Right of Way Condition Inventory for Stormwater Management, Phase II - Wards 2&3 City of Burlington, Vermont

STONE ENVIRONMENTAL

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PROJECT NO.

17-061-E

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BAM

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Disclaimer:

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Cover Photo: Soil Investigation at 16 Loomis Street on March 31, 2022.

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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 2 and 3. 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 virtually on July 27, 2021. Project goals, objectives, community outreach and Arc GIS data management logistics were discussed. An additional, kickoff meeting was held on August 11, 2021 with the City to discuss GIS data layers and management and detailed aspects of the project.

In Phase I (Wards 5 and 6), Stone obtained and organized the necessary geospatial datasets, for both the desktop analysis and ArcGIS Online web maps, within the City. These data encompassed Wards 2 and 3 and continued to be used in Phase II. 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

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- Natural resource constraints (wetlands, flood hazard areas, river corridors, etc.)

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 2 or 3
- Areas spaced to be representative of the range of soils and subsurface conditions known to exist throughout Wards 2 and 3
- 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 2 and 3, 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

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- No Electric Support Structures within the ROW area
- ROW Width > 5 ft
- Not within an existing Public/Private BMP drainage area
- Not within 150 meters of Complete/Final Design/Under Construction BMPs
- ROW is on Exterior (street side of sidewalk or no sidewalk present), or ROW is on Interior of city-owned parcels

Stone documented the site selection as stated above, and the web map was provided to the City for consideration. After feedback from the City which requested additional analysis around the Greene Street and Hickcok Place intersection. Stone identified supplementary sites by reducing the available ROW width criteria from five to four feet and hand selecting several sites around the Green Street and Hickok Place intersection. Upon completion of this refinement and inclusion of additional boring sites, the initial screening yielded 100 possible stormwater treatment practice areas to be investigated.

Unfortunately, there were not any viable locations south of Pearl Street due to either utility conflicts, hazardous waste sites, power poles being present, and/or being designated as an 'Interior' ROW area. The latter we excluded to avoid issues with landowners when the ROW is on the inside strip of land rather than the outside (i.e. street side of sidewalk or landowner side of sidewalk).

4. First Round of Soil Investigation

The initial 100 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 some instances, locations were removed from the list for further investigation due to large trees, a more favorable location in close proximity, lack of available right of way, first-hand knowledge gained regarding utilities, input from the City, topographic restrictions, and drainage area size and characteristics. Ultimately, 20 sites were removed from the list of potential 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 notify 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 80 sites were pre-marked for utility clearance in groups of approximately 15 at a time. This was done in an effort to group locations by neighborhood, gain clearance for a reasonable number of locations to advance soil borings in a 30-day window, and not overwhelm utility providers. After utility markings had been made, an additional 30 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 the end of April 2022, Stone had conducted the first round of successful soil borings at 50 sites.

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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. The borings were advanced to a depth where a substantial limiting layer or seasonal high-water table was found, refusal was encountered and the boring was conclusive about the infiltrative potential in that location, or a depth of approximately 120" was reached without any indications of seasonal high-water table. In general, at the vast majority of sites we were able to determine conditions were favorable for infiltration to a sufficient depth to support stormwater treatment via infiltrative practices.

5. Additional Utility Screening and Second Round of Soil Investigation

The scope of work included advancing up to 56 borings at 28 locations or more throughout Wards 2 and 3. Based on previous discussions with the City during the Phase I (Wards 5 and 6) study and discussions at the kick-off meeting, it was established that evaluating more locations is more useful to the City than having multiple borings in the same location. Therefore, we continued utilizing the "broad brush" approach that would allow more areas to be evaluated throughout Wards 2 and 3.

To generate new soil boring sites, the desktop analysis was refined to reduce the criteria of available ROW width from five feet to four feet. This refinement provided an additional 61 sites to be evaluated.

After site selection and input from the City, Stone pre-marked and submitted DigSafe tickets for an additional 12 boring sites. Particular focus was placed in portions of Wards 2 and 3 which had noticeable gaps in soil borings. Stone ultimately advanced soil borings at all 12 of the sites, bringing the total number of soil borings advanced in Wards 2 and 3 to 62.

6. GeoProbe Borings

Stone successfully advanced all soil borings via hand auger within Wards 2 and 3 and did not have to utilize a GeoProbe for supplemental borings.

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 a selection of sites with soils characterized as favorable for infiltration, Stone identified infiltration rates ranging from 2.7 in/hr to over 28 in/hr, as seen in Table 1 below.

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Table 1. Measured Infiltration Rates

Boring #	Address	Infiltration Rate (in/hr)
146	16 Loomis Street	7.04
151	Charles and Russell Street	19.70
161	93 Intervale Avenue	8.28
166	227 Intervale Avenue	2.71
168	219 Intervale Avenue	5.30
171	Willow Street	3.11
177	80 Ward Street	17.95
182	258 North Avenue	20.43
187	39 Pitkin Street	12.95
191	Drew and Strong Street	8.23
200	38 Monroe Street	5.85
208	116 Hyde Street	14.00
210	3 Spring Street	6.55
214	7 Canfield Street	28.21

8. Summary of Results

In total, Stone has assessed over 161 potential boring locations throughout Wards 2 and 3 and successfully advanced soil borings at 62 unique sites. 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 favorable results.

While investigating soils within Wards 2 and 3, 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.

Generally, soils within Wards 2 and 3 were found to be very suitable for infiltrative stormwater practices. Seasonal high-water table (SHWT) and/or restrictive soils were not encountered at shallow depths across most of this part of the City, with a few exceptions. The areas identified with moderate to poor conditions for infiltration and stormwater treatment are:

- 40 Hickok Place
    - The soil profile transitions from Fine Sandy Loam (0”-8”), to Sandy Loam (8”-18”), to a Very Fine Sandy Loam (18”-41”) that increased in firmness and compaction with depth. Few faint redoximorphic features were present in the bottom horizon.

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- 32 Greene Street
    - The soil profile transitions from Fine Sandy Loam (0”-32”) to dense Clay (32”-50”). Common and distinct redoximorphic features were present in the bottom horizon.
- 16, 39, 78, and 80 Loomis Street
    - 16 Loomis Street transitioned from Fine Sandy Loam (0”-20”), to Fine Sand (20”-36”), to Silty Fine Sand (36”-46”), to Silt Loam (46”-56”). Few faint redoximorphic features were observed at approximately 36”. Common distinct redoximorphic features were observed at 42”.
    - 39 Loomis Street transitioned to Silt Loam at 15” and remained Silt Loam with common distinct redoximorphic features from 15” to 46” where the boring was abandoned.
    - At 78 and 80 Loomis street we encountered a shallow silt loam that transitioned to sands, but the profile was back to a Silt Loam by approximately 45-50”. Redoximorphic features were observed in the upper 30” at both locations.
- 139 North Willard Street
    - The soil profile transitions from Fine Sandy Loam (0”-11”), to Fine Sand (11”-45”), to Silt (45-60”). Common distinct redoximorphic features were first observed at 34”.
- 52 Booth Street
    - The soil profile transitions from Fine Sandy Loam (0”-7”), to Sandy Loam (7”-16”), to Fine Sand (16”-30”), to Very Fine Sand (30”-50”), back to Fine Sand (50”-58”), and eventually to Silt Loam (58”-70”). The soil moisture increased with depth, transitioning from moist to wet around 40”. Redoximorphic features were first observed at 32”.
- 16 Murray Street
    - The soil profile transitions from a Fine Sandy Loam (0”-7”), to a Cobbly Very Coarse Sand (7”-18”), to a Fine Sandy Silt Loam (18”-48”). Common and distinct redoximorphic features were observed within the horizon of Fine Sandy Silt Loam.
- 31 George Street
    - Soils higher in the profile at 31 George Street consist of Fine Sandy Loam, Loamy Fine Sand, Silty Very Fine Sand, and Silt. Below 54” soils are generally Medium-Coarse Sand and Gravelly Medium-Coarse Sand to 100” below ground surface. If the soil could be amended for this area or other areas with similar soil profiles, they could be utilized for infiltrative stormwater treatment during dry seasons.
- Intersection of Grant Street and North Union Street
    - The soil profile transitions from Fine Sandy Loam (0”-6”), to Urban Fill (6”-10”), to Loamy Fine Sand (10”-20”), to Medium Sand (20”-40”), to Silt Loam (40”-82”). Silt Loam compaction increases with depth. Redoximorphic features were first observed at 40” and increase in prevalence with depth.

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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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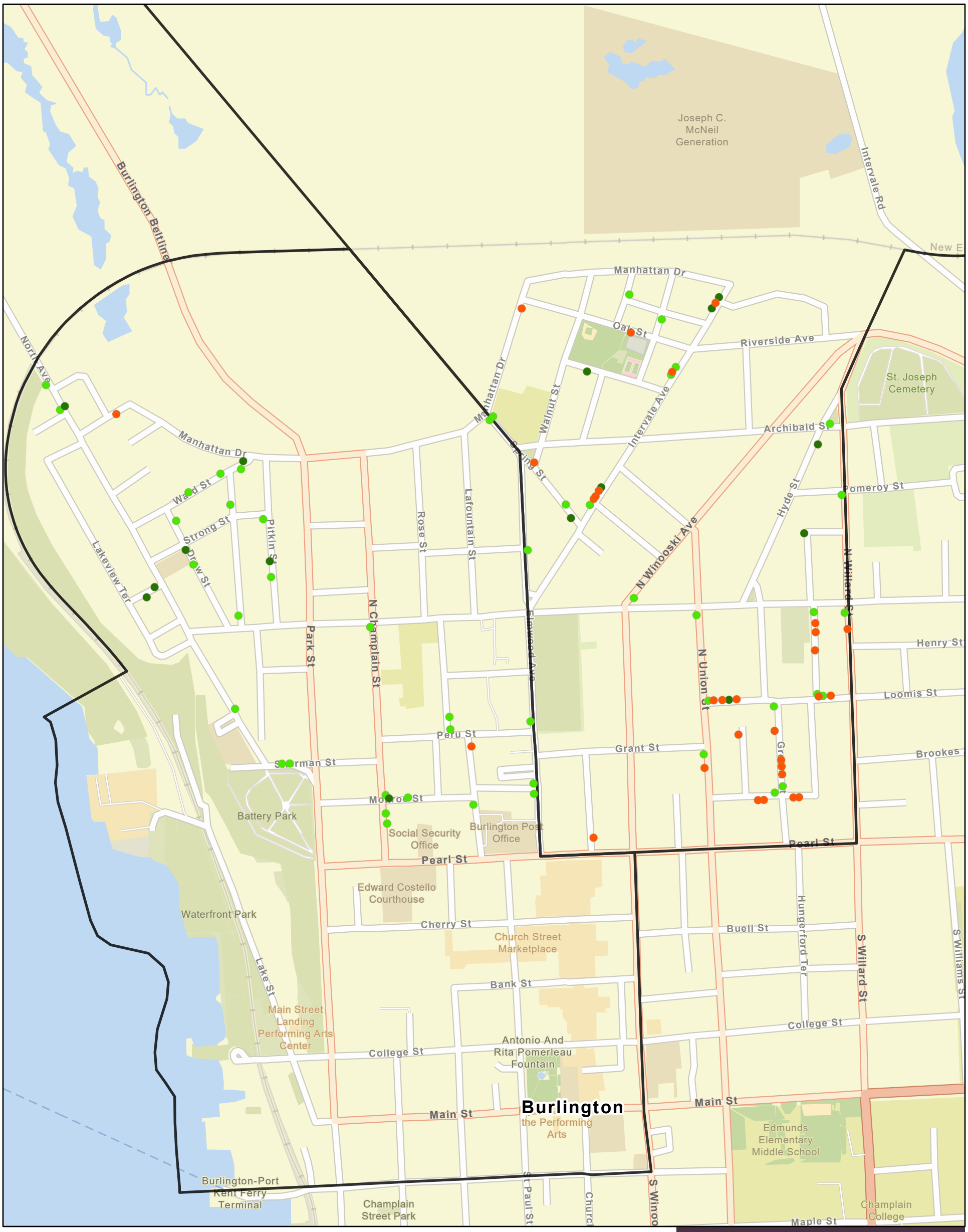
Attachment A: Soil Boring Status Map



LEGEND

- Burlington City Wards Boundaries
- Soil Boring Locations and Status
- Boring Completed
- Boring Completed, Infiltration Completed
- Location Discarded due to conflicts

N

0 430 860

Feet

Source: Esri World Imagery

Path: O:\PROJ-17\WRM\17-061-E Burlington ROW Scoping Wards 5-6\GIS\MapDocuments\DataDevelopment\17-061E_BTV_Wards2_3\17-061E_BTV_Wards2_3.aprx Layout Exported: 6/9/2022 10:55 AM by

Attachment A: Soil Boring Status Map

Right of Way Condition Inventory for Stormwater Management, Phase I - Wards 2&3, City of Burlington, VT

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

Attachment B: Flyer for Stakes/Pre-Marking

Right-of-Way Condition Inventory for Stormwater Management – Wards 2&3

Stone Environmental is leading a scoping effort to determine where it may be feasible to treat stormwater runoff within the Wards 2&3 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

Right-of-Way Condition Inventory for Stormwater Management – Wards 2&3

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Attachment C: Spreadsheet of Locations Analyzed

Soil Boring Status					
Boring	Address	Status	Date	Soil Condition / Notes	Infiltration Rate (in/hr)
127	78 Loomis Street	No Boring	3/31/2022	Density Considerations	
128	80 Loomis Street	Boring Complete	3/31/2022	Little Capacity for Infiltration	
129	84 Loomis Street	No Boring	10/14/2021	Density Considerations	
130	78 Loomis Street	Boring Complete	3/31/2022	No Capacity for Infiltration	
131	39 Loomis Street (On Greene)	Boring Complete	3/21/2022	No Capacity for Infiltration	
132	67 Greene Street	No Boring	10/14/2021	Density Considerations	
133	50 Greene Street	No Boring	3/31/2022	Utility Conflicts	
134	44 Greene Street	No Boring	10/14/2021	Density Considerations	
135	38 Greene Street	No Boring	10/14/2021	Density Considerations	
136	32 Green Street	Dig Safe Complete	5/11/2022	No Capacity for Infiltration	
137	51 Hickok Place	No Boring	10/14/2021	Density Considerations	
138	55 Hickok Place	No Boring	10/14/2021	Density Considerations	
139	40 Hickok Place	Boring Complete	3/31/2022	No Capacity for Infiltration	
140	33 Hickok Place	No Boring	10/14/2021	Density Considerations	
141	27 Hickok Place	No Boring	10/14/2021	Density Considerations	
142	45 Converse Court	No Boring	10/14/2021	Large Tree, Very Little Run-On, Utility Conflicts	
143	4 Loomis Street	Boring Complete	3/31/2022	Good Infiltrative Capacity - Confining Layer at 65"	
144	8 Loomis Street	No Boring	3/31/2022	Density Considerations	
145	10 Loomis Street	No Boring	3/31/2022	Density Considerations	
146	16 Loomis Street	Boring Complete, Infiltration Testing Complete	3/31/2022	Moderate Infiltrative Capacity - Confining Layer at 46"	7.04
147	16 Loomis Street	No Boring	10/14/2021	Density Considerations	
148	137 North Willard Street	Boring Complete	4/12/2022	Little Capacity for Infiltration	
149	129 North Willard Street	No Boring	10/14/2021	Density Considerations	
150	207 North Willard Street	Boring Complete	11/18/2021	Good Infiltrative Capacity - No Confining Layer to Depth	
151	Intersection of Charles St. and Russell St.	Boring Complete, Infiltration Testing Complete	11/17/2021	Good Infiltrative Capacity - Confining Layer at 96"	19.7
152	52-56 Booth Street	Boring Complete	4/12/2022	Little Capacity for Infiltration	
153	44 Booth Street	No Boring	10/14/2021	Density Considerations	
154	40 Booth Street	No Boring	10/14/2021	Density Considerations	
155	28 Booth Street	No Boring	10/14/2021	Existing BMP Already Located Here	
156	149 North Union Street	Boring Complete	4/12/2022	Good Infiltrative Capacity - Silt Loam 25"-30"	
157	156 US Rte 7 Alt	Boring Complete	4/12/2022	Good Infiltrative Capacity - Confining Layer at 86"	
158	77 Intervale Avenue	No Boring	10/14/2021	Density Considerations	
159	77 Intervale Avenue	Boring Complete	11/17/2021	Good Infiltrative Capacity - Lens of Silt Loam 58"-60"	
160	83 Intervale Avenue	No Boring	10/14/2021	Density Considerations	
161	93 Intervale Avenue	Boring Complete, Infiltration Testing Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	8.28
162	87 Intervale Avenue	No Boring	10/14/2021	Density Considerations	
163	165 Intervale Avenue	Boring Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	
164	165 Intervale Avenue	No Boring	10/14/2021	Density Considerations	
165	171 Intervale Avenue	Boring Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	
166	227 Intervale Avenue	Boring Complete, Infiltration Testing Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	2.71
167	219 Intervale Avenue	No Boring	10/14/2021	Density Considerations	
168	219 Intervale Avenue	Boring Complete, Infiltration Testing Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	5.3
169	94 St. Louis Street	Boring Complete	11/17/2021	Good Infiltrative Capacity - Lens of Moist/Firm at 57"	
170	25 Luck Street	Boring Complete	11/17/2021	Good Infiltrative Capacity - No Confining Layer to Depth	
171	Roosevelt Park (Willow Street)	Boring Complete, Infiltration Testing Complete	11/18/2021	Good Infiltrative Capacity - No Confining Layer to Depth	3.11
172	353 Manhattan Drive	No Boring	11/18/2021	Utility Conflicts, Busy Intersection	
173	Intersection of Spring Street and Walnut Street	No Boring	10/14/2021	Large Tree, Little Available Space	

Soil Boring Status

Boring	Address	Status	Date	Soil Condition / Notes	Infiltration Rate (in/hr)
174	192-196 Elmwood Avenue	Boring Complete	11/18/2021	Good Infiltrative Capacity - No Confining Layer to Depth	
175	Intersection of Clarke St. and Pearl Street	No Boring	4/14/2022	Utility Conflicts	
176	Roosevelt Park (Oak Street)	No Boring	11/18/2021	Little Flow and Minimal Available Space	
177	80 Ward Street	Boring Complete, Infiltration Testing Complete	4/12/2022	Good Infiltrative Capacity - No Confining Layer to Depth	17.95
178	83 Ward Street	Boring Complete	4/12/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
179	79 Blodgett Street	Boring Complete	4/21/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
180	40-44 Ward Street	Boring Complete	4/12/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
181	66-72 Ward Street	Boring Complete	6/2/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
182	258 North Avenue	Boring Complete, Infiltration Testing Complete	4/14/2022	Good Infiltrative Capacity - Silt 50"-55"	20.48
183	259 North Avenue	Boring Complete	4/14/2022	Good Infiltrative Capacity - Silt 60"-70"	
184	267 North Avenue	Boring Complete	4/14/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
185	25-27 Washington Street	No Boring	4/14/2022	Existing Gardens	
186	61 Pitkin Street (On Strong)	Boring Complete	4/21/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
187	39 Pitkin Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
188	33 Pitkin Street	Boring Complete	4/21/2022	Good Infiltrative Capacity - Silt Loam 60"-72"	
189	20 Blodgett Street (behind China Express 2)	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
190	47 Drew Street	Boring Complete	4/21/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
191	32 Strong Street (On Drew)	Boring Complete, Infiltration Testing Complete	4/21/2022	Good Infiltrative Capacity - Silt Loam 68"-80"	8.23
192	76 Drew Street	Boring Complete	4/21/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
193	85 Elmwood Avenue	Boring Complete	5/6/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
194	37 Elwood Avenue	Boring Complete	5/6/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
195	43 Elmwood Avenue	Boring Complete	5/6/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
196	74 George Street	No Boring	5/6/2022	Utility Conflicts	
197	50 Peru Street (on Murray)	Boring Complete	5/6/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
198	16 Murray Street	Boring Complete	5/6/2022	Little Capacity for Infiltration - Fine Sandy Silt Loam 18"-48"	
199	48 Monroe Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
200	38 North Champlain Street (on Monroe)	Boring Complete, Infiltration Testing Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	5.85
201	38 North Champlain Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
202	33 North Champlain Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
203	24 North Champlain Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
204	30 Sherman Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
205	38 Sherman Street	Boring Complete	4/27/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
206	Intersection of North Champlain St. and North St.	Boring Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
207	Archibald Street and Hyde Street	Boring Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
208	116 Hyde Street	Boring Complete, Infiltration Testing Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	14
209	16 Spring Street	Boring Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
210	3 Spring Street	Boring Complete, Infiltration Testing Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	6.55
211	51 North Union Street	No Boring	6/2/2022	Density Considerations	
212	95 Grant Street	Boring Complete	6/2/2022	Little Capacity for Infiltration - Silt Loam 40"-81"	
213	129 North Avenue	Boring Complete	6/2/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
214	7 Canfield Street	Boring Complete, Infiltration Testing Complete	6/2/2022	Good Infiltrative Capacity - No Confining Layer to Depth	28.21
215	32 North Avenue	Boring Complete	6/2/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
216	31 George Street	Boring Complete	5/11/2022	Little Capacity for Infiltration - Tight Soils and Silt 44"-54"	
217	87 Spring Street	Boring Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	
218	Spring Street and Manhattan Drive	Boring Complete	5/11/2022	Good Infiltrative Capacity - No Confining Layer to Depth	

Attachment D: Infiltration Test Results

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	12/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	146	16 Loomis Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	33	33	16	2	60.60606061
	96	63	14	2	31.74603175
	201	105	12	2	19.04761905
	304	103	10	2	19.41747573
	412	108	8	2	18.51851852
	532	120	6	2	16.66666667
	652	120	4	2	16.66666667
	770	118	4	2	16.94915254
	889	119	4	2	16.80672269
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 $\Delta v/\Delta t$ 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 =	40.64	cm
Q_e =	16.772	cm^3/sec
K =	**0.0050**	**cm/sec**
	14	**ft/day**
	7.0438	**in/hr**

Results $s_i > 2L_w$		
L_w =	38	cm
r_w =	3.8	cm
S_i =	40.64	cm
Q_e =	16.7723	cm^3/sec
K =	0.0054	cm/sec
	15	ft/day
	7.70774	in/hr

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	151	Charles and Russell Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	30	30	16	2	66.66666667
	61	31	14	2	64.51612903
	95	34	12	2	58.82352941
	138	43	10	2	46.51162791
	181	43	8	2	46.51162791
	228	47	6	2	42.55319149
	275	47	4	2	42.55319149
	321	46	4	2	43.47826087
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 $\Delta v/\Delta t$ for last run

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

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

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 =	167.64	cm
Q_e =	42.862	cm^3/sec
K =	0.0055	cm/sec
	16	ft/day
	7.8239	in/hr

Results $s_i > 2L_w$

L_w =	38	cm
r_w =	3.8	cm
S_i =	167.64	cm
Q_e =	42.8615	cm^3/sec
K =	0.0139	cm/sec
	39	ft/day
	19.6971	in/hr

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	161	93 Intervale Ave
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	36	36	16	2	55.55555556
	80	44	14	2	45.45454545
	173	93	12	2	21.50537634
	268	95	10	2	21.05263158
	379	111	8	2	18.01801802
	490	111	6	2	18.01801802
	640	150	4	2	13.33333333
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

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

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

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 =	152.4	cm
Q_e =	18.018	cm^3/sec
K =	0.0025	cm/sec
	7	ft/day
	3.5284	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**152.4**	**cm**
Q_e =	**18.018**	**cm^3/sec**
K =	**0.0058**	**cm/sec**
	17	**ft/day**
	8.28021	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW
SEI Study #:	17-061-E
Date:	5/20/2022
Sampling Personnel:	BAM / APH / EMR
Backhoe test pit #:	166 227 Intervale Ave
Auger hole radius:	1.5 in
Auger hole depth:	27 in

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	20		
	70	70	18	2	28.57142857
	343	273	16	2	7.326007326
	652	309	14	2	6.472491909
	990	338	12	2	5.917159763
	1328	338	10	2	5.917159763
	1667	339	8	2	5.899705015
			6	2	
			4	2	
			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 =	266.7	cm
Q_e =	5.9113	cm^3/sec
K =	0.0005	cm/sec
	1	ft/day
	0.7488	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**266.7**	**cm**
Q_e =	**5.91134**	**cm^3/sec**
K =	**0.0019**	**cm/sec**
	5	**ft/day**
	2.71657	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/20/2022	
Sampling Personnel:	BAM / APH / EMR	
Backhoe test pit #:	168	219 Intervale Ave
Auger hole radius:	1.5 in	
Auger hole depth:	33 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	48	48	16	2	41.66666667
	219	171	14	2	11.69590643
	423	204	12	2	9.803921569
	635	212	10	2	9.433962264
	867	232	8	2	8.620689655
	1019	152	6	2	13.15789474
	1139	120	4	2	16.66666667
	1258	119	2	2	16.80672269
2	0	0	20		
	72	72	18	2	27.77777778
	212	140	16	2	14.28571429
	355	143	14	2	13.98601399
	518	163	12	2	12.26993865
	697	179	10	2	11.17318436
	874	177	8	2	11.29943503
	1049	175	6	2	11.42857143
		177	4	2	
			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 $\Delta v/\Delta t$ 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 =	160.02	cm
Q_e =	11.543	cm^3/sec
K =	0.0015	cm/sec
	4	ft/day
	2.181	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**160.02**	**cm**
Q_e =	**11.5428**	**cm^3/sec**
K =	**0.0037**	**cm/sec**
	11	**ft/day**
	5.30451	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW
SEI Study #:	17-061-E
Date:	5/20/2022
Sampling Personnel:	BAM / APH / EMR
Backhoe test pit #:	171 Willow Street
Auger hole radius:	1.5 in
Auger hole depth:	30 in

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	34	34	20	2	58.82352941
	307	273	18	2	7.326007326
	582	275	16	2	7.272727273
	877	295	14	2	6.779661017
	1172	295	12	2	6.779661017
	1469	297	10	2	6.734006734
			8	2	
			6	2	
			4	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 $\Delta v/\Delta t$ 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 =	238.76	cm
Q_e =	6.7644	cm^3/sec
K =	0.0007	cm/sec
	2	ft/day
	0.9379	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**238.76**	**cm**
Q_e =	**6.76444**	**cm^3/sec**
K =	**0.0022**	**cm/sec**
	6	**ft/day**
	3.10861	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	177	80 Ward Street
Auger hole radius:	1.5 in	
Auger hole depth:	25 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	30	30	20	2	66.66666667
	62	32	18	2	62.5
	96	34	16	2	58.82352941
	131	35	14	2	57.14285714
	170	39	12	2	51.28205128
	210	40	10	2	50
	250	40	8	2	50
	298	48	6	2	41.66666667
	338	40	4	2	50
2	30	30	20	2	66.66666667
	70	40	18	2	50
	122	52	16	2	38.46153846
	175	53	14	2	37.73584906
	225	50	12	2	40
	275	50	10	2	40

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 =	259.08	cm
Q_e =	39.049	cm^3/sec
K =	0.0036	cm/sec
	10	ft/day
	5.0659	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**259.08**	**cm**
Q_e =	**39.0493**	**cm^3/sec**
K =	**0.0127**	**cm/sec**
	36	**ft/day**
	17.9452	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/20/2022	
Sampling Personnel:	APH / EMR	
Backhoe test pit #:	182	258 North Avenue
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	29	29	16	2	68.96551724
	58	29	14	2	68.96551724
	87	29	12	2	68.96551724
	117	30	10	2	66.66666667
	148	31	8	2	64.51612903
	181	33	6	2	60.60606061
	213	32	2	2	62.5
		32	0	2	62.5
		33			0
2	0	0	18		
	31	31	16	2	64.51612903
	68	37	14	2	54.05405405
	101	33	12	2	60.60606061
	138	37	10	2	54.05405405
	175	37	8	2	54.05405405
	213	38	6	2	52.63157895
	250	37	2	2	54.05405405
			0	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 $\Delta v/\Delta t$ 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 =	50.8	cm
Q_e =	53.698	cm^3/sec
K =	**0.0144**	**cm/sec**
	41	**ft/day**
	20.43	**in/hr**

Results $s_i > 2L_w$		
L_w =	38	cm
r_w =	3.8	cm
S_i =	20	cm
Q_e =	53.69844	cm^3/sec
K =	0.0174	cm/sec
	49	ft/day
	24.67721	in/hr

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	187	39 Pitkin Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	20		
	33	33	18	2	60.60606061
	66	33	16	2	60.60606061
	130	64	14	2	31.25
	192	62	12	2	32.25806452
	259	67	10	2	29.85074627
	330	71	8	2	28.16901408
	401	71	6	2	28.16901408
	472	71	4	2	28.16901408
			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 $\Delta v/\Delta t$ 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 =	254	cm
Q_e =	28.169	cm^3/sec
K =	0.0026	cm/sec
	7	ft/day
	3.7141	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**254**	**cm**
Q_e =	**28.169**	**cm^3/sec**
K =	**0.0091**	**cm/sec**
	26	**ft/day**
	12.9451	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	191	Drew and Strong Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	33	33	16	2	60.60606061
	99	66	14	2	30.3030303
	174	75	12	2	26.66666667
	290	116	10	2	17.24137931
	401	111	8	2	18.01801802
	514	113	6	2	17.69911504
	625	111	4	2	18.01801802
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 $\Delta v/\Delta t$ 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 =	228.6	cm
Q_e =	17.912	cm^3/sec
K =	0.0018	cm/sec
	5	ft/day
	2.5717	in/hr

Results $s_i>2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**228.6**	**cm**
Q_e =	**17.9117**	**cm^3/sec**
K =	**0.0058**	**cm/sec**
	16	**ft/day**
	8.23136	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	200	38 Monroe Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	29	29	16	2	68.96551724
	60	31	16	2	64.51612903
	130	70	14	2	28.57142857
	233	103	12	2	19.41747573
	345	112	10	2	17.85714286
	448	103	8	2	19.41747573
	573	125	6	2	16
	698	125	4	2	16
	844	146	2	2	13.69863014
2					
	0	0	20	2	
	57	57	18	2	35.0877193
	221	164	16	2	12.19512195
	360	139	14	2	14.38848921
	503	143	12	2	13.98601399
	672	169	10	2	11.83431953
	829	157	8	2	12.7388535
	985	156	6	2	12.82051282
	1143	158	4	2	12.65822785

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 =	241.3	cm
Q_e =	12.739	cm^3/sec
K =	0.0012	cm/sec
	4	ft/day
	1.7512	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**241.3**	**cm**
Q_e =	**12.7392**	**cm^3/sec**
K =	**0.0041**	**cm/sec**
	12	**ft/day**
	5.85432	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/18/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	208	116 Hyde Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	18		
	31	31	16	2	64.51612903
	76	45	14	2	44.44444444
	123	47	12	2	42.55319149
	177	54	10	2	37.03703704
	245	68	8	2	29.41176471
	312	67	6	2	29.85074627
	377	65	4	2	30.76923077
	442	65	2	2	30.76923077
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 $\Delta v/\Delta t$ for last run

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

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

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 =	241.3	cm
Q_e =	30.463	cm^3/sec
K =	0.0030	cm/sec
	8	ft/day
	4.1876	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**241.3**	**cm**
Q_e =	**30.4631**	**cm^3/sec**
K =	**0.0099**	**cm/sec**
	28	**ft/day**
	13.9994	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW
SEI Study #:	17-061-E
Date:	5/20/2022
Sampling Personnel:	BAM / APH / EMR
Backhoe test pit #:	210 3 Spring Street
Auger hole radius:	1.5 in
Auger hole depth:	31 in

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	62	22		
	82	82	20	2	24.3902439
	175	93	18	2	21.50537634
	282	107	16	2	18.69158879
	391	109	14	2	18.34862385
	500	109	12	2	18.34862385
	624	124	10	2	16.12903226
	738	114	8	2	17.54385965
	850	112		2	17.85714286
2	0	0	22	2	
	36	36	20	2	55.55555556
	159	123	18	2	16.2601626
	292	133	16	2	15.03759398
	428	136	14	2	14.70588235
	571	143	12	2	13.98601399
	712	141	10	2	14.18439716
	850	138	8	2	14.49275362
	989	139	6	2	14.38848921

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 =	86.36	cm
Q_e =	14.263	cm^3/sec
K =	0.0029	cm/sec
	8	ft/day
	4.0796	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**86.36**	**cm**
Q_e =	**14.2629**	**cm^3/sec**
K =	**0.0046**	**cm/sec**
	13	**ft/day**
	6.55455	**in/hr**

Auger Hole Hydraulic Conductivity Measurement

Project Title:	Burlington Wards 2 & 3 ROW	
SEI Study #:	17-061-E	
Date:	5/20/2022	
Sampling Personnel:	BAM / EMR	
Backhoe test pit #:	214	7 Canfield Street
Auger hole radius:	1.5 in	
Auger hole depth:	30 in	

Field Measurements:

Run	Time	Δ t	Volume (v) Liters	Δ v	Flow Rate (Q_e) cm^3/sec
1	0	0	22		
	33	33	20	2	60.60606061
	67	34	18	2	58.82352941
	99	32	16	2	62.5
	132	33	14	2	60.60606061
	166	34	12	2	58.82352941
	198	32	10	2	62.5
	230	32	8	2	62.5
			6	2	
			4	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 $\Delta v/\Delta t$ 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 =	228.6	cm
Q_e =	61.386	cm^3/sec
K =	0.0062	cm/sec
	18	ft/day
	8.8136	in/hr

Results $s_i > 2L_w$

L_w =	**38**	**cm**
r_w =	**3.8**	**cm**
S_i =	**228.6**	**cm**
Q_e =	**61.3859**	**cm^3/sec**
K =	**0.0199**	**cm/sec**
	56	**ft/day**
	28.21	**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

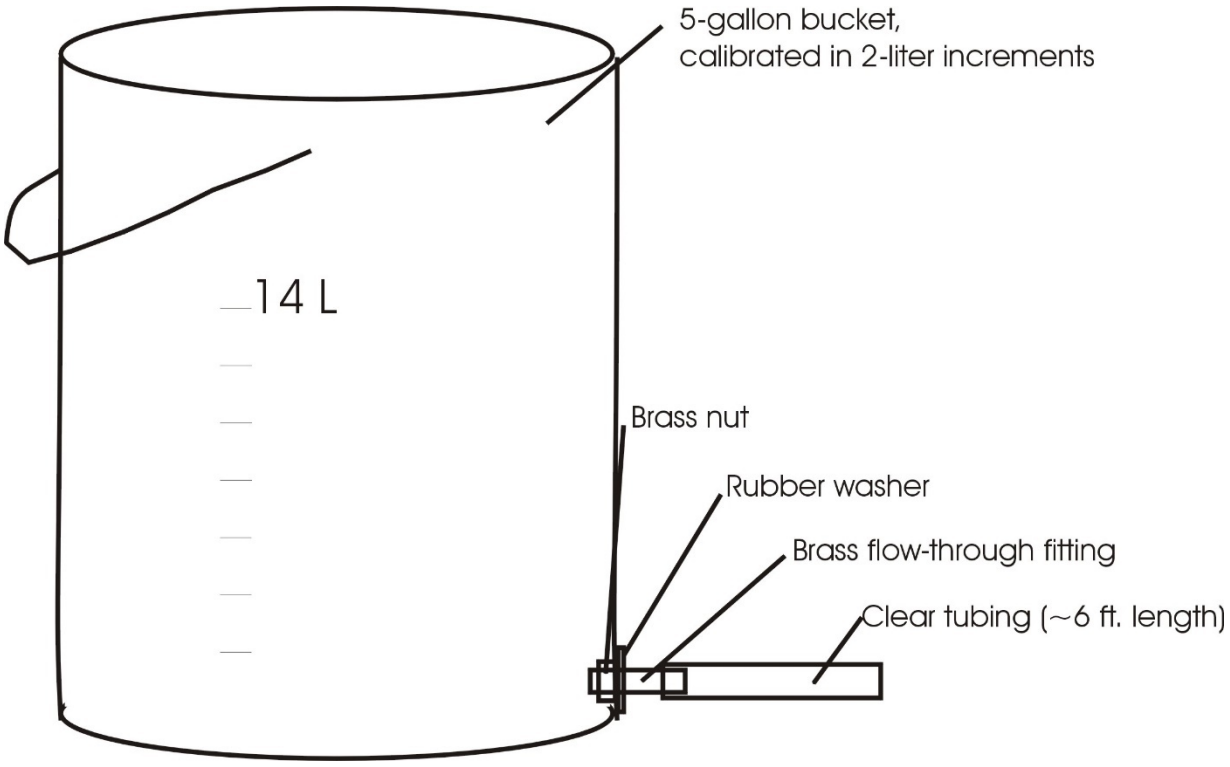
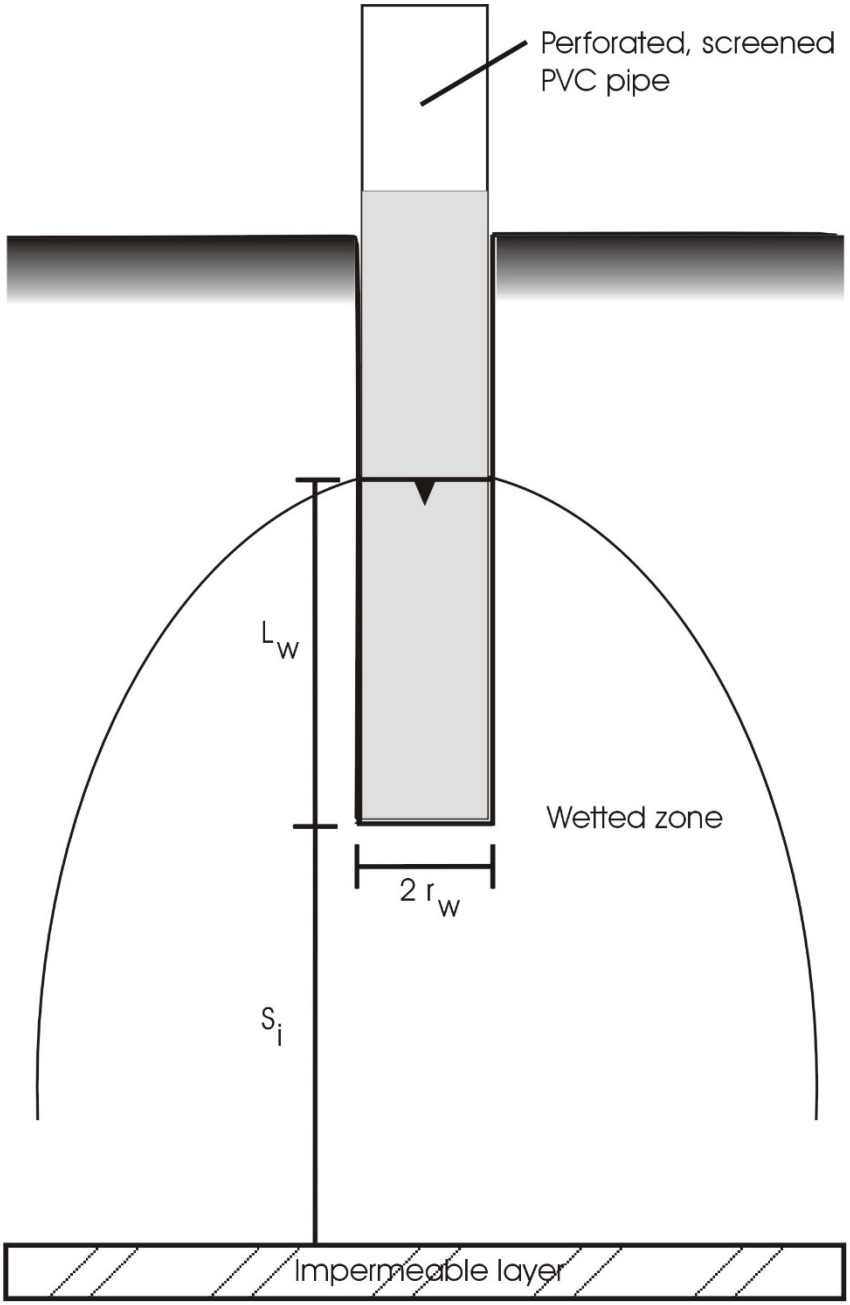


Figure 2. Schematic of Well Pump-in Technique (including perforated PVC pipe)



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