of the total site, and a larger zone, 97%, which is underlain by marine clay.

Surface water was observed ponded in local depressions in various locations across the site, and saturated conditions were found within 10 cm to 30 cm below ground level in shallow auger holes dug across the site in the clay zones, though variability was noted with saturated conditions encountered at greater depths in some locations. In areas where surface infiltration was measured with the DHI, the field saturated hydraulic conductivity ranged from 100 mm/hr to 210 mm/hr. Generally, these are relatively high infiltration rates that suggest the surface infiltration rate is sufficient to capture all or most of the rainfall from frequent storms (25 mm total volume and less). There was one measurement of low surface infiltration rate, 7 mm/hr at site 11 using the SR falling head test. Based on field observations, the high water table may have influenced this test. Overall, based on these field test results, the majority of surface soils within the EUC boundary have high surface infiltration rates, described by the range of results listed above. To provide a representative average surface infiltration value, the highest and lowest values were omitted to provide a more representative average rate. In doing so, the mean surface infiltration rate is 147 mm/hr. Surface runoff will occur when the rainfall exceeds either: the surface infiltration rate, or the topsoil percolation rate (following wetting of the soil) or when the topsoil layer becomes saturated. Surface runoff will drain to nearby ditches and eventually to Mud Creek or McKinnon's Creek.

In contrast, the percolation rates measured in the lower topsoil and underlying marine clay were generally low, and highly influenced by the perched water table depth. The percolation rates in the deeper grey coloured clay unit ranged from 0 mm/hr (immeasurable) to approximately 24 mm/hr. This is representative of the low permeability clay which restricts groundwater recharge. The sites with zero percolation were due to a shallow perched water table. Percolation rates measured within the overlying mottled grey/brown upper clayey silt and clayey silt topsoil, generally found between 0.0 and 0.2 mbgs, varied with sediment composition and depth to the perched water table, but ranged between 0 mm/hr and 76 mm/hr.

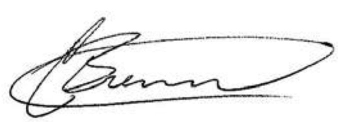
To provide a representative average percolation value, the highest and lowest values were omitted to provide more representative average percolation rates for each unit. In doing so, the mean percolation rate within the shallow mottled grey/brown upper clayey silt and clayey silt topsoil unit is 21.7 mm/hr, and 2.8 mm/hr within the deeper grey marine clay. It is important to note that once the perched water table is reached at depths that range from approximately 0.15 to 0.40 m, the percolation rate drops to zero and water movement is now controlled by saturated phase hydraulic conductivity (K) and hydraulic gradients. No infiltration or percolation of precipitation will occur under these conditions, although groundwater recharge will still occur albeit limited by the low hydraulic conductivity estimated at 10^{-9} m/s or lower. A unit of slightly higher permeability sand and sandy clay was identified overlying the marine clay at Site 8. Based on the two tests performed at this test location, the average percolation rate of the sandy clay unit is approximately 31 mm/hr. This unit is discontinuous across the site as it was not encountered in any other auger hole.

Therefore, while water can easily seep into the topsoil layer, the vertical movement is restricted by the low permeability of the marine clay soils or perched water table. Here, a perched water table is present and lateral groundwater flow dominates. Shallow groundwater is directed to nearby ditches and eventually to Mud Creek or McKinnon's Creek as baseflow. As such, in these areas the existing water that seeps into the surface layer would eventually be transpired by plants or be detained within the surface soil layer. While the field results do not preclude infiltration measures at all locations, the potential infiltration volumes would be limited due to the low permeability of the clay layer and the high water table. Therefore, considering the existing hydraulic behavior of water at the site, future water balance measures should focus on detention, storage, filtration, and if feasible, evaporation.

Where bedrock is exposed at surface or near the surface, the majority of precipitation will infiltrate (estimated at 80-90%) along solution enhanced fractures. Infiltration along these fractures recharges the deeper water table below the influence of the marine clay. As shown in PECG (2014), deep groundwater flow is to the north, towards the Ottawa River.

6. Signatures

This report was prepared, reviewed and approved by the undersigned:



Surface water characterization and
infiltration test interpretation.

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Subsurface characterization and
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GRADING PLAN

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SCALE	1:4000
DATE:	OCTOBER 2018
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