MEMORANDUM

MORRISON HERSHFIELD

TO:	Dr. Ranjit Perera President Humanics Institute	**FROM:**	Noah Chauvin, EIT. and James Fookes, P.Eng.
		PROJECT No.:	210647100
Subject:	Humanics Sanctuary & Sculpture Park- Ottawa Site Plan Development Stormwater Management Design Brief	**DATE:**	November 22, 2021 R1: April 28, 2023
		REVISION:	1

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1 Introduction

This memorandum is part of the Site Plan application amendment for D07-12-16-0081, the memo gives an overview of the new stormwater management/drainage approach and measures for the development of 3400 Old Montreal Road, East of Ottawa. The proposed site development includes the 3 buildings, a pavilion and a lodge as well as an access route and parking areas. A site plan agreement based on an old Site Plan has been previously submitted and signed by the City of Ottawa.

Figure 2 shows the proposed development and access roads/parking area locations and layout. Proposed stormwater management/drainage measures for the new development consists of a Low Impact Development (LID) Treatment Train Approach which includes a series of grass swales, vegetated filter strips, and a bioretention feature.

To provide a complete overview of the servicing of the new development, other new components include water servicing from an existing privately operated water well and a septic system, in addition to the enhanced grass swales.

2 Site Description

2.1 Existing Conditions

The site is located on the south side of Old Montreal Road, approximately 440 m west of Beckett's Creek Road as shown on **Figure 1**. The site is zoned Rural Residential 1. The municipal address of the proposed site is 3468 Old Montreal Road (PIN 145340141) and a portion of 3400 Old Montreal Road (PIN 145340140) in the City of Ottawa.

The site is primarily undeveloped with stone dust covered pathways and a number of stone sculptures. There are no permanent buildings on the site, however the owner is using a metal storage container for some landscaping equipment. The owner of the site has also constructed temporary gravel access roads to connect the site to Nirmala Drive and Old Montreal Road. These gravel roads were considered in the existing catchment runoff coefficients. The proposed site is bisected by a hydro corridor with overhead transmission lines mounted on wooden hydro poles which are found at two locations on the subject site. Surrounding properties consist of Old Montreal Road to the north of the property, vacant land to the south (which will become Cumberland Estates Phase 2), a residential property to the east, and vacant woodlots to the west.

3 Proposed Stormwater Management (SWM)

The overarching stormwater management strategy for the development of this site will maintain the existing drainage patterns to minimize the impacts to the Ravines which the site drains to today. To mitigate impact on these Ravines, Low Impact Development (LID) solutions such as enhanced grass swales and bioretention facilities for stormwater quality and quantity control are proposed.

The principles and methodologies of the Ministry of the Environment, Conservation and Parks (MECP) Stormwater Management Planning and Design Guidelines (2003) and Toronto Region Conservation Authority/Credit Valley Conservation Authority (TRCA/CVC) Low Impact Development Stormwater Management Planning and Design Guide (2010) were applied for the analysis and design of the drainage and SWM system.

4 Stormwater Approach and Criteria

4.1 Quantity Control

For quantity control, the proposed stormwater management system will reduce the post-development peak flow to the pre-development runoff during storm events up to and including the 100-year event. This approach is consistent with the previous Stormwater Management study completed by EXP and was approved by the City of Ottawa. The required quantity control will be achieved by means of stormwater detention within the Bioretention Pond.

4.2 Pre-Development Flows

A review of the topographic contours based on 2015 City of Ottawa LIDAR data was performed. LIDAR, or Light Detection and Ranging, is a remote sensing method of measuring distances (or ground surface elevation in this case) using lasers. The vertical accuracy of the LIDAR data provided by the City is reported as 8.6 centimetres. The topography of the site reveals that the natural ground slopes northerly towards a ravine located though the middle of the property with a watercourse running west to east. The southern section of the property is divided in two. The southernmost portion slopes towards the south boundary of the property to a smaller ravine located immediately to the south of the hydro corridor. The middle section flows towards the ravine running through the property. The larger deeper ravine has an approximate depth of 13.5m (49m - 62.5m), whereas the smaller shallower ravine is only 7.5m in depth (55m - 62.5m).

In its current condition, the site plan consists of both open fields and wooded areas. Stormwater runoff from the northern portion of the property currently drains in a southerly direction to the deeper ravine which flows from west to east and ultimately flows north to the Ottawa River. The flow path for the southern portion of the property is divided in two. The southernmost section flows down towards the shallower ravine which ultimately flows to Beckett’s Creek. The mid-section flows to the north towards the deeper ravine. Both ravines are deeply incised in the landscape, with runoff from the development area being conveyed to two possible outlets denoted as North Outlet and South Outlet. The site is fairly self-contained and does not receive flows from the surrounding properties. Pre-development and post-development drainage conditions are illustrated in **Figures 1 and 2.**

As control of runoff to pre-development conditions is required, an estimation of peak flows prior to development was necessary. Although the Sanctuary Lands area is 7.52 hectares, only approximately 1.59 hectares is being developed. In order to compare the same pre-development and post-development drainage areas, the northern limit of drainage area was taken as the centre of the ravine, making the total area under consideration to be **3.85 hectares**. In accordance with the City of Ottawa’s Sewer Design Guidelines, the Rational Method was utilized for calculations of the pre-development runoff rates from drainage catchments. **Figure 2** illustrates the pre-development boundaries.

Catchment area OUT1 flow to the north ravine designated as the North Outlet. Catchment areas OUT2.1 and OUT2.2 flow to the south ravine designated as South Outlet.

Using rational method analysis of the existing catchment areas, the pre-development runoff coefficients as well as the pre-development flows during the 5-year and 100-year storm events were determined. Catchment area plans, which illustrate the existing drainage patterns, are included on **Figure 1.**

Total allowable release rate for the site will be **207.16 L/s for 5-year** and **442.91 L/s for 100-year,** this allowable rate is divided between the northern (OUT1) and southern (OUT2.1 & 2.2) outlets as per the below table.

Pre-development catchment parameters and peak flows are summarized in the table below with additional details in **Appendix A.2.**

Table 1 - Pre-Development Peak Flows

Drainage Area	Existing Condition	5-year		100-year	
	Area, A (ha)	Runoff Coefficient, R	Q (L/s)	Runoff Coefficient, R	Q (L/s)
OUT1	3.17	0.23	213.20	0.29	456.71
North Outlet 1 Sub-Total	**3.17**		**213.20**		**456.71**
OUT2.1	0.3248	0.23	21.46	0.29	45.97
OUT2.2	0.3594	0.21	21.64	0.26	46.36
South Outlet 2 Sub-Total	**0.68**		**43.1**		**92.3**
Total	**3.85**		**256.30**		**549.04**

5 Proposed Stormwater System

The proposed stormwater system consists of roadside swales, and culverts as a means to conveying stormwater to the bioretention pond, the flows to the ravines will be controlled to meet pre-development rates. The overall drainage patterns have remained wholly the same as shown on the proposed catchment area plan.

5.1 Post-Development Flows

The post-development catchment areas are illustrated in **Figure 2**.

Most of North catchment area (A1.1 and A1.2) will stay draining uncontrolled to the existing north ravine, no significant changes in the northern pervious area are proposed as most of the development will be within the southern catchment area.

The South Catchment will include the proposed development (A2.1-A2.5) and the Hydro One easement (A2.6) which will be undisturbed. Runoff from the undisturbed area (A2.6) will be released uncontrolled to the southern existing ravine following the existing draining pattern. As for the development (A2.1-A2.5), it will be controlled through proposed swales adjacent to the access route conveying the captured storm water to the proposed Bioretention Pond.

The following table shows the post-development catchments areas, imperviousness and peak flows:

Table 2 - Post-Development Peak Flows

Drainage Area	Sub Area	Proposed Conditions	5-year		100-year	
		Area, A (ha)	Runoff Coefficient, R	Q (L/s)	Runoff Coefficient, R	Q (L/s)
	A1.1	2.15	0.20	124.5	0.25	266.8
	A1.2	0.23	0.45	30.4	0.56	65.0
North Outfall 1 Sub-Total		**2.38**		**154.9**		**331.8**
	A2.1	0.36	0.36	37.8	0.45	81.0
	A2.2	0.14	0.45	18.5	0.57	39.6
	A2.3	0.26	0.37	28.3	0.47	60.7
	A2.4	0.13	0.39	14.2	0.49	30.5
	A2.5	0.07	0.20	3.9	0.25	8.3
	A2.6	0.51	0.22	32.6	0.28	69.9
South Outfall 2 Sub-Total		**1.47**		**135.4**		**290.0**
Total		**3.85**		**290.3**		**621.8**

Complete post-development calculations are provided in **Appendix A.3.**

5.2 Post-Development Peak Flow Reduction and Storage

Considering the existing topography conditions, the site will be discharging to 2 outlets. The north of the site including most of the pre-development north catchment will drain to the same outlet as pre-development conditions. The south of site will include the development area and the rest of the south areas of the site.

Table 3 - Impact on Peak Flows

Drainage Area	5-year Pre-Development Flow	5-year Post-Development Flow	Difference	Percent Change	100-year Pre-Development Flow	100-year Post-Development Flow	Difference
	(L/s)	(L/s)	(L/s)	(%)	(L/s)	(L/s)	(L/s)
North Outlet	213.2	154.9	-58.3	-27.3%	456.7	331.8	-124.9
South Outlet	43.1	135.4	92.3	214.1%	92.3	290.0	197.7
Total	**256.3**	**290.3**	**34.0**	**13.3%**	**549.0**	**621.8**	**72.8**

According to the above table, the north outlet post-development calculated flows are **154.90 L/s for 5-year** and **331.8 L/s for 100-year**. These flows are reduced when compared to pre-development conditions, accordingly no stormwater management solution is needed.

As for the south outfall, calculated post-development flows are **135.4 L/s for 5-year** and **290.0 L/s for 100-year**. The south outlet will have an increase in stormwater runoff as a result of the site development. As such, the peak flows within this catchment area will be reduced by means of retaining storm water in the proposed Bioretention Pond. The South catchment will include an area of **0.51 hectares** that will be left **uncontrolled** resulting in an uncontrolled flow of **32.63 L/s for 5-year** and **69.89 L/s for 100-yr**. As such, the allowable release rate that will be used to control the south part of the site will be **10.5 L/s for 5-year** and **22.4 l/s for 100-year.**

Analysis of the pre- and post-development flows shows that the different in flows for different return periods (5year & 100year) requires a storage **of 93.7 cubic meters for 5 years** and **161.2 cubic meters for 100 years**. The full storage analysis can be found in **Appendix A.4.**

6 Stormwater Quality Control

Stormwater quality protection has been designed to meet the MECP's "Enhanced" standard of 80% Total Suspended Solids (TSS) removal rate prior to discharge to the Ravines.

6.1 Infiltration

A Low Impact Development approach will be taken for this development due to the nature of the site and soil conditions. The SWM design will rely on infiltration to achieve the required quality criteria for this design. To have the information to proceed with this approach an infiltration test was done in site and report was prepared, this report includes design infiltration rates to be used specifically for this site. Refer to the Memo in Appendix for Infiltration Testing. The report used the 2800K1 Guelph Permeameter to provide the design infiltration rate that varies from 52 to 29 mm/hr can be used. Complete results of the infiltration testing are provided in **Appendix B**.

The design of the Bio-retention Pond is to be as per MECP requirements, and the bottom of pond will be minimum 1m above the high groundwater. The bottom of Pond is **62.00**. Based on the geotechnical report prepared by EXP, the current **groundwater** in the area is approximately **58.0 m** which meets the requirements for MECP.

In accordance with TRCA SWM Criteria (2010), Section 7.4: "As a minimum, to achieve the enhance level of water quality control, the LID practice must be sized to provide storage for a minimum 5mm of rainfall."

As mentioned previously the site presented very suitable conditions for LID approach, this was done through proposing side swales that conveys water to a proposed Bioretention pond, this pond will provide the enhanced treatment required for this site. The proposed Bioretention pond will be designed to retain the first **10mm** of stormwater, this is equivalent to **35.5** cubic meters of water that will need to be infiltrated to the soil.

The proposed Bioretention cross section has a **0.75m** wide flat bottom with **3.6:1** side slopes, the elevation of the bottom is at **61.65** and the spill elevation is at **62.55**. The 100-year water level in the pond is 62.25m with a freeboard of **0.3m** between the spill elevation and the adjacent roadway/parking lot. The proposed Bioretention swale can capture a volume up to **161 cubic meters**, at an elevation of **62.55.** To provide the required retention, a **200 mm** diameter outlet pipe equipped with a **152 mm** orifice ICD is proposed at an invert elevation of **61.88**. A volume of **36.7 cubic meters** will be retained with in the Bioretention pond, and an expected time of infiltration will be **7.2 hr** with a rate of **39 mm/hr**. For more detailed calculation refer to **Appendix A.5 and A.6.** A detailed cross section of the proposed bioretention pond is presented in **Figure 3.**

Analysis for the entire site was done based on the drainage area and daily precipitation data (excluding winter months) to establish overflow volume based on measured historical data. The maximum potential infiltration at source (through runoff coefficient) and in the pond was analyzed using pond size and precipitation norms for the area and the overflow was then subtracted. Below table shows a summary for each year, more than 90% of rainwater will infiltrate into soil on site at source or through Bio-retention Pond. The following tables and graph provide a summary of the analysis.

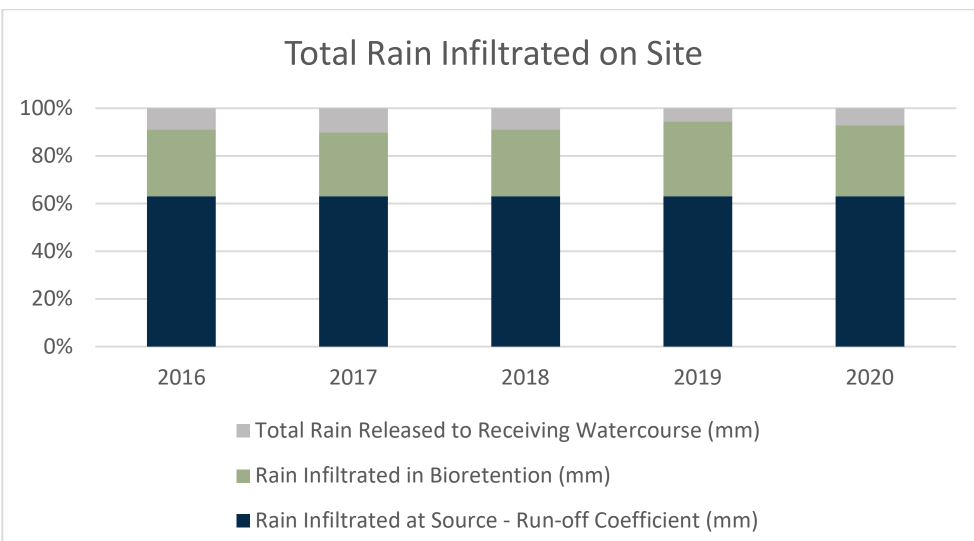
Table 4 - Anticipated Infiltration Volumes based on Historical Rainfall Data

Year	Total rain (mm)	Runoff (m³)	Infiltrated runoff (m³)	Released Volume (m³)	Infiltration %
2016	614	2171	1890	281	87%
2017	925	3271	2991	280	91%
2018	659	2330	2048	282	88%
2019	627	2219	2102	117	95%
2020	586	2074	1946	128	94%

Note: Analysis excludes winter months (Jan - Apr). Winter conditions were excluded from the calculation as it is not possible to identify and model snow, winter rainfall and snow melt with accuracy. Instead, as is common practice, the analysis was completed for the spring, summer and fall period to provide a more accurate representation of the expected percentage of rainfall that will be infiltrated.

Table 5 - Total Rain Infiltration on Site

Year	Total rain (mm)	Rain Infiltrated at Source - Run-off Coefficient (mm)	Rain Infiltrated in Bioretention (mm)	Total Rain Infiltrated (mm)	Total Rain Released to Receiving Watercourse (mm)	Percentage of Rain Infiltrated on Site
2016	614	387	172	559	55	91%
2017	925	583	249	832	93	90%
2018	659	415	186	601	58	91%
2019	627	395	197	593	35	94%
2020	586	369	174	544	43	93%



7 Erosion and Sediment Control during Construction

The contractor shall implement best management practices to provide for protection of the area drainage system and the receiving watercourses during construction activities, as per the Erosion and

Sediment Control Plans included on the design drawings. Refer to Drawing ESC-PH1B prepared by EXP for proposed ESC measures for the site.

8 Conclusions

In conclusion the stormwater management design meets all required servicing constraints and associated design criteria/requirements.

Sincerely,

Morrison Hershfield Limited

LICENSED PROFESSIONAL ENGINEER
J. G. FOOKES
100202820
April 28, 2023
PROVINCE OF ONTARIO

Digitally signed by Noah Chauvin
DN: E=NChauvin@morrisonhershfield.com, CN=Noah Chauvin, OU=Users, OU=Vancouver, OU=Location, DC=mh, DC=local
Date: 2023.04.28 13:57:22-07'00'

James Fookes, P.Eng.

Civil Engineer

Noah Chauvin, EIT

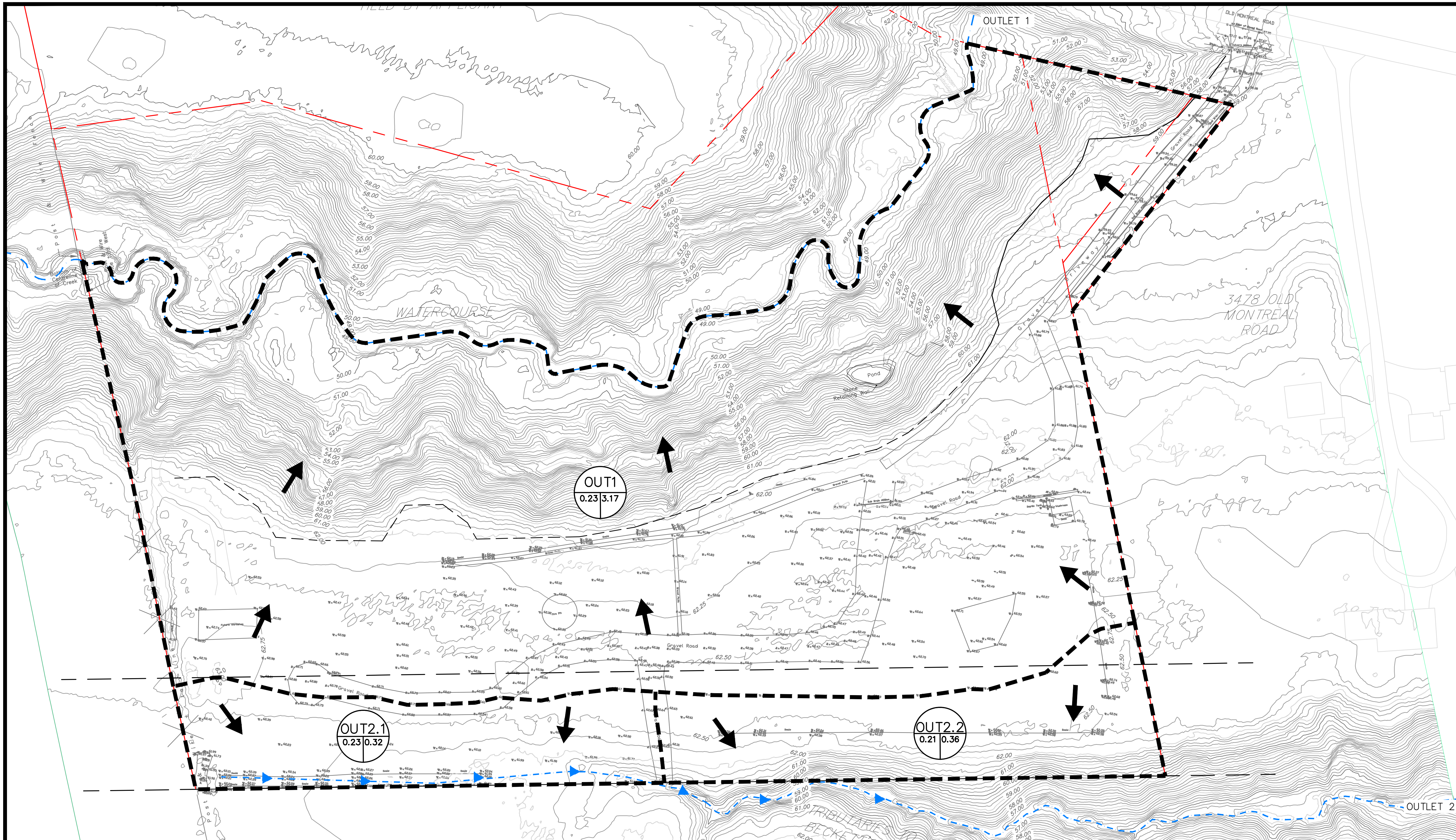
Municipal Designer

Figures

Figure 1	Existing Catchments
Figure 2	Proposed Catchments
Figure 3	Stormwater Management Details

Attachments

Appendix A	Stormwater Management Calculations
Appendix B	Infiltration Testing Memorandum



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HUMANICS SANCTUARY
EXISTING STORM DRAINAGE AREA PLAN

LEGEND

AREA ID

RUNOFF COEFFICIENT %

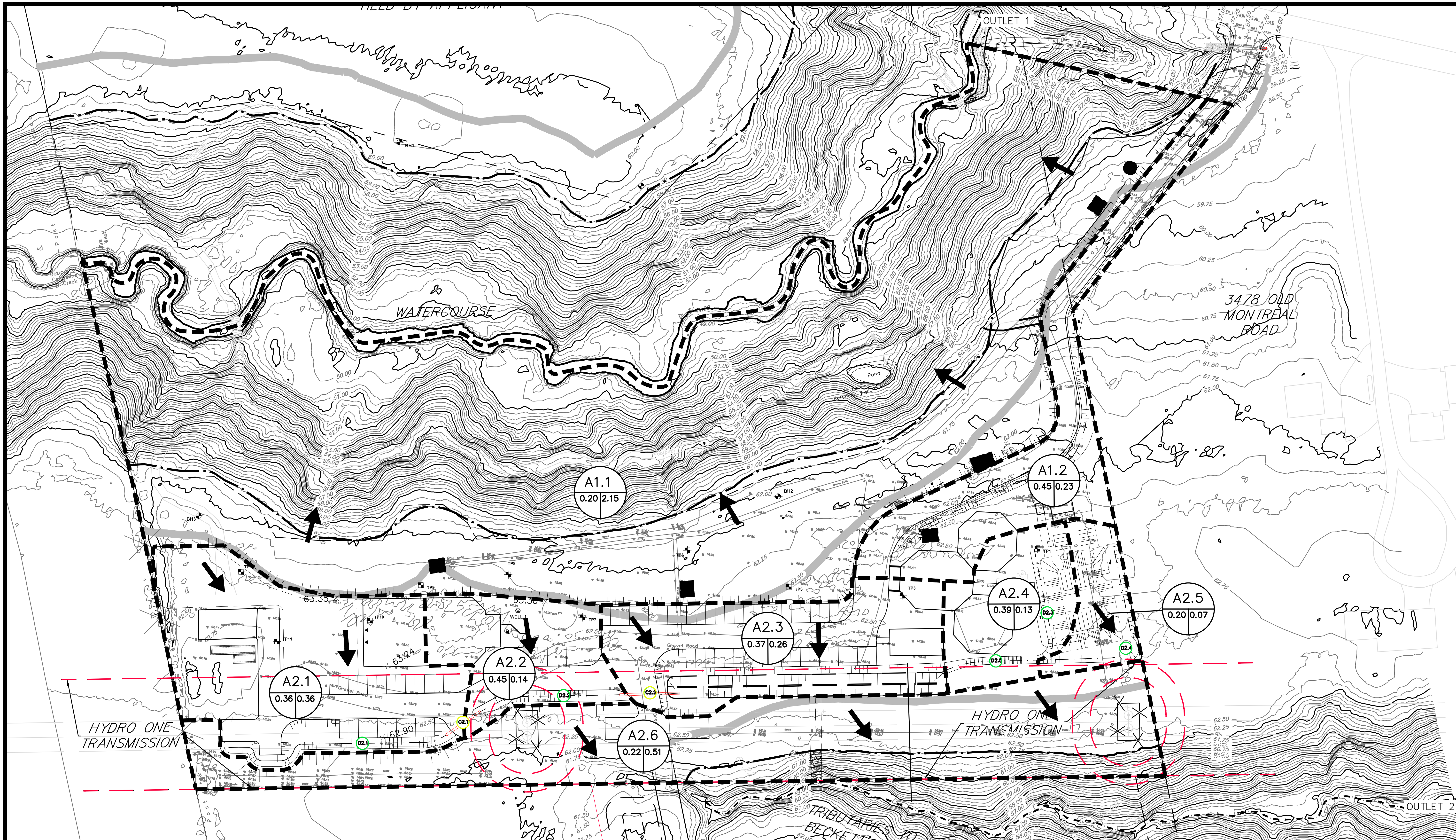
AREA ha

DRAINAGE AREA CHARACTERISTICS

FIGURE 1

DATE: 2021-11-22

SCALE: N.T.S.



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HUMANICS SANCTUARY
PROPOSED STORM DRAINAGE AREA PLAN

LEGEND

AREA ID

RUNOFF COEFFICIENT %

AREA ha

DRAINAGE AREA CHARACTERISTICS

FIGURE 2

DATE: 2021-11-22

SCALE: N.T.S.

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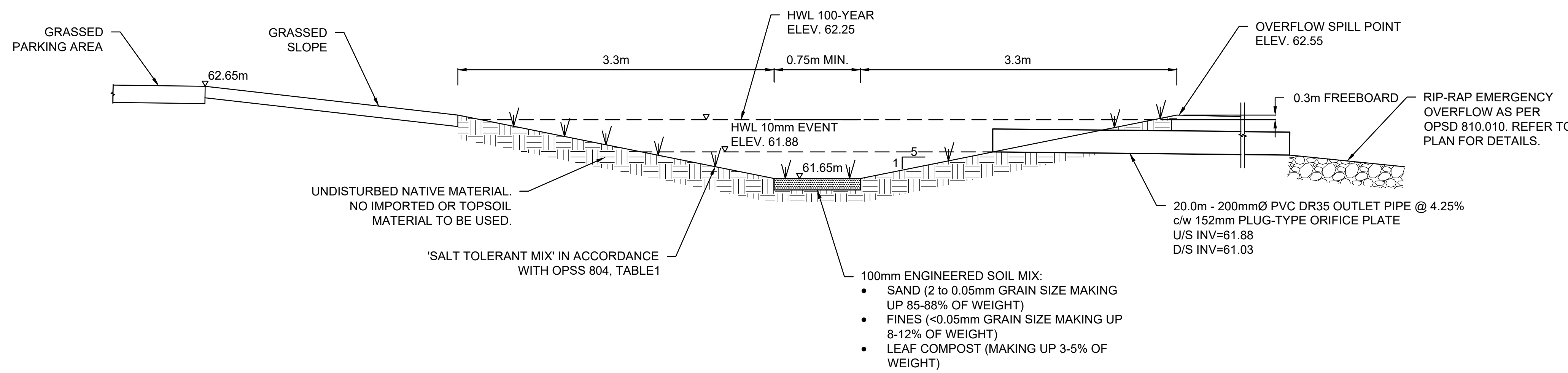

1 BIORETENTION POND CROSS SECTION
NTS

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HUMANICS SANCTUARY
STORMWATER MANAGEMENT DETAILS

FIGURE 3

DATE: 2021-11-22

SCALE: N.T.S.

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Appendix A

Stormwater Management Calculations

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A.1. Stormwater Management Summary

Humanics Centre, Ottawa, Ontario

Project No.	210647100
Date:	2023-04-28
Prepared By:	N Chauvin
Check By:	J Fookes

Impact of Development on Drainge Areas

Drainage Area	Pre-development				Post-development			
	Area (ha)	Imp.	Imp Area (ha)	Runoff Coefficient, R	Area (ha)	Imp.	Imp. Area (ha)	Runoff Coefficient, R
North Outlet	3.17	8%	0.25	0.23	2.38	6%	0.15	0.22
South Outlet	0.68	4%	0.03	0.22	1.47	23%	0.34	0.32
Total	**3.85**	**7%**	**0.28**	**0.23**	**3.85**	**13%**	**0.48**	**0.26**

Impact on Peak Flows

Drainage Area	5-year Pre-Development Flow	5-year Post-Development Flow	Difference	Percent Change	100-year Pre-Development Flow	100-year Post-Development Flow	Difference	Percent Change
	(L/s)	(L/s)	(L/s)	(%)	(L/s)	(L/s)	(L/s)	(%)
North Outlet	213.2	154.9	-58.3	-27.3%	456.7	331.8	-124.9	-27.3%
South Outlet	43.1	135.4	92.3	214.1%	92.3	290.0	197.7	214.1%
Total	**256.3**	**290.3**	**34.0**	**13.3%**	**549.0**	**621.8**	**72.8**	**13.3%**

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Project No.	210647100
Date:	2023-04-28
Prepared By:	N Chauvin
Check By:	J Fookes

A.2. Pre Development Peak Flows

Humanics Centre, Ottawa, Ontario

Rational Method
Q = RAIN, where

Q =	Peak runoff flow (L/s)	Woodland Area:	R = 0.30
R =	Runoff coefficient	Lawn Area:	R = 0.20
A =	Area (ha)	Building Area:	R = 0.90
I =	Rainfall intensity (mm/hr)	Gravel Area:	R = 0.60
N =	2.78	Water Area:	R = 1.00

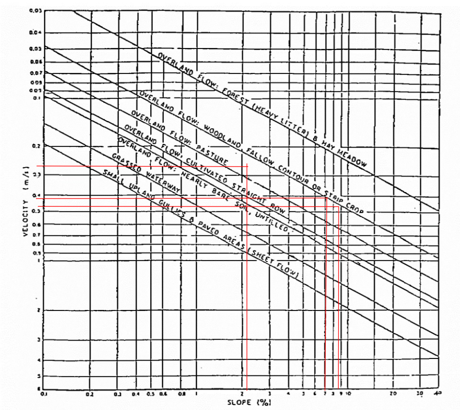
Existing Drainage Area Characteristics

Drainage Area	Existing Conditions				
	Area, A (ha)	Pervious Area (ha)	Impervious Area (ha)	Imp.	Runoff Coefficent, R
OUT1	3.17	2.92	0.25	8%	0.23
OUT2.1	0.32	0.30	0.02	7%	0.23
OUT2.2	0.36	0.35	0.01	2%	0.21
Total	3.85	3.57	0.28	7%	0.23

Existing Peak Flows

Where $i = \frac{A}{(T_d + C)^B}$

Calculation of Time of Concentration, using the Uplands Method (SCS National Engineering Handbook, 1971)



Drainage Area	Runoff Coefficent, R	Length, L (m)	Average Slope, S_w (%)	Velocity (m/s)	Time of Concentration, T_c
OUT1	0.23	143	9.5	0.47	5.07
OUT2.1	0.23	22.6	3.00	0.42	0.90
OUT2.2	0.21	24.8	7.2	0.27	1.53

Drainage Area	Existing Conditions		5-year			100-year		
	Area, A (ha)	Time of Concentration (Note 1)	I (mm/hr)	Runoff Coefficent, R	Q (L/s)	I (mm/hr)	Runoff Coefficent, R (Note 2)	Q (L/s)
OUT1	3.17	10.00	104.2	0.23	213.20	178.6	0.29	456.71
Outlet 1 Sub-Total	**3.17**				**213.20**	**178.6**		**456.71**
OUT2.1	0.3248	10.00	104.2	0.23	21.46	178.6	0.29	45.97
OUT2.2	0.3594	10.00	104.2	0.21	21.64	178.6	0.26	46.36
Outlet 2 Sub-Total	**0.68**				**43.1**			**92.3**
Total	**3.85**				**256.30**			**549.04**

Note 1: A minimum time of concentration of 10 mins was taken

Note 2: For 100-year event, Runoff Coefficient is increased by 25% to a maximum of 1.0.

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A.3. Post Development Peak Flows

Humanics Centre, Ottawa, Ontario

	Project No.	210647100
	Date:	2023-04-28
	Prepared By:	N Chauvin
	Check By:	J Fookes

Rational Method

Q = RAIN, where

Q =	Peak runoff flow (L/s)	Woodland Area:	R = 0.30
R =	Runoff coefficient	Lawn Area:	R = 0.20
A =	Area (ha)	Building Area:	R = 0.90
I =	Rainfall intensity (mm/hr)	Gravel Area:	R = 0.60
N =	2.78	Water Area:	R = 1.00

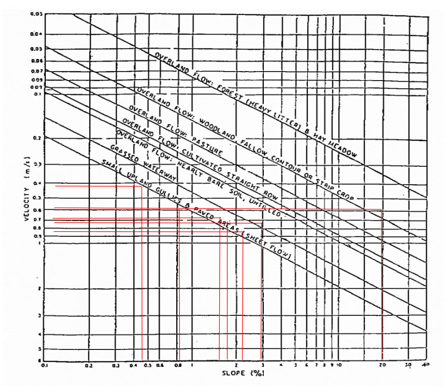
Proposed Drainage Area Characteristics

Drainage Area	Sub Area	Proposed Conditions						
		Area, A (ha)	Pervious Area (ha)	Gravel	Building	Impervious Area (ha)	Imp.	Runoff Coefficent, R
OUT1		2.38	2.24			0.15	6%	0.22
	A1.1	2.15	2.15			0.00	0%	0.20
	A1.2	0.23	0.09			0.15	63%	0.45
OUT2		1.47	1.13			0.34	23%	0.32
	A2.1	0.36	0.25	0.07	0.04	0.11	31%	0.36
	A2.2	0.14	0.08	0.03	0.03	0.06	46%	0.45
	A2.3	0.26	0.16	0.08	0.02	0.10	38%	0.37
	A2.4	0.13	0.09		0.03	0.03	27%	0.39
	A2.5	0.07	0.07			0.00	0%	0.20
	A2.6	0.51	0.49	0.03		0.03	5%	0.22
Total		**3.85**	**3.37**			**0.48**	**13%**	**0.26**

Proposed Peak Flows

Where $i = \frac{A}{(T_d + C)^B}$

Calculation of Time of Concentration, using the Uplands Method (SCS National Engineering Handbook, 1971)



Drainage Area	Runoff Coefficent, R	Length, L (m)	Average Slope, S_w (%)	Area, A	Velocity (m/s)	Time of Concentration, T_c
A1.1	0.20	83.00	17.00	2.15	0.6	2.31
A1.2	0.45	175.00	2.70	0.23	0.75	3.89
A2.1	0.36	93.00	1.30	0.36	0.7	2.21
A2.2	0.45	32.00	2.00	0.14	0.88	0.61
A2.3	0.37	30.00	1.50	0.26	0.75	0.67
A2.4	0.39	60.00	1.00	0.13	0.6	1.67
A2.5	0.20	60.00	0.50	0.07	0.38	2.63
A2.6	0.22	23.00	1.60	0.51	0.75	0.51

Drainage Area	Sub Area	Proposed Conditions		5-year			100-year		
		Area, A (ha)	Time of Concentration (Note 1)	I (mm/hr)	Runoff Coefficent, R	Q (L/s)	I (mm/hr)	Runoff Coefficent, R (Note 2)	Q (L/s)
	A1.1	2.15	10.00	104.19	0.20	124.5	178.56	0.25	266.8
	A1.2	0.23	10.00	104.19	0.45	30.4	178.6	0.56	65.0
Outlet 1 Sub-Total		2.38				154.9			331.8
	A2.1	0.36	10.00	104.19	0.36	37.8	178.6	0.45	81.0
	A2.2	0.14	10.00	104.19	0.45	18.5	178.6	0.57	39.6
	A2.3	0.26	10.00	104.19	0.37	28.3	178.6	0.47	60.7
	A2.4	0.13	10.00	104.19	0.39	14.2	178.6	0.49	30.5
	A2.5	0.07	10.00	104.19	0.20	3.9	178.6	0.25	8.3
	A2.6	0.51	10.00	104.19	0.22	32.6	178.6	0.28	69.9
Outlet 2 Sub-Total		1.47				135.4			290.0
Total		3.85				290.3			621.8

Note 1: A minimum time of concentration of 10 mins was taken

Note 2: For 100-year event, Runoff Coefficient is increased by 25% to a maximum of 1.0.

MORRISON HERSHFIELD

A.4. Proposed Storage

Humanics Centre, Ottawa, Ontario

Project No.	210647100
Date:	2023-04-28
Prepared By:	N Chauvin
Check By:	J Fookes

4a. Outlet 2 Storage

Summary of all Drainage Areas:

Drainage Area	Sub Area	Proposed Conditions					
		Area, A (ha)	Pervious Area (ha)	Impervious Area (ha)	Imp.	Runoff Coefficent, R	Runoff Coefficent, 100-year Event (Note 1)
OUT2		1.47	1.13	0.34	23%	0.32	0.40
	A2.1	0.36	0.25	0.11	31%	0.36	0.45
	A2.2	0.14	0.08	0.06	46%	0.45	0.57
	A2.3	0.26	0.16	0.10	38%	0.37	0.47
	A2.4	0.13	0.09	0.03	27%	0.39	0.49
	A2.5	0.07	0.07	0.00	0%	0.20	0.25
	A2.6	0.51	0.49	0.03	5%	0.22	0.28

Note 1: For 100-year event, Runoff Coefficient is increased by 25% to a maximum of 1.0.

Summary of Uncontrolled Drainage Areas:

Drainage Area	Sub Area	Proposed Conditions					Runoff Rate	
		Area, A (ha)	Pervious Area (ha)	Impervious Area (ha)	Imp.	Runoff Coefficent, R	5-year (L/s)	100-year (L/s)
OUT2	A2.6	0.51	0.49	0.03	5%	0.22	32.63	69.89

100-year Pre-Development Flow (L/s)= 92.3
100-year Uncontrolled Runoff (L/s)= 69.9
100-year Allowable Release Rate (L/s)= 22.4

5-year Pre-Development Flow (L/s)= 43.1
5-year Uncontrolled Runoff (L/s)= 32.6
5-year Allowable Release Rate (L/s)= 10.5

Orifice Sizing

Q =	CA(2gH)^0.5	
C =	0.61	
Design Flow Rate =	22.4	(L/s)
Proposed 100-year pond depth =	0.60	(m)
Proposed 100-year head above centreline of orifice =	0.27	(m)
Orifice Area =	15990	(mm2)
Orifice diameter =	143	(mm) (if <75mm then vortex ICD required)
Standard orifice diameter =	152	(mm)
Standard orifice area =	18146	(mm2)
Maximum release rate during 100-year event =	25.46	(L/s)

Release Rates during 5-year event

Water depth during 5-year event =	0.35	(m) *(based on result of Req. Storage Vol. calc below)*
Proposed 5-year head above centreline of orifice =	0.019	(m)
Maximum release rate during 5-year event =	6.67	(L/s)

Summary of Controlled Areas:

Drainage Area	Sub Area	Proposed Conditions					
		Area, A (ha)	Pervious Area (ha)	Impervious Area (ha)	Imp.	Runoff Coefficent, R	Runoff Coefficent, 100-year Event
	A2.1	0.36	0.25	0.11	31%	0.36	0.45
	A2.2	0.14	0.08	0.06	46%	0.45	0.57
	A2.3	0.26	0.16	0.10	38%	0.37	0.47
	A2.4	0.13	0.09	0.03	27%	0.39	0.49
	A2.5	0.07	0.07	0.00	0%	0.20	0.25
Total		0.96	0.64	0.31		0.37	0.46

Required Storage Volume (using Modified Rational Method)

Q = RAIN

Q = runoff rate (L/s)
R = runoff coefficient
i = rainfall intensity (mm/hr)
A = drainage area (ha)
N = 2.78

$$i = \frac{A}{(T_d + C)^B}$$

where i = Rainfall Intensity (mm/hr)
T_d = Time of Concentration (min)

Time, Td	5-Year Event				100-Year Event			
	Intensity	Peak Flow	Release Rate	Storage Volume	Intensity	Peak Flow	Release Rate	Storage Volume

(min)	(mm/hr)	(L/s)	(L/s)	(m^3)	(mm/hr)	(L/s)	(L/s)	(m^3)
10	104.19	102.7	6.67	57.6	178.56	220.1	25.46	116.8
20	70.25	69.3	6.67	75.1	119.95	147.9	25.46	146.9
30	53.93	53.2	6.67	83.7	91.87	113.2	25.46	158.0
40	44.18	43.6	6.67	88.6	75.15	92.6	25.46	161.2
50	37.65	37.1	6.67	91.4	63.95	78.8	25.46	160.1
60	32.94	32.5	6.67	92.9	55.89	68.9	25.46	156.4
70	29.37	29.0	6.67	93.6	49.79	61.4	25.46	150.8
80	26.56	26.2	6.67	93.7	44.99	55.5	25.46	144.0
90	24.29	24.0	6.67	93.3	41.11	50.7	25.46	136.1
100	22.41	22.1	6.67	92.6	37.90	46.7	25.46	127.5
110	20.82	20.5	6.67	91.5	35.20	43.4	25.46	118.3
120	19.47	19.2	6.67	90.2	32.89	40.5	25.46	108.6
130	18.29	18.0	6.67	88.7	30.90	38.1	25.46	98.5
140	17.27	17.0	6.67	87.0	29.15	35.9	25.46	88.0
150	16.36	16.1	6.67	85.2	27.61	34.0	25.46	77.1
160	15.56	15.3	6.67	83.2	26.24	32.3	25.46	66.1
170	14.83	14.6	6.67	81.2	25.01	30.8	25.46	54.7
180	14.18	14.0	6.67	79.0	23.90	29.5	25.46	43.2

minimum time = time of concentration

Storage volume used	93.7 m^3	Storage volume used	161.2 m^3

MORRISON HERSHFIELD

A.5. Bioretention Pond Sizing
Humanics Centre, Ottawa, Ontario

Project No.	210647100
Date:	2023-04-28
Prepared By:	N Chauvin
Check By:	J Fookes

The bioretention pond was sized in accordance with the LID Stormwater Management Planning and Design Guide. TRCA, 2010

In accordance with TRCA SWM Criteria (2021), Section 7.4:
"As a minimum, to achieve the enhance level of water quality control, the LID practice must be sized to provide storage for a minimum 5mm of rainfall."

Bioretention Sizing Characteristics

Contributing Drainage Area, A_c = 9559.00 m^2 *(Catchments A1.1-A1.5)*
Catchment Runoff Coefficient, C = 0.37
Catchment Impervious Area, A_i = 3111.00 m^2

Infiltration Volume Target, V_i = 35.471 m^3 *(10mm rainfall retention was used for this design)*

Field Measured Infiltration Rate, f = 97 mm/hr *(Median of field measured infiltration rates)*
Safety Factor, z = 2.5
Design Infiltration Rate, f' = 39 mm/hr *(Median of field measured infiltration rates, f divided by z)*

Filter Media Depth, d_f = 100 mm *(To support shrubs, flowering perennial and deeply rooting decorative grasses)*
Filter Media Porosity, n_f = 0.35 *(for more loamy Blend B, water quality treatment priority)*

Side Slopes, m:1 =	3.66666667	max	Side Width=	3.3	m	
Bottom Width. B =	0.75	m (min)	Total Top Width=	7.35	m	
Total Pond Height, H=	0.90			0.27273		
100-year Height, h =	0.60	m		3.66667		0.55
Base Length, L =	100	m				
Elevation of Base of Pond=	61.65	m				
Pond Spill Elevation=	62.55	m				
Freeboard=	0.3	m				
100-year Water Level=	62.25	m	Top Width at 100-year=			

1. Decide if an underdrain will be included:

If the median field measured or estimated infiltration rate of the underlying native soil (f) is less than 15 mm/h, include an underdrain.

Field Measured Infiltration Rate, f = 97 mm/hr

Include underdrain = No

2. Select a surface ponding depth to begin sizing with

For practices without underdrain: $d_{p,max}$ = f' x 48

Where: *f' = Design infiltration rate (mm/h), and*
48 = Maximum permissible drainage time for surface ponded water (h)

$d_{p,max}$ = 1.87 m

3. Select a design surface ponding depth

For practices with soft (i.e. landscaped) edges and bowl-shaped ponding areas calculate the mean surface ponding depth:

$d'_p = d_{p,max} \times 0.5$

d'_p = 0.94 m

4. Determine Water Quality Volume requiremtns

Infiltration Volume Target, V_i = 35.47 m^3 *(10mm rainfall retention was used for this design)*

Water Depth,y = 0.23 m
Cross Sectional Area, A = 0.37 m^2
Volume Provided, $V_{i,actual}$= 36.72 m^3

Invert Elevation of Overflow = 61.88 m

MORRISON HERSHFIELD

A.6. Pond Draindown Time

Humanics Centre, Ottawa, Ontario

Project No.	210647100
Date:	2023-04-28
Prepared By:	N Chauvin
Check By:	J Fookes

Release Rate from Pond

Equation 4.10 from MOE Stormwater Design Guidelines:

$$t = \frac{2A_P}{CA_o(2g)^{0.5}}\left({h_1}^{0.5} - {h_2}^{0.5}\right)$$

where:

Pond Volume	161.2	cu.m	Side Slopes, m:1 =	3.6
Water depth when full, h1	0.60	m	Bottom Width. B =	0.75
Water depth when empty, h2	0.0	m	Length, L =	100
Orifice coefficient, C	0.61			
Acceleration due to gravity, g	9.81	m/s²		

Incremental draindown calculation (100-year event), based on equivalent orifice to proposed ICD:

The drawdown when the water level is above the overflow will be governed by the orifice:

Water Depth at start of step, h1 (m)	Water depth at end of step, h2 (m)	Pond Surface Area, Ap (m2)	Duration of Step, t (s)	Realease Rate (L/s)
0.60	0.55	507	682.01	37.17
0.55	0.50	471	663.10	35.52
0.50	0.45	435	643.88	33.78
0.45	0.40	399	624.42	31.95
0.40	0.35	363	604.85	30.01
0.35	0.23	327	1490.19	10.97
		Total draindown duration	4708.45	seconds
			1.3	hours

Draindown Calculation (100-year event), based of infiltration rate of native soil:

The drawdown when the water level is below the overflow will be governed by the infilitration rate of the soil:

Depth of ponding, h (m)	Infiltration Rate of Soil, f (mm/hr)	Duration, t (hr)
0.23	39	5.9

Total draindown duration = 7.2 hours

Appendix B

Infiltration Testing Memorandum

MEMORANDUM

MORRISON HERSHFIELD

TO:	Ahmed Elsayed, P.Eng Project Manager / Engineer (Municipal)	**FROM:**	Mitchell Dawley and Ant West
		PROJECT No.:	210647100
RE:	Infiltration Testing for Stormwater Management Design at the Humanics Sanctuary	**DATE:**	10/25/2021

\\EGNYTEDRIVE\MH CLOUD\PROJ\2021\210647100-HUMANICS SANCTUARY CIVIL\08. WORKING\1. INFILTRATION TESTING\210647100 INFILTRATION TEST MEMO_REV0.DOCX

1. Introduction

Morrison Hershfield Ltd. (MH) was retained by Humanics Universal Inc. (the Client) to perform civil engineering design services associated with proposed improvements to the Humanics Sanctuary at 3400/3468 Old Montreal Road, Ottawa.

Specifically, MH is completing the Stormwater Management and Drainage Design as part of future development of the site. The Stormwater Management design will make use of Low Impact Development (LID) solutions that encourage infiltration.

Prior to design, MH's scope of services included infiltration testing to assist in selecting the LID solutions. The infiltration testing consisted of Guelph Permeameter testing at five (5) locations. This memorandum presents the methods findings and results of this testing.

2. Methodology

Infiltration testing was performed at five (5) locations using a 2800K1 Guelph Permeameter (GP) in accordance with ASTM D5126. The GP is an in-hole constant-head Permeameter that measures the steady-state rate of water recharge into unsaturated soil from a cylindrical borehole.

The locations of the infiltration testing are shown on **Figure 1** in **Attachment A**.

The field procedures used with the GP were as follows:

- A 6 cm diameter borehole was hand augured to depths between 0.24 to 0.36 m. Basic soil characteristics were observed and recorded during augering.
- The GP reservoir was filled with water and the instrument was lowered into the borehole.
- A well head height (H) was established in the open borehole by adjusting the Air Tube.
- The water level in the instrument reservoir was recorded at regular time intervals and the rate of fall (of water) was determined for each interval.
- Operation of the GP continued until the "Steady-State Rate of Fall" was attained. This occurred when the rate of fall did not significantly change over three (3) consecutive time intervals.
- For each borehole, the above procedure was repeated by establishing a different well head height (H).

3. Results

Soil Conditions

The soil conditions observed in each borehole augured for the GP testing was noted and is the results are summarized in Table 1 below.

Table 1: Observed Soil Conditions

Borehole ID	Depth of Borehole (mbgs)	Observed Soil Conditions
IN-1	0.24	Med to Fine Sand (SP) (0 – 0.17 m); Clayey Sand (SC) (0.17 – 0.24 m)
IN-2	0.27	Silty Sand (SM) (0.09 – 0.22 m); Med to Fine Sand (SP) (0.22 – 0.27 m)
IN-3	0.36	Silty Sand to Sand (SM-SP) (0.08 – 0.20); Med to Fine Sand (SP) (0.20 – 0.36 m)
IN-4	0.30	Silty Sand (SM) (0.08 – 0.14 m); Med to Fine Sand (SP) (0.14 – 0.30 m)
IN-5	0.26	Silty Sand (SM) (0.08 – 0.16 m); Med to Fine Sand (SP) (0.16 – 0.26 m)

Infiltration Testing

Hydraulic properties of the subgrade soils in the unsaturated zone were determined using a Guelph Permeameter (GP), by applying the single head method and averaging results of two (2) tests.

The GP instrument maintains a constant head of water in a borehole, causing water to infiltrate into the surrounding unsaturated soil. As water infiltrates, a “bulb” of saturated soil of specific dimensions develops around the borehole. Once the bulb develops, the steady-state flow rate of water out of the borehole is established and combined saturated-unsaturated flow occurs in the soil (Soilmoisture Corp., 2012).

For conditions of saturated-unsaturated flow, hydrostatic pressure, gravity and capillarity all contribute to the steady-state flow rate. Matric flux potential (Φ_m) is a measure of the capillarity/capillary pull that the unsaturated soil exerts on infiltrating water while the field-saturated hydraulic conductivity (K_{fs}) represents the hydrostatic pressure and gravity contributions to flow (Elrick & Reynolds, 1992).

Hydraulic conductivity is a function of water content in the soil and the maximum hydraulic conductivity value for a given soil unit occurs under conditions of saturation. With that said, the measured K_{fs} from infiltration testing is always slightly less than the saturated hydraulic conductivity (K_{sat}) for the same soil type due to the fact that the infiltration process often does not expel all air from the voids in the unsaturated soil, leaving some air entrapped. This entrapped air results in a smaller available surface area for water to flow through resulting in K_{fs} being less than K_{sat}.

The calculations of these hydraulic parameters from the GP field results are provided in **Attachment B**.

For the design of LID stormwater infiltration systems, the measured K_{fs} values must be converted to an infiltration rate (f) using the approximate relationship provided below (Ontario Ministry of Municipal Affairs and Housing, 1997):

$$f = (\frac{K_{fs}}{6x10^{-11}})^{\frac{1}{3.7363}}$$

A factor of safety of 2.5 was applied to this calculated infiltration rate to account for soil variability, potential reductions in soil permeability due to compaction or smearing during construction and gradual accumulation of fine sediments over the lifespan of the facility (Credit Valley and the Toronto and Region Conservation Authority, 2010)

Table 2: Infiltration Rates and Hydraulic Properties of Soils in Unsaturated Zone

Infiltration Location ID	Soil Type	Φ_m (cm²/min)	K_{fs} (cm/s)	Infiltration Rate, f, (mm/hr)	Design Infiltration Rate (mm/hr)
IN-1	Sand (SP) and Clayey Sand (SC)	$4.29x10^{-3}$	$5.15x10^{-4}$	72	29
IN-2	Silty Sand (SM) and Sand (SP)	$5.60x10^{-3}$	$6.72x10^{-4}$	77	31
IN-3	Silty Sand (SM) and Sand (SP)	$3.82x10^{-2}$	$4.58x10^{-3}$	129	52
IN-4	Silty Sand (SM) and Sand (SP)	$2.76x10^{-2}$	$3.32x10^{-3}$	118	47
IN-5	Silty Sand (SM) and Sand (SP)	$1.34x10^{-2}$	$1.61x10^{-3}$	97	39

4. References

Credit Valley and the Toronto and Region Conservation Authority. (2010). *Low Impact Developement Stormwater Management Planning and Design Guide. Appendix C.*

Elrick, D. E., & Reynolds, W. D. (1992). Methods for Analyzing Constant Head Well Permeameter Data. *Soil Science*, 320-323.

Ontario Ministry of Municipal Affairs and Housing. (1997). *Supplementary Guidelines to the Ontario Building Code 1997. SG-6 Percolation Time and Soil Descriptions.* Toronto.

Soilmoisture Corp. (2012). *Guelph Permeameter 2800 Operating Instructions.* Santa Barbara: Soilmoisture Corp.

Attachments:

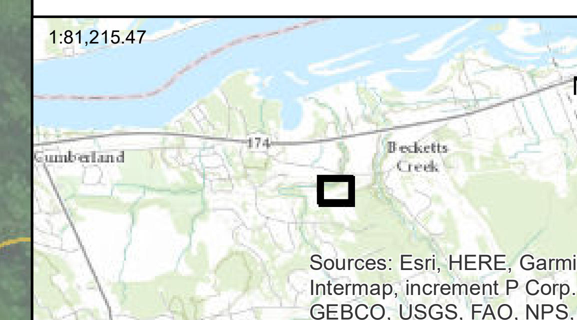
Attachment A: Site Plan

Appendix B: GP Results

LEGEND

- Infiltration Test Locations
- Topographic Contour (mASL)

ID	Easting	Northing
IN1	471533.9	5040209.08
IN2	471486.27	5040170.11
IN3	471403.14	5040155.07
IN4	471346.51	5040134.53
IN5	471510.42	5040142.8



Coordinate System: NAD 1983 UTM Zone 18N

MORRISON HERSHFIELD

SCALE: 1:1,000

0 12.5 25 50 Meters

TITLE:

Infiltration Test Locations

PROJECT NO.: 210647100

Infiltration Testing for Stormwater Management Design at the Humanics Sanctuary

DATE: October 2021

Figure 1

ENVIRONMENTAL SERVICES DEPARTMENT

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SOILMOISTURE® Guelph Permeameter

Input

Result

Single Head Method (1)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	7
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 0.6000

Res Type	35.22
H	7
a	3
H/a	2.333
a*	0.12
C0.01	0.991
C0.04	1.04
C0.12	1.014
C0.36	1.014
C	1.014
R	0.600
Q	0.352
pi	3.142

α*= 0.12 cm^{-1}

C = 1.0139

Q = 0.3522

K_{fs} =	5.08E-04	cm/sec
	3.05E-02	cm/min
	5.08E-06	m/sec
	1.20E-02	inch/min
	2.00E-04	inch/sec

Φ_m = 4.23E-03 cm^2/min

Single Head Method (2)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	15
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 1.2000

Res Type	35.22
H	15
a	3
H/a	5
a*	0.12
C0.01	1.51827
C0.04	1.62914
C0.12	1.66689
C0.36	1.66689
C	1.66689
R	1.200
Q	0.7044
pi	3.1415

α*= 0.12 cm^{-1}

C = 1.66689

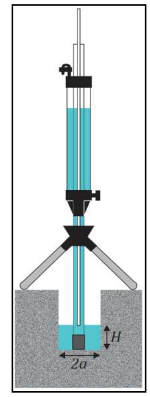
Q = 0.7044

K_{fs} =	5.23E-04	cm/sec
	3.14E-02	cm/min
	5.23E-06	m/ses
	1.23E-02	inch/min
	2.06E-04	inch/sec

Φ_m = 4.36E-03 cm^2/min

Average

K_{fs} =	5.15E-04	cm/sec
	3.09E-02	cm/min
	5.15E-06	m/s
	1.22E-02	inch/min
	2.03E-04	inch/sec
Φ_m =	4.29E-03	cm^2/min



Calculation formulas related to shape factor (C). Where H_1 is the first water head height (cm), H_2 is the second water head height (cm), a is borehole radius (cm) and α* is microscopic capillary length factor which is decided according to the soil texture-structure category. For one-head method, only C_1 needs to be calculated while for two-head method, C_1 and C_2 are calculated (Zang et al., 1998).

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_2/a}{2.081 + 0.121(H_2/a)}\right)^{0.672}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Calculation formulas related to one-head and two-head methods. Where R is steady-state rate of fall of water in reservoir (cm/s), K_{fs} is Soil saturated hydraulic conductivity (cm/s), ϕ_m is Soil matric flux potential (cm^2/s), a^* is Macroscopic capillary length parameter (from Table 2), a is Borehole radius (cm), H_1 is the first head of water established in borehole (cm) , H_2 is the second head of water established in borehole (cm) and C is Shape factor (from Table 2).

One Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$	$K_{fs} = \frac{C_1 \times Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi\left(\frac{H_1}{a^*}\right)}$ $\phi_m = \frac{C_1 \times Q_1}{(2\pi H_1^2 + \pi a^2 C_1)a^* + 2\pi H_1}$
One Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$	
Two Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$ $Q_2 = \bar{R}_2 \times 35.22$	$G_1 = \frac{H_2 C_1}{\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $G_2 = \frac{H_1 C_2}{\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $K_{fs} = G_2 Q_2 - G_1 Q_1$ $G_3 = \frac{(2H_2^2 + a^2 C_2)C_1}{2\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $G_4 = \frac{(2H_1^2 + a^2 C_1)C_2}{2\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $\phi_m = G_3 Q_1 - G_4 Q_2$
Two Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$ $Q_2 = \bar{R}_2 \times 2.16$	

SOILMOISTURE Guelph Permeameter

Input

Result

Single Head Method (1)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	5
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 0.5000

Res Type	35.22
H	5
a	3
H/a	1.667
a*	0.12
C0.01	0.809
C0.04	0.842
C0.12	0.803
C0.36	0.803
C	0.803
R	0.500
Q	0.294
pi	3.142

α* = 0.12 cm^{-1}

C = 0.80315

Q = 0.2935

K_{fs} = 5.34E-04 cm/sec

3.20E-02 cm/min

5.34E-06 m/sec

1.26E-02 inch/min

2.10E-04 inch/sec

Φ_m = 4.45E-03 cm^2/min

Single Head Method (2)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	12
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 1.5000

Res Type	35.22
H	12
a	3
H/a	4
a*	0.12
C0.01	1.34796
C0.04	1.43553
C0.12	1.44896
C0.36	1.44896
C	1.44896
R	1.500
Q	0.8805
pi	3.1415

α* = 0.12 cm^{-1}

C = 1.44896

Q = 0.8805

K_{fs} = 8.11E-04 cm/sec

4.86E-02 cm/min

8.11E-06 m/ses

1.91E-02 inch/min

3.19E-04 inch/sec

Φ_m = 6.75E-03 cm^2/min

Average

K_{fs} = 6.72E-04 cm/sec

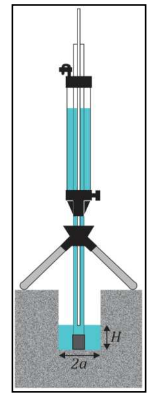
4.03E-02 cm/min

6.72E-06 m/s

1.59E-02 inch/min

2.65E-04 inch/sec

Φ_m = 5.60E-03 cm^2/min



Calculation formulas related to shape factor (C). Where H_1 is the first water head height (cm), H_2 is the second water head height (cm), a is borehole radius (cm) and α* is microscopic capillary length factor which is decided according to the soil texture-structure category. For one-head method, only C_1 needs to be calculated while for two-head method, C_1 and C_2 are calculated (Zang et al., 1998).

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_2/a}{2.081 + 0.121(H_2/a)}\right)^{0.672}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Calculation formulas related to one-head and two-head methods. Where R is steady-state rate of fall of water in reservoir (cm/s), K_{fs} is Soil saturated hydraulic conductivity (cm/s), Φ_m is Soil matric flux potential (cm²/s), a^* is Macroscopic capillary length parameter (from Table 2), a is Borehole radius (cm), H_1 is the first head of water established in borehole (cm) , H_2 is the second head of water established in borehole (cm) and C is Shape factor (from Table 2).

One Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$	$K_{fs} = \frac{C_1 \times Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi\left(\frac{H_1}{a^*}\right)}$
One Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$	$\Phi_m = \frac{C_1 \times Q_1}{(2\pi H_1^2 + \pi a^2 C_1)a^* + 2\pi H_1}$
Two Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$ $Q_2 = \bar{R}_2 \times 35.22$	$G_1 = \frac{H_2 C_1}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $G_2 = \frac{H_1 C_2}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $K_{fs} = G_2Q_2 - G_1Q_1$ $G_3 = \frac{(2H_2^2 + a^2C_2)C_1}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$
Two Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$ $Q_2 = \bar{R}_2 \times 2.16$	$G_4 = \frac{(2H_1^2 + a^2C_1)C_2}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $\Phi_m = G_3Q_1 - G_4Q_2$

SOILMOISTURE Guelph Permeameter

Input

Result

Single Head Method (1)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	5
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 5.0000

Res Type	35.22			
H	5			
a	3	α^* =	0.12	cm^{-1}
H/a	1.667			
a*	0.12	C =	0.80315	
C0.01	0.809	Q =	2.935	
C0.04	0.842			
C0.12	0.803	K_{fs} =	5.34E-03	cm/sec
C0.36	0.803		3.20E-01	cm/min
C	0.803		5.34E-05	m/sec
R	5.000		1.26E-01	inch/min
Q	2.935		2.10E-03	inch/sec
pi	3.142	Φ_m =	4.45E-02	cm^2/min

Single Head Method (2)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	17
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

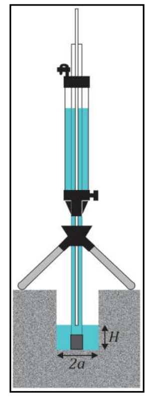
1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 10.0000

Res Type	35.22			
H	17			
a	3	α^* =	0.12	cm^{-1}
H/a	5.66667			
a*	0.12	C =	1.79884	
C0.01	1.61898	Q =	5.87	
C0.04	1.7451			
C0.12	1.79884	K_{fs} =	3.83E-03	cm/sec
C0.36	1.79884		2.30E-01	cm/min
C	1.79884		3.83E-05	m/ses
R	10.000		9.05E-02	inch/min
Q	5.87		1.51E-03	inch/sec
pi	3.1415	Φ_m =	3.19E-02	cm^2/min

Average

K_{fs} =	4.58E-03	cm/sec
	2.75E-01	cm/min
	4.58E-05	m/s
	1.08E-01	inch/min
	1.80E-03	inch/sec
Φ_m =	3.82E-02	cm^2/min



Calculation formulas related to shape factor (C). Where H_1 is the first water head height (cm), H_2 is the second water head height (cm), a is borehole radius (cm) and α^* is microscopic capillary length factor which is decided according to the soil texture-structure category. For one-head method, only C_1 needs to be calculated while for two-head method, C_1 and C_2 are calculated (Zang et al., 1998).

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_2/a}{2.081 + 0.121(H_2/a)}\right)^{0.672}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Calculation formulas related to one-head and two-head methods. Where R is steady-state rate of fall of water in reservoir (cm/s), K_{fs} is Soil saturated hydraulic conductivity (cm/s), Φ_m is Soil matric flux potential (cm^2/s), α^* is Macroscopic capillary length parameter (from Table 2), a is Borehole radius (cm), H_1 is the first head of water established in borehole (cm), H_2 is the second head of water established in borehole (cm) and C is Shape factor (from Table 2).

One Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$	$K_{fs} = \frac{C_1 \times Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi\left(\frac{H_1}{a^*}\right)}$ $\Phi_m = \frac{C_1 \times Q_1}{(2\pi H_1^2 + \pi a^2 C_1)a^* + 2\pi H_1}$
One Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$	
Two Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$ $Q_2 = \bar{R}_2 \times 35.22$	$G_1 = \frac{H_2 C_1}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $G_2 = \frac{H_1 C_2}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $K_{fs} = G_2Q_2 - G_1Q_1$ $G_3 = \frac{(2H_2^2 + a^2C_2)C_1}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$
Two Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$ $Q_2 = \bar{R}_2 \times 2.16$	$G_4 = \frac{(2H_1^2 + a^2C_1)C_2}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $\Phi_m = G_3Q_1 - G_4Q_2$

SOILMOISTURE Guelph Permeameter

Input

Result

Single Head Method (1)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	6
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 4.2000

Res Type	35.22
H	6
a	3
H/a	2
a*	0.12
C0.01	0.904
C0.04	0.945
C0.12	0.912
C0.36	0.912
C	0.912
R	4.200
Q	2.465
pi	3.142

α^* = 0.12 cm^{-1}

C = 0.91197

Q = 2.4654

K_{fs} = 3.97E-03 cm/sec; 2.38E-01 cm/min; 3.97E-05 m/sec; 9.38E-02 inch/min; 1.56E-03 inch/sec

Φ_m = 3.31E-02 cm^2/min

Single Head Method (2)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	14
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 5.7000

Res Type	35.22
H	14
a	3
H/a	4.66667
a*	0.12
C0.01	1.4643
C0.04	1.56745
C0.12	1.59712
C0.36	1.59712
C	1.59712
R	5.700
Q	3.3459
pi	3.1415

α^* = 0.12 cm^{-1}

C = 1.59712

Q = 3.3459

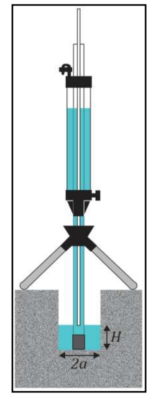
K_{fs} = 2.66E-03 cm/sec; 1.60E-01 cm/min; 2.66E-05 m/ses; 6.28E-02 inch/min; 1.05E-03 inch/sec

Φ_m = 2.22E-02 cm^2/min

Average

K_{fs} = 3.32E-03 cm/sec; 1.99E-01 cm/min; 3.32E-05 m/s; 7.83E-02 inch/min; 1.31E-03 inch/sec

Φ_m = 2.76E-02 cm^2/min



Calculation formulas related to shape factor (*C*). Where H_1 is the first water head height (cm), H_2 is the second water head height (cm), a is borehole radius (cm) and α^* is microscopic capillary length factor which is decided according to the soil texture-structure category. For one-head method, only C_1 needs to be calculated while for two-head method, C_1 and C_2 are calculated (Zang et al., 1998).

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_2/a}{2.081 + 0.121(H_2/a)}\right)^{0.672}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Calculation formulas related to one-head and two-head methods. Where R is steady-state rate of fall of water in reservoir (cm/s), K_{fs} is Soil saturated hydraulic conductivity (cm/s), Φ_m is Soil matric flux potential (cm^2/s), a^* is Macroscopic capillary length parameter (from Table 2), a is Borehole radius (cm), H_1 is the first head of water established in borehole (cm), H_2 is the second head of water established in borehole (cm) and C is Shape factor (from Table 2).

One Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$	$K_{fs} = \frac{C_1 \times Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi\left(\frac{H_1}{a^*}\right)}$ $\Phi_m = \frac{C_1 \times Q_1}{(2\pi H_1^2 + \pi a^2 C_1)a^* + 2\pi H_1}$
One Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$	
Two Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$ $Q_2 = \bar{R}_2 \times 35.22$	$G_1 = \frac{H_2 C_1}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $G_2 = \frac{H_1 C_2}{\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $K_{fs} = G_2Q_2 - G_1Q_1$ $G_3 = \frac{(2H_2^2 + a^2C_2)C_1}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $G_4 = \frac{(2H_1^2 + a^2C_1)C_2}{2\pi(2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1))}$ $\Phi_m = G_3Q_1 - G_4Q_2$
Two Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$ $Q_2 = \bar{R}_2 \times 2.16$	

Guelph Permeameter

Input

Result

Single Head Method (1)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	5
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 1.5000

Res Type	35.22			
H	5			
a	3	α*=	0.12	cm^{-1}
H/a	1.667			
a*	0.12	C =	0.80315	
C0.01	0.809	Q =	0.8805	
C0.04	0.842			
C0.12	0.803	K_{fs} =	1.60E-03	cm/sec
C0.36	0.803		9.61E-02	cm/min
C	0.803		1.60E-05	m/sec
R	1.500		3.78E-02	inch/min
Q	0.881		6.31E-04	inch/sec
pi	3.142			
		Φ_m =	1.33E-02	cm^2/min

Single Head Method (2)

Reservoir Cross-sectional area in cm^2

(enter "35.22" for Combined and "2.16" for Inner reservoir):	35.22
Enter water Head Height ("H" in cm):	12
Enter the Borehole Radius ("a" in cm):	3
Enter the soil texture-structure category (enter one of the below numbers):	3

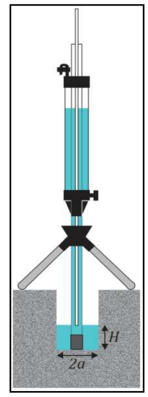
1. Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.
2. Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.
3. Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.
4. Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macropors, etc

Steady State Rate of Water Level Change ("R" in cm/min): 3.0000

Res Type	35.22			
H	12			
a	3	α*=	0.12	cm^{-1}
H/a	4			
a*	0.12	C =	1.44896	
C0.01	1.34796	Q =	1.761	
C0.04	1.43553			
C0.12	1.44896	K_{fs} =	1.62E-03	cm/sec
C0.36	1.44896		9.73E-02	cm/min
C	1.44896		1.62E-05	m/ses
R	3.000		3.83E-02	inch/min
Q	1.761		6.38E-04	inch/sec
pi	3.1415			
		Φ_m =	1.35E-02	cm^2/min

Average

K_{fs} =	1.61E-03	cm/sec
	9.67E-02	cm/min
	1.61E-05	m/s
	3.81E-02	inch/min
	6.34E-04	inch/sec
Φ_m =	1.34E-02	cm^2/min



Calculation formulas related to shape factor (C). Where H_1 is the first water head height (cm), H_2 is the second water head height (cm), a is borehole radius (cm) and α* is microscopic capillary length factor which is decided according to the soil texture-structure category. For one-head method, only C_1 needs to be calculated while for two-head method, C_1 and C_2 are calculated (Zang et al., 1998).

Soil Texture-Structure Category	$\alpha^*(cm^{-1})$	Shape Factor
Compacted, Structure-less, clayey or silty materials such as landfill caps and liners, lacustrine or marine sediments, etc.	0.01	$C_1 = \left(\frac{H_2/a}{2.081 + 0.121(H_2/a)}\right)^{0.672}$
Soils which are both fine textured (clayey or silty) and unstructured; may also include some fine sands.	0.04	$C_1 = \left(\frac{H_1/a}{1.992 + 0.091(H_1/a)}\right)^{0.683}$ $C_2 = \left(\frac{H_2/a}{1.992 + 0.091(H_2/a)}\right)^{0.683}$
Most structured soils from clays through loams; also includes unstructured medium and fine sands. The category most frequently applicable for agricultural soils.	0.12	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$
Coarse and gravely sands; may also include some highly structured soils with large and/or numerous cracks, macro pores, etc.	0.36	$C_1 = \left(\frac{H_1/a}{2.074 + 0.093(H_1/a)}\right)^{0.754}$ $C_2 = \left(\frac{H_2/a}{2.074 + 0.093(H_2/a)}\right)^{0.754}$

Calculation formulas related to one-head and two-head methods. Where R is steady-state rate of fall of water in reservoir (cm/s), K_{fs} is Soil saturated hydraulic conductivity (cm/s), Φ_m is Soil matric flux potential (cm^2/s), a^* is Macroscopic capillary length parameter (from Table 2), a is Borehole radius (cm), H_1 is the first head of water established in borehole (cm) , H_2 is the second head of water established in borehole (cm) and C is Shape factor (from Table 2).

One Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$	$K_{fs} = \frac{C_1 \times Q_1}{2\pi H_1^2 + \pi a^2 C_1 + 2\pi\left(\frac{H_1}{a^*}\right)}$ $\Phi_m = \frac{C_1 \times Q_1}{(2\pi H_1^2 + \pi a^2 C_1)a^* + 2\pi H_1}$
One Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$	
Two Head, Combined Reservoir	$Q_1 = \bar{R}_1 \times 35.22$ $Q_2 = \bar{R}_2 \times 35.22$	$G_1 = \frac{H_2 C_1}{\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $G_2 = \frac{H_1 C_2}{\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $K_{fs} = G_2 Q_2 - G_1 Q_1$ $G_3 = \frac{(2H_2^2 + a^2 C_2)C_1}{2\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $G_4 = \frac{(2H_1^2 + a^2 C_1)C_2}{2\pi(2H_1 H_2(H_2 - H_1) + a^2(H_1 C_2 - H_2 C_1))}$ $\Phi_m = G_3 Q_1 - G_4 Q_2$
Two Head, Inner Reservoir	$Q_1 = \bar{R}_1 \times 2.16$ $Q_2 = \bar{R}_2 \times 2.16$	