Right of Way Condition Inventory for Stormwater Management, Phase I - Wards 5&6 City of Burlington, Vermont

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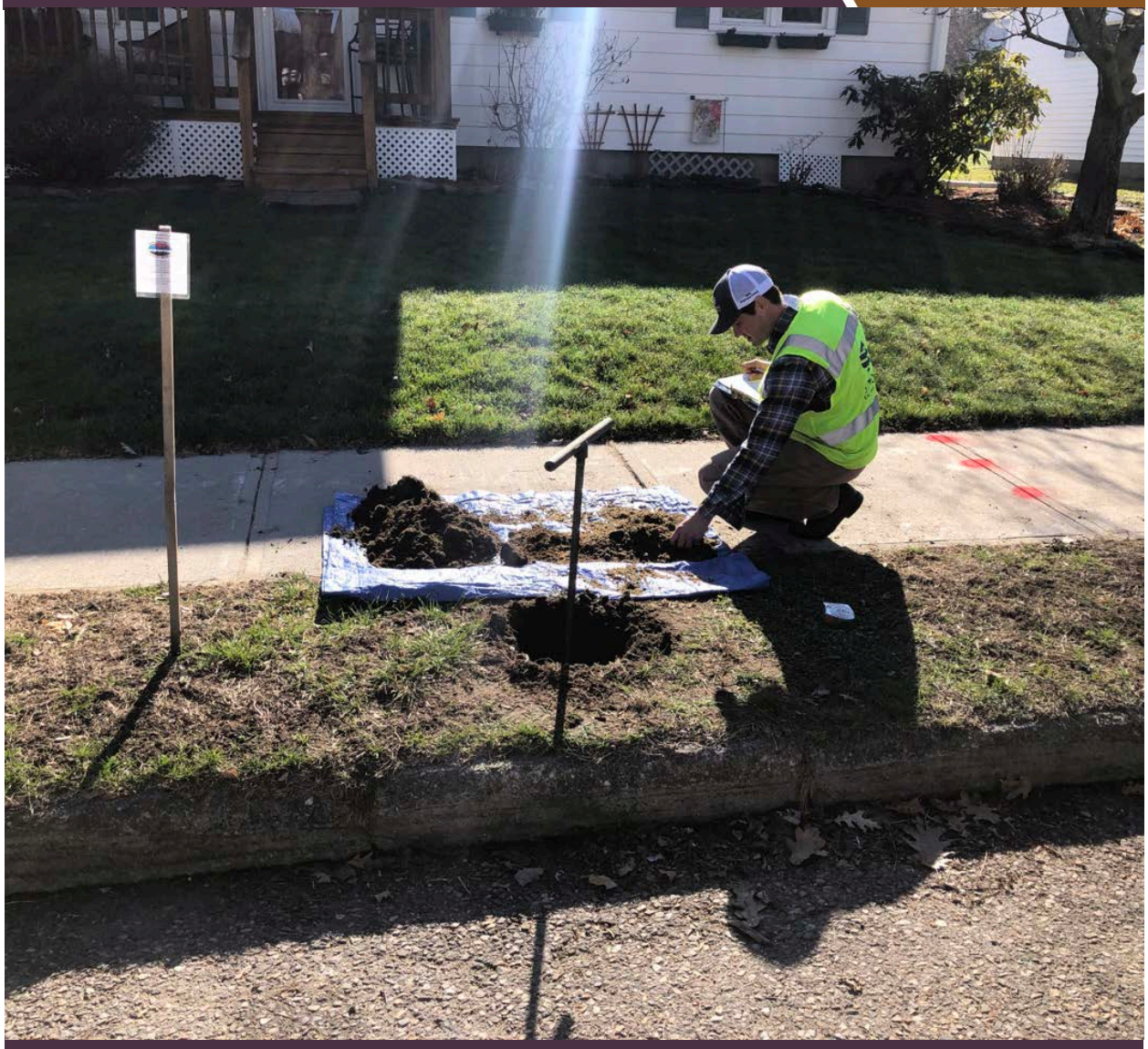

Submitted June 30, 2021

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Disclaimer:

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Cover Photo: Soil Investigation at 22 Alder Street on April 8, 2021.

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1. Introduction

On behalf of Chittenden County Regional Planning Commission (CCRPC) and the City of Burlington (City), Stone Environmental, Inc. (Stone) has completed the Right of Way Condition Inventory for Stormwater Management within Burlington Wards 5 and 6. A summary of the inventory and tasks completed are described below. Data from the project is in two web maps Soil Boring Status Map and BTV Soil and Utility ROW Assessment Map.

2. Interactive Base Map of Existing Data

A kickoff meeting with the City and CCRPC staff was held at the City of Burlington Department of Public Works offices on September 5, 2019. Project goals, objectives, community outreach and Arc GIS data management logistics were discussed.

Following the kick-off meeting, Stone obtained and organized the necessary geospatial datasets, for both the desktop analysis and ArcGIS Online web maps, within Wards 5 and 6 of the City. The following layers were utilized:

Desktop Analysis and Web Map Layers

- Parcel boundaries (symbolized to emphasize municipal ROW areas)
- Municipal and Ward boundaries
- Soils data (DPW's from previous work, NRCS soil survey, or both), including specific filters or display layers for HSG, soil texture, depth to groundwater, depth to bedrock
- Existing sewer and storm infrastructure
- Existing subsurface utilities:
- Vermont Gas (as included in AGOL, Burlington VT - Utility GIS Exchange)
- Burlington Electric Department (as included in AGOL, Burlington VT - Utility GIS Exchange)
- Subwatersheds by drainage area (Main Plant, Englesby Brook, etc.) and/or by system (combined sewer above CSO, combined sewer, etc.)
- IP-identified runoff management opportunity drainage areas and/or BMP points
- City BMPs and managed impervious surfaces as included in the Burlington, VT - Mapping Managed Stormwater Dashboard

Desktop Analysis Only

Existing information available electronically from Vermont ANR via the ANR Natural Resources Atlas and related feature services, including:

- ANR hazardous sites layers (both map service and additional screening layers provided by VT DEC, with draft layers clearly marked as 'internal not for distribution or public display')
- Operational stormwater permits
- Act 250 permits
- Natural resource constraints (wetlands, flood hazard areas, river corridors, etc.)

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In addition to the web map, Stone developed templates for utility assessment and clearance review to be used during field activities. These templates were generated to be used with the ArcGIS Collector and ArcGIS Survey123 applications using handheld devices in the field.

3. Identify Areas for Utility Screening and Soil Investigation

Using available data collected to construct the interactive base map, Stone recommended areas for initial utility assessment and collection of GPS points to document potential soil boring locations. Areas proposed for assessment were highlighted in the web map and symbolized as polygons. Criteria utilized to identify areas for initial assessment included:

- Areas within ROW in Wards 5 or 6
- Areas spaced to be representative of the range of soils and subsurface conditions known to exist throughout Wards 5 and 6
- Width of available ROW
- Locations chosen to minimize subsurface utility conflicts where mapping data are available
- Locations chosen to minimize ANR hazardous sites conflicts where mapping data are available
- Locations chosen to not impact lands governed by operational stormwater permits where mapping data are available
- Locations chosen to not impact lands governed by Act 250 permits where mapping data are available
- Locations chosen to minimize natural resource conflicts where mapping data are available
- Priority given to areas outside the drainage areas of completed stormwater BMPs

Following the collection, compilation, and determination of factors used to screen the potential ROW areas to include in this analysis, a series of geoprocessing steps were conducted to associate the relevant screening criteria with each ROW area, allowing for a streamlined assessment. A field was added to the ROW dataset for each of the criteria above, based on either the proximity or intersection of any of the above datasets to the ROW areas. Approximate width was also calculated for each ROW area and included as a field in the dataset. Utilizing each of these relevant characteristics, several queries were conducted to begin reducing the total ROW datasets to only those areas that may be suitable for further field inspection. The result of each query was analyzed visually to ensure that the ROW areas resulting from the query were evenly distributed throughout Wards 5&6, and not clustered in one area more than another to ensure an even sampling for the soil borings. Of the three query scenarios that were run, it was ultimately determined that following criteria was best to begin the field work and soil borings, representing an even spatial distribution throughout both wards and an adequate number of ROW areas:

- Does not intersect Electric/Gas/SW/Sanitary utility lines
- Not within 200 ft of Haz Sites
- No Electric Support Structures within the ROW area

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- ROW Width > 7 ft
- Not within 150 meters of Complete/Final Design/Under Construction BMPs
- ROW is on Exterior (street side of sidewalk or no sidewalk present)

Stone documented the site selection as stated above, and the web map was provided to the City for consideration. The initial screening yielded 78 possible stormwater treatment practice areas to be investigated.

4. First Round of Soil Investigation

The initial 78 possible boring sites were further analyzed and inspected via Google Earth Street View and in-person site visits to determine feasibility of future BMP construction and/or soil boring advancement. In many instances, locations were removed from the list for further investigation due to presence of bedrock, large trees, lack of available right of way, first-hand knowledge gained regarding utilities and irrigation systems, input from the City, topographic restrictions, and drainage area size and characteristics. Ultimately, 31 sites were removed from the list of borings to be advanced.

Once a consensus was reached regarding proposed soil investigation sites, Stone pre-marked for utility clearance by DigSafe and the City. The City had an outreach program which included Front Porch Forum (FPF) postings to notified residents of the work to be performed in their neighborhood. As part of the DigSafe process each boring was staked with a laminated notice that informed landowners of the project and its goals including instructions to contact the City with questions. (Attachment A).

The remaining 47 sites were pre-marked for utility clearance. After utility markings had been made, an additional 18 sites were discarded due to utility conflicts, property owner conflicts, additional input from the City, or site density considerations in any given neighborhood. Soil borings were advanced at the remaining sites, and by October 2020, Stone had conducted the first round of successful soil borings at 29 sites.

Soil profiles were evaluated in the field for redoximorphic features characteristic of seasonal high groundwater conditions in horizons within and below where potential retrofit practices would be constructed. In general, the borings were advanced to a depth where a limiting layer, seasonal high water table, or refusal was encountered and the boring was conclusive about the infiltrative potential in that location.

5. Additional Utility Screening and Second Round of Soil Investigation

The original scope of work included advancing approximately 80 borings at 40 locations with an average of two borings per location. The scope of work assumed that the desktop analysis would be sufficient for identifying the sites and didn't account for large number of sites that were discarded for various reasons not considered by the GIS analysis. After completing the first-round site visits and boring advancement, it became apparent that evaluating more locations would be more useful to the City than having multiple

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borings in the same location. The City agreed that they preferred this "broad brush" approach that would allow more areas to be evaluated throughout Wards 5 and 6.

To generate new soil boring sites, the desktop analysis was refined to reduce the criteria of available ROW from seven feet to five feet. This refinement provided an additional 72 sites to be evaluated.

After site selection and input from the City, Stone pre-marked and submitted DigSafe tickets for an additional 45 boring sites, and ultimately advanced soil borings at 32 of the sites. With the onset of the COVID-19 pandemic, and in an effort to display transparency and effectively communicate to the public, soil investigation became an iterative process and borings were grouped into 1-2 week efforts in targeted areas.

6. GeoProbe Borings

During soil explorations, Stone encountered a selection of sites not well suited for hand auger exploration due to rocks, roots or other obstructions. Some of these sites were suspected to have soils favorable for stormwater infiltration. As such, with the approval of the City and CCRPC the scope of work was modified to include a day of GeoProbe explorations to adequately characterize those soils to depth. On May 6, 2021, Platform Environmental Drilling advanced a total of six direct push GeoProbe borings to depths up to 10 feet below ground surface.

7. Infiltration Testing

In an effort to verify soil characterization as it relates to a given soil's ability to infiltrate stormwater, sites with soil profiles and an estimated SHWT conducive to infiltration testing were chosen to conduct infiltration testing. Stone performed testing via the methodology outlined in "Standard Operating Procedure SEI-5.99.0 – Measuring Hydraulic Conductivity in Unsaturated Soils" (provided as an attachment). At sites with soils characterized as favorable for infiltration, Stone identified infiltration rates ranging from 8 in/hr to over 30 in/hr, as seen in Table 1 below.

Table 1. Measured Infiltration Rates

Boring #	Address	Infiltration Rate (in/hr)
19	46 Crescent Road	8.27
49	426 South Willard Street	>30.79
72	88 Crescent Road	8.16
88	46 Charlotte Street	18.24
93	103 Maple Street	16.08
105	22 Alder Lane	21.00

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8. Conclusions

In total, Stone has assessed over 150 potential boring locations throughout Wards 5 and 6 and successfully advanced soil borings at 61 unique sites. Four of the sites received multiple borings resulting in a total current count of 67 soil borings throughout Wards 5 and 6. Soil borings were logged using the program LogPlot to generate boring logs in pdf format. A summary table of soil borings, infiltration tests and areas evaluated is attached. The table has been color coded with a green shade identifying the areas with more promising results.

While investigating soils within Wards 5 and 6, Stone consistently updated a web map that has been supplied to the City as a tool to depict soil boring sites with applicable attributes, site-specific information, and links to the associated boring logs. This web map equips the City with valuable knowledge when planning stormwater treatment practices (STPs) or retrofits in the future.

In general, soils within Wards 5 and 6 were not found to be very suitable for infiltrative stormwater practices. Shallow seasonal high-water table (SHWT) and/or restrictive soils were encountered across most of this part of the City. The areas identified with favorable soils for infiltration and stormwater treatment are:

- 46, 50, 88, and 120 Crescent Road
  - A confining layer was identified at 120 Crescent road relatively shallow (38")
- 426, 436, and 500 South Willard Street
  - Possible redoximorphic features were identified at 500 South Willard Street though the soils appeared to be favorable for infiltration.
- 46 and 58 Charlotte Street
- 103 Maple Street
- 22 and 86 Alder Lane
  - While favorable soils were identified on Alder Lane to a depth of approx. 40", two separate residents (22 and 78 Alder Lane) reported frequent and historic basement flooding issues.
- 161 and 171 Home Avenue
  - While the soils at these sites appeared to favor infiltration, ultimately infiltration testing was unsuccessful due to the inability to conduct testing because of site-specific soil characteristics and GeoProbe borings were not advanced due to the amount of traffic and challenging access on Home Avenue.

As discussed in this report, Phase I of the Right of Way Condition Inventory for Stormwater Management within Burlington allowed the City and Stone to work together to fine tune the scope of work and workflow to efficiently evaluate the Wards. We are excited to apply what we have learned to expand upon this resource for the City in other Wards. Please do not hesitate to reach out to us with questions.

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9. Attachments

A – Project Map
B – Flyer for Stakes/Pre-Marking
C – Spreadsheet of all Locations Analyzed
D – Infiltration Test Results
E – Standard Operating Procedure SEI-5.99.0

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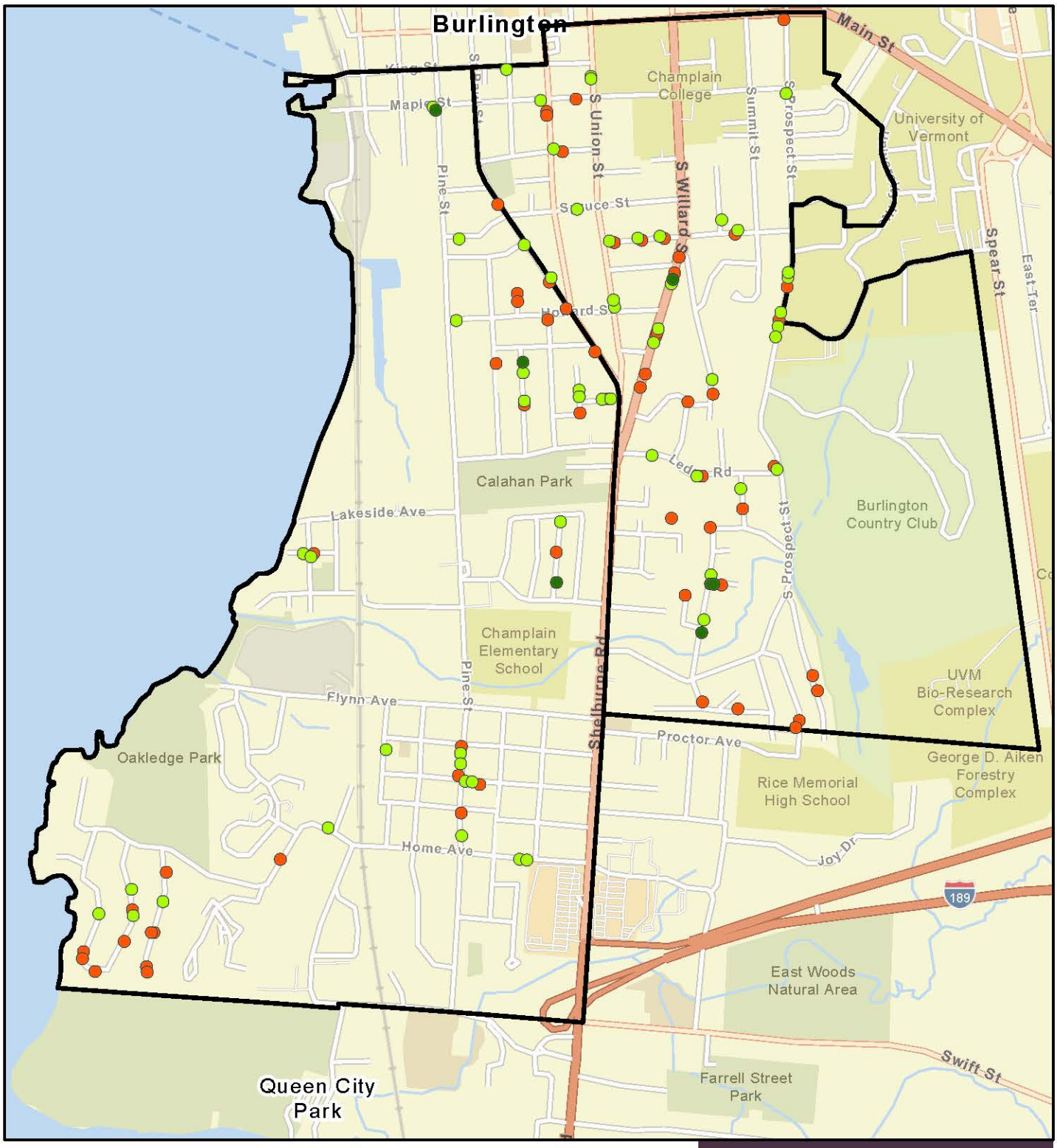
Attachment A: Soil Boring Status Map



LEGEND

- Wards 5 & 6 Boundary

Soil Boring Locations

- Boring Completed
- Boring Completed, Infiltration Testing Completed
- Location Discarded due to conflicts

Source: Esri World Topography

Path: O:\PROJ-17\WRM\17-061-E Burlington ROW Scoping Wards 5-6\GIS\MapDocuments\DataDevelopment\17-061E_BTV_Wards5_6\17-061E_BTV_Wards5_6.aprx

N

0 600 1,200

Feet

Attachment A: Soil Boring Status Map

Right of Way Condition Inventory for Stormwater Management, Phase I - Wards 5&6, City of Burlington, VT

Prepared for Dan Albrecht, CCRPC and James Sherrard, City of Burlington

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Attachment B: Flyer for Stakes/Pre-Marking

Right-of-Way Condition Inventory for Stormwater Management – Wards 5&6

Stone Environmental is leading a scoping effort to determine where it may be feasible to treat stormwater runoff within the Wards 5&6 drainage area in Burlington, VT. This stake represents the location of a proposed soil boring.

PLEASE DO NOT REMOVE

Please contact the Department of Public Works, Water Resources Division at 802-863-4501 with any questions

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Attachment C: Spreadsheet of Locations Analyzed

Soil Boring Status					
Boring	Address	Status	Date	Soil Condition / Notes	Infiltration Rate (in/hr)
2	Near 60 Austin Drive	Hand Auger	12/22/2019	No Capacity for Infiltration	N/A
3	91 Austin Drive	Discarded	N/A	Utility Conflicts	N/A
4	136 Dunder Road	Discarded	N/A	Irrigation	N/A
5	136 Dunder Road	Discarded	N/A	Irrigation	N/A
6	80/96 Dunder Road	Not Considered	N/A	Poor Topography	N/A
7	97 Dunder Road	Discarded	N/A	Utility Conflicts	N/A
8	56 Dunder Road	Hand Auger	11/5/2020	No Capacity for Infiltration	N/A
9	285 South Cove Road	Not Considered	N/A	Poor Topography	N/A
10	24/36 Dunder Road	Discarded	N/A	Utility Conflicts	N/A
11	317 South Cove Road	Hand Auger	11/5/2020	No Capacity for Infiltration	N/A
12	285 South Cove Road	Hand Auger	11/5/2020	No Capacity for Infiltration	N/A
13	241/267 South Cove Road	Discarded	N/A	Bedrock in Vicinity	N/A
14	191 South Cove Road	Not Considered	N/A	No Run-on	N/A
15	159 South Cove Road	Discarded	N/A	Poor Topography and Soils	N/A
16	169 South Cove Road	Not Considered	N/A	Poor Soils	N/A
17	111 South Cove Road	Hand Auger	11/5/2020	No Capacity for Infiltration	N/A
18	End of Crescent Terrace	Not Considered	N/A	Poor Topography and Minimal Impervious Drainage	N/A
19	46 Crescent Road	Hand Auger	11/5/2020	Good Infiltrative Capacity	8.27
19_2	46 Crescent Road	GeoProbe	5/6/2021	Good Infiltrative Capacity	N/A
20	50 Crescent Road	Hand Auger	6/24/2020	Good Infiltrative Capacity	N/A
21	884/887 South Prospect Street	Not Considered	N/A	BMPs Already Considered in Vicinity	N/A
22	884 South Prospect Street	Not Considered	N/A	BMPs Already Considered in Vicinity	N/A
23	10 Holt Street	Not Considered	N/A	BMPs Already Considered in Vicinity	N/A
24	10 Holt Street	Not Considered	N/A	BMPs Already Considered in Vicinity	N/A
25	94 Glen Road	Discarded	N/A	Contentious Home Owners	N/A
26	2/4 Crescent Road	Discarded	N/A	Utility Conflicts	N/A
27	Corner of Ferguson and Pine	Discarded	N/A	Utility Conflicts	N/A
28	905 Pine Street	Hand Auger	6/24/2020	No Capacity for Infiltration	N/A
29	915 Pine Street	Hand Auger	6/24/2020	No Capacity for Infiltration	N/A
30	72 Lyman Avenue	Not Considered	N/A	Density Considerations	N/A
31	75/79 Lyman Avenue	Hand Auger	12/22/2019	No Capacity for Infiltration	N/A
32	83 Lyman Avenue	Hand Auger	6/24/2020	No Capacity for Infiltration	N/A
33	89 Lyman Avenue	Not Considered	N/A	Large Trees	N/A
34	161 Home Avenue	Hand Auger	6/24/2020	Moderate Infiltrative Soils to Refusal (58") - Many rocks	N/A
35	St. Paul/Howard Street	Discarded	N/A	Construction Project Taking Place	N/A
36	418 St. Paul Street	GeoProbe	5/6/2021	No Capacity for Infiltration	N/A
37	239 Maple Street	Not Considered	N/A	Large Trees	N/A
38	Howard Street/Pine Street	Hand Auger	7/24/2020	No Capacity for Infiltration	N/A
39	2 Golden Place	Not Considered	N/A	Minimal Drainage	N/A
40	6 Golden Place	Not Considered	N/A	Minimal Drainage	N/A
41	Saint Paul Street	Not Considered	N/A	Elevated Green Strip With Many Trees	N/A
42	544/550 South Willard Street	Discarded	N/A	Utility Conflicts	N/A
43	536 South Willard Street	Discarded	N/A	Poor Topography	N/A
44	500 South Willard Street	Hand Auger	7/24/2020	Good Infiltrative Soils	N/A
45	498 South Willard Street	Discarded	N/A	Minimal Available Space	N/A
46	498 South Willard Street	Discarded	N/A	Minimal Available Space	N/A
47	480 South Willard Street	Hand Auger	7/24/2020	Moderate Infiltrative Capacity - Shallow SHGW	N/A
48	436 South Willard Street	Hand Auger	7/24/2020	Moderate Infiltrative Soils to Refusal (36")	N/A
49	426 South Willard Street	Hand Auger	7/24/2020	Excellent Infiltrative Soils	>30.79
50	416 South Willard Street	Discarded	N/A	Poor Topography and Trees	N/A
51	15 Deforest Road	Not Considered	N/A	Bedrock in Vicinity	N/A
52	433 South Prospect Street	Hand Auger	6/19/2020	No Capacity for Infiltration - Shallow SHGW	N/A
53	429 South Prospect Street	Hand Auger	6/19/2020	No Capacity for Infiltration - Shallow SHGW	N/A
54	443 South Prospect Street	Discarded	N/A	Utility Conflicts	N/A
55	473/487 South Prospect Street	Not Considered	N/A	Better Opportunity Next Door	N/A
56	487 South Prospect Street	Hand Auger	6/19/2020	No Capacity for Infiltration - Shallow SHGW	N/A
57	499 South Prospect Street	Hand Auger	6/19/2020	No Capacity for Infiltration - Shallow SHGW	N/A
58	463/473 South Prospect Street	Hand Auger	6/19/2020	No Capacity for Infiltration - Shallow SHGW	N/A
59	16 Summit Ridge	Hand Auger	7/24/2020	No Capacity for Infiltration - Shallow SHGW	N/A
60	135/145 Cliff Street	Not Considered	N/A	Minimal Available Space / Elevated ROW	N/A
61	144 Cliff Street	Hand Auger	5/6/2021	No Capacity for Infiltration - Shallow SHGW	N/A
62	84 Deforest Heights	Hand Auger	7/24/2020	No Capacity for Infiltration - Bedrock	N/A
63	96 Deforest Heights	Not Considered	N/A	Bedrock in Vicinity	N/A
64	59 Iranistan Road	Not Considered	N/A	Irrigation	N/A
65	Ledge Road/South Prospect Street	Hand Auger	6/24/2020	No Capacity for Infiltration - Shallow SHGW	N/A
65_2	Ledge Road/South Prospect Street	Hand Auger	6/24/2020	No Capacity for Infiltration - Shallow SHGW	N/A
65_3	Ledge Road/South Prospect Street	GeoProbe	5/6/2021	No Capacity for Infiltration - Shallow SHGW	N/A
66	603 Ledge Road	Not Considered	N/A	Minimal Available Space	N/A
67	137 Ledge Road	Hand Auger	6/24/2020	Minimal Infiltrative Capacity - Shallow SHGW (24")	N/A
67_2	137 Ledge Road	GeoProbe	5/6/2021	Minimal Infiltrative Capacity - Shallow SHGW (24")	N/A
68	35 Hillcrest Road	Not Considered	N/A	Utility Conflicts	N/A
69	171 Crescent Road	Not Considered	N/A	No Drainage to Location	N/A
70	152 Crescent Road	Not Considered	N/A	Utility Conflicts	N/A
71	120 Crescent Road	Hand Auger	12/22/2019	Moderate Infiltrative Capacity - Shallow SHGW (40")	N/A
71_2	120 Crescent Road	GeoProbe	5/6/2021	Moderate Infiltrative Capacity - Shallow SHGW (40")	N/A

72	88 Crescent Road	Hand Auger	11/5/2020	Good Infiltrative Soils - Confining Layer at 48"	8.16
73	15 Woodcrest Lane	Not Considered	N/A	Better Opportunity Next Door	N/A
74	207 South Union Street	Hand Auger	11/12/2020	No Capacity for Infiltration	N/A
75	South Winooski Avenue at Maple Street	Hand Auger	11/12/2020	No Capacity for Infiltration	N/A
76	227 South Winooski Avenue	Discarded	N/A	Utility Conflicts	N/A
77	78 Adams Street	Hand Auger	11/12/2020	No Capacity for Infiltration	N/A
78	83 Adams Street	Discarded	N/A	Utility Conflicts	N/A
79	75 Spruce Street	Hand Auger	11/12/2020	No Capacity for Infiltration	N/A
80	Marion Street	Hand Auger	11/12/2020	Minimal Infiltrative Capacity - Shallow SHGW (26")	N/A
81	Legemere Street at Margaret Street	Not Considered	N/A	No Drainage to Location	N/A
82	88 Crescent Road	Hand Auger	11/5/2020	Good Infiltrative Soils - Confining Layer at 48"	8.16
83	32 Legemere Street	Hand Auger	11/19/2020	No Capacity for Infiltration	N/A
84	22 Legemere Street	Hand Auger	11/19/2020	No Capacity for Infiltration	N/A
85	92 Charlotte Street	Not Considered	N/A	Utility Conflicts	N/A
86	88 Charlotte Street	Hand Auger	11/19/2020	No Capacity for Infiltration	N/A
87	59 Charlotte Street	Hand Auger	11/19/2020	Excellent Infiltrative Soils	N/A
88	46 Charlotte Street	Hand Auger	11/19/2020	Excellent Infiltrative Soils	18.24
89	112 Locust Terrace	Not Considered	N/A	Minimal Avialable Space / Trees	N/A
90	3 Caroline Street	Not Considered	N/A	Utility Conflicts	N/A
91	15 Pine Place	Hand Auger	12/3/2020	No Capacity for Infiltration	N/A
92	103 Maple Street	Hand Auger	12/3/2020	Good Infiltrative Soils	N/A
93	Pine Street at Maple Street	Hand Auger	12/3/2020	Good Infiltrative Soils	16.08
94	199 Church Street	Hand Auger	12/3/2020	No Capacity for Infiltration	N/A
95	444 South Union Street	Hand Auger	12/3/2020	Minimal Infiltrative Capacity - Shallow SHGW (27")	N/A
96	444 South Union Street	Hand Auger	12/3/2020	No Capacity for Infiltration	N/A
97	101 Ledge Road	Discarded	N/A	Utility Conflicts	N/A
98	89 Ledge Road	Hand Auger	12/3/2020	No Capacity for Infiltration	N/A
99	171 Home Avenue	Hand Auger	12/10/2020	Moderate Infiltrative Soils to Refusal (48") - Many rocks	N/A
100	Marion Street	Hand Auger	11/12/2020	Minimal Infiltrative Capacity - Shallow SHGW (22")	N/A
101	Marion Street	Hand Auger	11/12/2020	Minimal Infiltrative Capacity - Shallow SHGW (26")	N/A
102	235 South Winooski Street	Discarded	N/A	Utility Conflicts	N/A
103	207 South Union Street	Hand Auger	11/12/2020	No Infiltrative Capacity - Shallow SHGW	N/A
104	86 Alder Lane	Hand Auger	4/8/2021	Good Infiltrative Soils - Confining Layer at 40"	N/A
105	22 Alder Lane	Hand Auger	4/8/2021	Good Infiltrative Soils - Confining Layer at 40"	21
106	53 Alder Lane	Discarded	N/A	Utility Conflicts	N/A
107	984 Pine Street	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
108	956 Pine Street	Discarded	N/A	Poor Soils	N/A
109	Briggs Street	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
110	33 Central Avenue (on Wright)	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
111	32 Central Ave (on Central)	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
112	32 Central Avenue (on Wright)	Discarded	N/A	Density Considerations	N/A
113	35 Ledge Road	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
114	56 Cliff Street	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
115	61 Cliff Street	Discarded	N/A	Density Considerations	N/A
116	39 Cliff Street	Discarded	N/A	Density Considerations	N/A
117	38 Cliff Street	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
118	378 South Union Street (on Cliff)	Hand Auger	4/8/2021	No Capacity for Infiltration - Shallow SHGW	N/A
119	15 Cliff Street	Discarded	N/A	Density Considerations	N/A
120	375 Saint Paul Street	GeoProbe	5/6/2021	No Capacity for Infiltration - Shallow SHGW	N/A
121	423 Saint Paul Street	Discarded	N/A	Poor Soils	N/A
122	153 South Prospect	Discarded	N/A	Utility Conflicts	N/A
123	231 South Prospect	Hand Auger	5/6/2021	No Capacity for Infiltration - Shallow SHGW	N/A

Attachment D: Infiltration Test Results

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	11/19/2020
Sampling Personnel:	BAM / PCL
Backhoe test pit #:	19
Auger hole radius:	1.5 in
Auger hole depth:	20 in

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	66	66	16	2	
	180	114	14	2	
	300	120	12	2	
	410	110	10	2	18.18181818
	520	110	8	2	18.18181818
	620	100	6	2	20
	707	87	4	2	22.98850575
	813	106	2	2	18.86792453
2	0		18		
			16	2	
	80	80	14	2	25
	167	87	12	2	22.98850575
	300	133	10	2	15.03759398
	420	120	8	2	16.66666667
	544	124	6	2	16.12903226
	667	123	4	2	16.2601626
3	0	0	16	2	
		0	14	2	
	113	113	12	2	17.69911504
	198	85	10	2	23.52941176
	318	120	8	2	16.66666667
	418	100	6	2	20
	528	110	4	2	18.18181818
	628	100	2	2	20
4	0	0	18	2	
	58	58	16	2	
	160	102	14	2	19.60784314
	285	125	12	2	16
	390	105	10	2	19.04761905
	503	113	8	2	17.69911504
	610	107	6	2	18.69158879
	715	105	4	2	19.04761905
	795	80	2	2	25

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average Δv/Δt for last run

$s_i < 2L_w$ $$K = \frac{3Q}{\pi L_w (3L_w + 2S_i)} \ln \frac{L_w}{r_w}$$

$s_i > 2L_w$ $$K = \frac{Q_e}{2\pi L_w^2} \left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Confining Layer:

$s_i > 2L_w$

$s_i < 2L_w$

Results $s_i < 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	157.48	cm
Q_e =	18	cm^3/sec
K =	0.0024	cm/sec
	7	ft/day
	3.4413	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**157.48**	**cm**
Q_e =	**18**	**cm^3/sec**
K =	**0.0058**	**cm/sec**
	17	**ft/day**
	8.27193	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	5/13/2021
Sampling Personnel:	BAM / MLS
Backhoe test pit #:	49
Auger hole radius:	1.5"
Auger hole depth:	27"

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	30	30	20	2	66.66666667
	60	30	18	2	66.66666667
	90	30	16	2	66.66666667
	120	30	14	2	66.66666667
	150	30	12	2	66.66666667
	180	30	10	2	66.66666667
	210	30	8	2	66.66666667
	240	30	6	2	66.66666667
	270	30	4	2	66.66666667
	300	30	2	2	66.66666667
2	0	0	22		
	30	30	20	2	66.66666667
	60	30	18	2	66.66666667
	90	30	16	2	66.66666667
	120	30	14	2	66.66666667
	150	30	12	2	66.66666667
	180	30	10	2	66.66666667
	210	30	8	2	66.66666667
	240	30	6	2	66.66666667
	270	30	4	2	66.66666667
	300	30	2	2	66.66666667
3	0	0	22		
	30	30	20	2	66.66666667
	60	30	18	2	66.66666667
	90	30	16	2	66.66666667
	120	30	14	2	66.66666667
	150	30	12	2	66.66666667
	180	30	10	2	66.66666667
	210	30	8	2	66.66666667
	240	30	6	2	66.66666667
	270	30	4	2	66.66666667
	300	30	2	2	66.66666667

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average Δv/Δt for last run

$s_i < 2L_w$ $$K = \frac{3Q}{\pi L_w (3L_w + 2S_i)} \ln \frac{L_w}{r_w}$$

$s_i > 2L_w$ $$K = \frac{Q_e}{2\pi L_w^2} \left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Confining Layer:

$s_i > 2L_w$

$s_i < 2L_w$

Results $s_i < 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	124	cm
Q_e =	67	cm^3/sec
K =	0.0107	cm/sec
	30	ft/day
	15.179	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**124**	**cm**
Q_e =	**67**	**cm^3/sec**
K =	**0.0217**	**cm/sec**
	62	**ft/day**
	30.79	**in/hr**

Note: Equilibrium could not be met even after supplementing inflow and dispersing more than 40 gallons of water into the boring

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	11/19/2020
Sampling Personnel:	BAM / PCL
Backhoe test pit #:	82
Auger hole radius:	1.5 in
Auger hole depth:	20 in

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	20		
	-		18	2	
	-		16	2	
	210		14	2	
	277	67	12	2	29.85074627
	345	68	10	2	29.41176471
	417	72	8	2	27.77777778
	490	73	6	2	27.39726027
	557	67	4	2	29.85074627
	626	69	2	2	28.98550725
2	0		20		
	60	60	18	2	33.33333333
	142	82	16	2	24.3902439
	237	95	14	2	21.05263158
	318	81	12	2	24.69135802
	398	80	10	2	25
	478	80	8	2	25
	560	82	6	2	24.3902439
	639	79	4	2	25.3164557
	714	75	2	2	

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average Δv/Δt for last run

$s_i<2L_w$ $$K=\frac{3Q}{\pi L_w(3L_w+2S_i)}\ln\frac{L_w}{r_w}$$

$s_i>2L_w$ $$K=\frac{Q_e}{2\pi L_w^2}\left[\ln\left(\frac{L_w}{r_w}+\sqrt{\left(\frac{L_w^2}{r_w^2}-1\right)}\right)-1\right]$$

Confining Layer:

$s_i>2L_w$

$s_i<2L_w$

Results $s_i<2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	68.58	cm
Q_e =	25	cm^3/sec
K =	**0.0058**	**cm/sec**
	16	**ft/day**
	8.1632	**in/hr**

Results $s_i>2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	68.58	cm
Q_e =	25	cm^3/sec
K =	0.0081	cm/sec
	23	ft/day
	11.48879	in/hr

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	12/10/2020
Sampling Personnel:	BAM / MLS
Backhoe test pit #:	88
Auger hole radius:	1.5 in
Auger hole depth:	26 in

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	30	30	16	2	66.66666667
	63	33	14	2	60.60606061
	98	35	12	2	57.14285714
	131	33	10	2	60.60606061
	168	37	8	2	54.05405405
	203	35	6	2	57.14285714
	239	36	4	2	55.55555556
	275	36	2	2	55.55555556
2	0	0	20		
	33	33	18	2	60.60606061
	65	32	16	2	62.5
	99	34	14	2	58.82352941
	132	33	12	2	60.60606061
	168	36	10	2	55.55555556
	202	34	8	2	58.82352941
	235	33	6	2	60.60606061
	270	35	4	2	57.14285714
	305	35	2	2	57.14285714

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average $\Delta v/\Delta t$ for last run

$s_i < 2L_w$ $$K = \frac{3Q}{\pi L_w (3L_w + 2S_i)} \ln \frac{L_w}{r_w}$$

$s_i > 2L_w$ $$K = \frac{Q_e}{2\pi L_w^2} \left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Confining Layer:

$s_i > 2L_w$

$s_i < 2L_w$

Results $s_i < 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	71.12	cm
Q_e =	57	cm^3/sec
K =	**0.0129**	**cm/sec**
	36	**ft/day**
	18.243	**in/hr**

Results $s_i > 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	71.12	cm
Q_e =	57	cm^3/sec
K =	0.0185	cm/sec
	52	ft/day
	26.19445	in/hr

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	12/10/2020
Sampling Personnel:	BAM / MLS
Backhoe test pit #:	93
Auger hole radius:	1.5 in
Auger hole depth:	27 in

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	50	50	20	2	40
	101	51	18	2	39.21568627
	158	57	16	2	35.0877193
	213	55	14	2	36.36363636
	269	56	12	2	35.71428571
	328	59	10	2	33.89830508
	384	56	8	2	35.71428571
	439	55	6	2	36.36363636
	495	56	4	2	35.71428571

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average $\Delta v/\Delta t$ for last run

$s_i < 2L_w$ $$K = \frac{3Q}{\pi L_w (3L_w + 2S_i)} \ln \frac{L_w}{r_w}$$

$s_i > 2L_w$ $$K = \frac{Q_e}{2\pi L_w^2} \left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Confining Layer:

$s_i > 2L_w$

$s_i < 2L_w$

Results $s_i < 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	121.92	cm
Q_e =	35	cm^3/sec
K =	0.0057	cm/sec
	16	ft/day
	8.0214	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**121.92**	**cm**
Q_e =	**35**	**cm^3/sec**
K =	**0.0113**	**cm/sec**
	32	**ft/day**
	16.0843	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 5 & 6 ROW
SEI Study #:	17-061-E
Date:	5/13/2021
Sampling Personnel:	BAM / MLS
Backhoe test pit #:	104
Auger hole radius:	105 in
Auger hole depth:	27 in

Field Measurements:

Run	Time (t) seconds	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	23	23	20	2	86.95652174
	68	45	18	2	44.44444444
	104	36	16	2	55.55555556
	144	40	14	2	50
	186	42	12	2	47.61904762
	226	40	10	2	50
	266	40	8	2	50

Calculations:

K = hydraulic conductivity (cm/sec)
L_w = wetted length of auger hole (cm)
r_w = radius of auger hole (cm)
S_i = vertical distance from bottom of auger hole to impeding layer (cm)
Q_e = equilibrium rate of water added (cm^3/sec) = average Δv/Δt for last run

$s_i < 2L_w$ $$K = \frac{3Q}{\pi L_w (3L_w + 2S_i)} \ln \frac{L_w}{r_w}$$

$s_i > 2L_w$ $$K = \frac{Q_e}{2\pi L_w^2} \left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Confining Layer:

$s_i > 2L_w$

$s_i < 2L_w$

Results $s_i < 2L_w$		
L_w =	38	cm
r_w =	3.8	cm
S_i =	40.64	cm
Q_e =	50	cm^3/sec
K =	0.0148	cm/sec
	42	ft/day
	20.998	in/hr

Results $s_i > 2L_w$		
L_w =	38	cm
r_w =	3.8	cm
S_i =	40.64	cm
Q_e =	50	cm^3/sec
K =	0.0162	cm/sec
	46	ft/day
	22.97759	in/hr

Attachment E: Standard Operating Procedure SEI-5.99.0

STANDARD OPERATING PROCEDURE

SEI-5.99.0

MEASURING HYDRAULIC CONDUCTIVITY IN UNSATURATED SOILS

SOP Number: 5.99.0
Revision Number: 0

Date Issued: 04/22/2020
Date of Revision: n/a

1.0 OBJECTIVE

This standard operating procedure (SOP) describes the procedure used by Stone Environmental, Inc. (SEI) staff to measure hydraulic conductivity in unsaturated soils using the Well Pump-In Technique, which is briefly outlined in Bouwer and Jackson, 1974. A hole is augered in the desired interval, and water is pumped into the hole until an equilibrium flow rate is achieved. The equilibrium flow rate is then used to calculate hydraulic conductivity. This SOP describes the procedure to be followed and describes how to document the process.

2.0 POLICIES

1. SEI personnel will read and understand this SOP prior to performing the procedure in the field.

3.0 SAFETY ISSUES

1. Work may be performed near heavy equipment or in backhoe test pits. Before entering soil test pits, SEI employees must be trained in OSHA 1926.651, Subpart P, Excavations, and use proper safety precautions.

4.0 PROCEDURES

4.1 Materials

The following materials are needed and must be available during the procedure:

1. Auger with extension flights
2. Shovel
3. Water source or containers of water
4. Dispensing bucket marked in 1- or 2- liter increments
5. Perforated pipe with filter fabric sleeve

6. Tape measure
7. Watch or stopwatch (preferably digital)
8. Marker, pens
9. Data collection form
10. Clipboard
11. Site map
12. Calculator (with scientific functions)

4.2 Preparation

Before performing this hydraulic conductivity test in the field, the following preparations should be made:

1. Ensure that a water source is available on-site (or nearby off-site), as each hydraulic conductivity test may take 15-30 gallons of water to complete. A 50-gallon barrel is available if you must transport water to the test site.
2. Calibrate a dispensing bucket in either 1- or 2- liter increments using a graduated cylinder. A 5-gallon bucket works well in the field in terms of portability but may be somewhat small if the hydraulic conductivity test is to be conducted in very coarse sands.
3. Modify the bucket so that outflow from the bucket may be easily controlled. Figure 1 shows a diagram of the dispensing bucket that will be used for this test.
4. Measure the diameter of the soil auger to be used in the hydraulic conductivity test. Use perforated PVC pipe that has a slightly larger diameter than that of the soil auger (i.e. 4 in. diameter PVC for a 3 in. diameter soil auger). Ideally, when you drive the PVC pipe into the augered hole, there should be no space between the pipe and the surrounding soil.
5. Measure and cut the perforated PVC pipe appropriately. For this method, the piece of pipe must be *at least* 10 times longer than its radius. Thus, for a pipe with a 4-inch diameter, the length must be at least 20 inches. It is recommended that the pipe be 18-20 times longer than its radius to prevent the top of the augered hole from caving. Figure 2 shows the correctly cut PVC pipe *in situ*.
6. Print out or photocopy an appropriate supply of data collection forms (shown in Figure 3).

4.3 Site Selection

An appropriate interval for the hydraulic conductivity test is chosen after the soil properties for the entire test pit are logged. The test interval will be located below any developed horizons in the soil profile at the top of the interval you wish to test. The test interval should not be located partly or completely in silty or clay-rich layers, as this method is only appropriate for unconsolidated sands. The perforated interval of the PVC pipe must be placed entirely within the layer to be tested. If the interval to be tested is more than 1 foot below ground surface, it may be necessary for the backhoe

operator to bench the test pit at the top of the interval. It is very important, however, that the hydraulic conductivity test be conducted in *undisturbed* soils.

4.4 Field Procedure

The letters in parenthesis in the following procedure refer to variables that must be recorded for use in the hydraulic conductivity calculations described in Section 4.5.

1. Auger a hole with a depth more than 10 times the radius (r_w) of the hole.
2. Put perforated pipe inside auger hole, driving the pipe into the hole if necessary.
3. Fill the pipe with water from the dispensing bucket to a depth(L_w) that is 10 times the radius.
4. Record the change in water level in the dispensing bucket over time until the flow rate rate (Qe) reaches equilibrium. Equilibrium is assumed when at least 3 consecutive flow rates are within 2 seconds/liter of each other.
    i. At the beginning of the test, water inflow from the calibrated bucket may be supplemented to keep the water level near equilibrium, but any flow rate measurements taken during this time should not be used to calculate hydraulic conductivity.
5. Using the equations in Section 4.5, calculate the hydraulic conductivity (K).
6. If the hydraulic conductivity value appears to be reasonable, use the shovel to dig out the perforated pipe.

4.5 Calculations

Use the following equations to calculate hydraulic conductivity in the field. In the equations, S_i is the distance from the bottom of the auger hole to the top of the impermeable layer (if no impermeable layer is encountered, assume that the bottom of the test pit constitutes an impermeable layer). If S_i is greater than 2 times L_w, use Equation 1 to calculate hydraulic conductivity. If $S_i < 2L_w$, use Equation 2.

Upon returning to the office, enter the data into a table or Excel spreadsheet such as that shown in Table 1.

Equation 1:

$$K = \frac{Q_e}{2\Pi L_w^2}\left[\ln\left(\frac{L_w}{r_w} + \sqrt{\left(\frac{L_w^2}{r_w^2} - 1\right)}\right) - 1\right]$$

Equation 2:

$$K = \frac{3Q_e \ln \frac{L_w}{r_w}}{\pi L_w (3L_w + 2S_i)}$$

where:

K = hydraulic conductivity (cm/sec)

Q_e = equilibrium flow rate (cm^3/sec, calculated by averaging $\Delta v/\Delta t$ for last "run" of flow rate measurements

L_w = wetted depth of perforated PVC pipe (cm)

r_w = auger hole radius; same as radius of perforated PVC pipe (cm)

S_i = distance from bottom of auger hole to top of impermeable layer (cm)

5.0 RESPONSIBILITIES

5.1 Principals/Group Officers/Group Leaders/Personnel

1. SEI personnel will have read and understood the procedures set forth in this SOP prior to performing the procedure in the field.
2. SEI personnel will ensure that appropriate documentation as noted in this SOP is maintained with the study files.

6.0 DEFINITIONS

1. *Standard Operating Procedures (SOP)* means standard documented operating procedures, which describe how to perform tests or activities normally not specified in detail in study plans or test guidelines.

7.0 REFERENCES

OSHA 1926.651, Subpart P, Excavations.

Bouwer, H. and R.D. Jackson. 1974. Determining soil properties. *Agronomy Monographs*, 17: 611-672.

8.0 TABLES, DIAGRAMS, FLOWCHARTS, AND VALIDATION DATA

Figure 1. Diagram of Dispensing Bucket

Figure 2. Schematic of Well-Pump-in Technique (including perforated PVC pipe)

Figure 3. Data Collection Form for Hydraulic Conductivity Measurement

Table 1. Data Reporting Form for Hydraulic Conductivity Measurement

Figure 1. Diagram of Dispensing Bucket

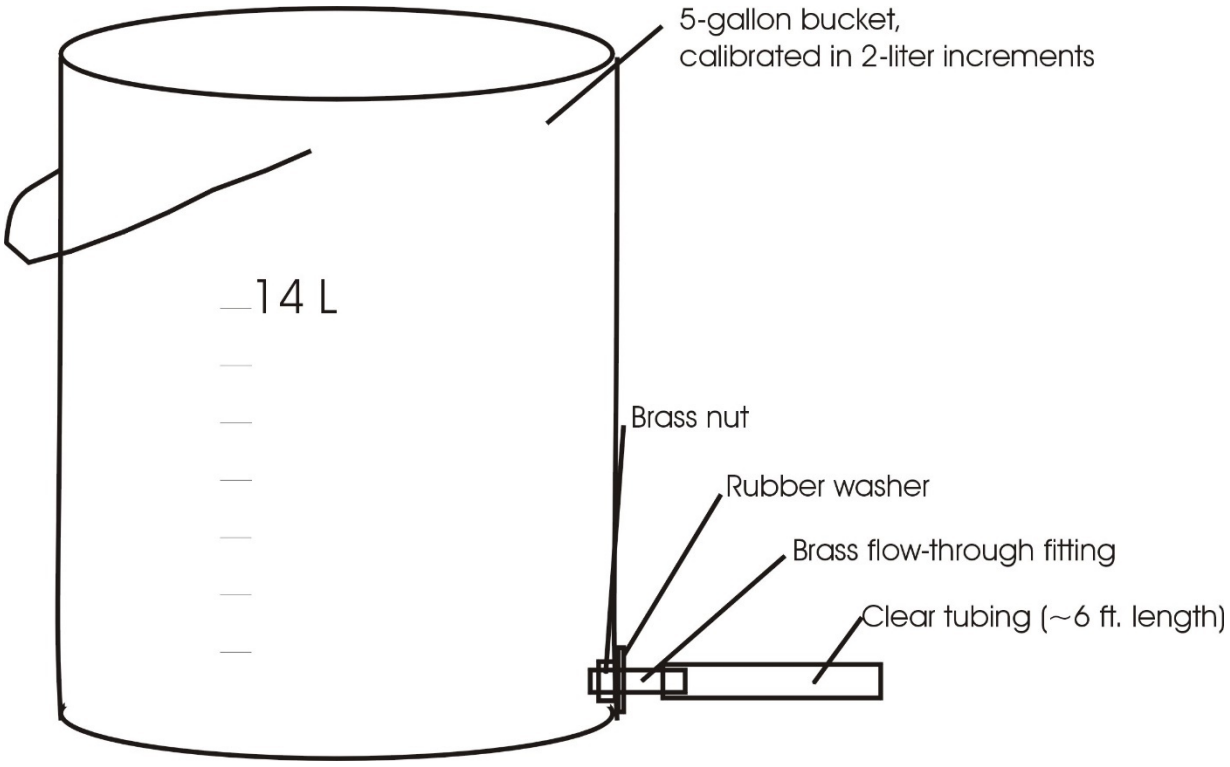
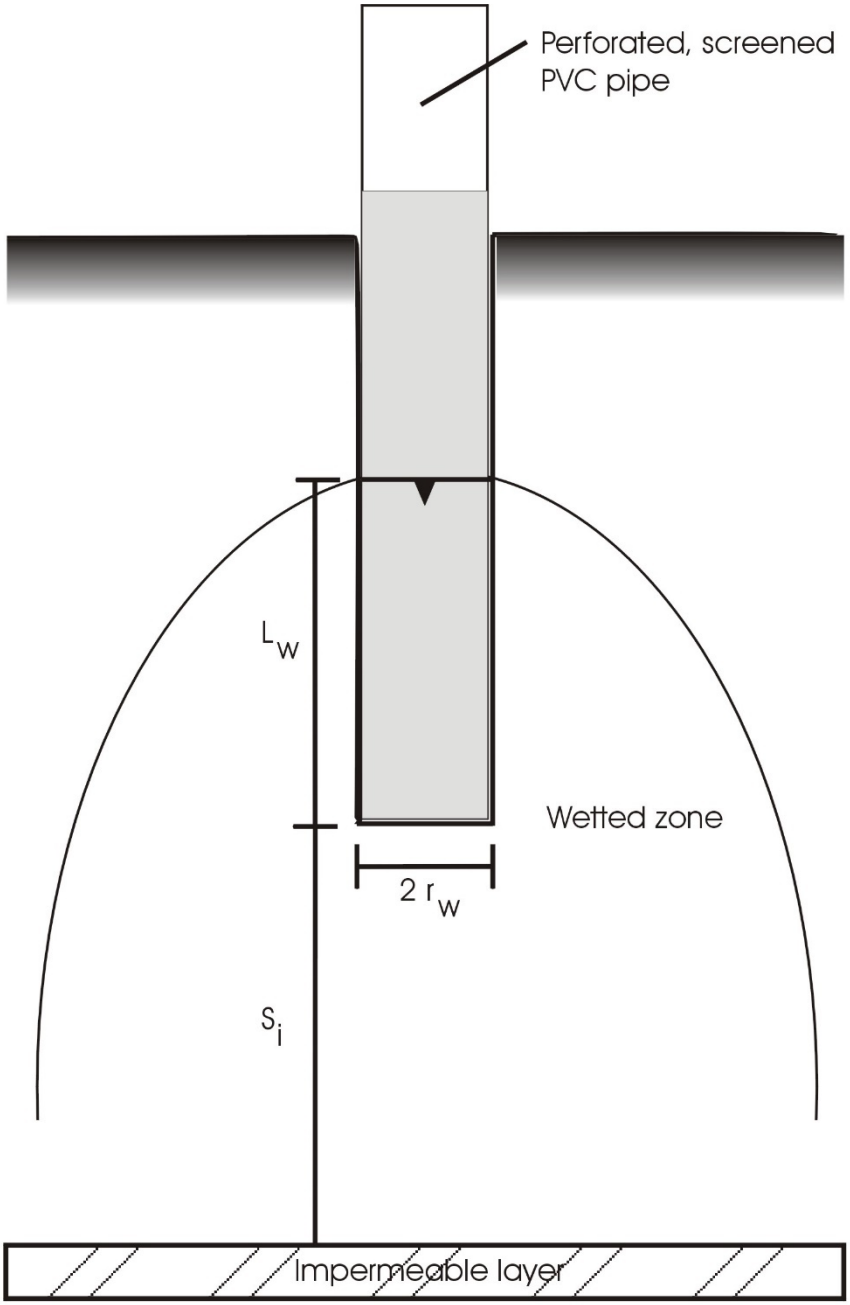


Figure 2. Schematic of Well Pump-in Technique (including perforated PVC pipe)



ATTACHMENTS

Figure 3: Data Collection Form for Hydraulic Conductivity Measurement

Table 1: Data Reporting Form for Hydraulic Conductivity Measurement

Pages 628-9 from Bouwer and Jackson, 1974