Comparison of New to Established Rain Gardens

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Abstract

The purpose of this project was to determine whether there is a difference in the infiltration rates between new and established rain gardens. To test this, two rain gardens located in Wauwatosa, Wisconsin, were utilized. The flow of water into the gardens and the depth of water present in the gardens were measured over the course of several weeks, and direct infiltration tests were conducted in order to calculate the infiltration rates for each garden. After these data were analyzed, it appeared that there was no change in the infiltration rates between the newer and established gardens that were analyzed. It was found, however, that the infiltration rates of rain gardens in general may be underestimated in technical design standards.

Keywords: rain garden, infiltration

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Unlike traditional stormwater management, which focuses on limiting the peak runoff flow rate from an area but neglects the increase in runoff volume (Selbig, 2010), rain gardens are designed to promote infiltration of water into the soil while also reducing the peak runoff flow rate from an area. While the concept behind the operation is the same among rain gardens, there are many different ways that they can be designed. For example, Selbig describes a rain garden as “a shallow depression that gathers runoff generated from nearby impervious surfaces and infiltrates that runoff into the ground” (Selbig, 2010, p. 2), while Dietz and Clausen describe them as “shallow depressions in the landscape that are planted with trees and/or shrubs, and covered with a bark mulch layer or ground cover. They allow stormwater to infiltrate, recharge aquifers, and reduce peak flows” (Dietz & Clausen, 2005, p. 124).

In residential applications, homeowners may design and construct their own rain gardens. As a result, there are many guides available to help homeowners design and construct rain gardens in a beneficial way. One example of this is the Wisconsin Department of Natural Resources’ (WDNR) homeowner’s guide to rain gardens. Before a rain garden can be constructed, a suitable location must first be determined. Because rain gardens promote infiltration, the WDNR suggests that a rain garden should be placed at least 10 feet from homes and not directly over a septic system (Bannerman & Considine, 2003). This is to help prevent the water that infiltrates as a result of the rain garden from finding its way into foundations and wastewater systems, which can result in damage and other environmental impacts. It is also recommended that the rain garden be placed in a flat open area in the yard that does not usually pond in storms (Bannerman & Considine, 2003). The flat area makes construction of the garden easier since the base and berm of the garden must be leveled. A ponded area in a yard shows where water has a difficult time infiltrating, which would have a negative impact on the performance of the garden.

The next step is to design the rain garden. Two key aspects of rain garden design are the depth and surface area of the rain garden. The WDNR recommends a depth of between three to eight inches deep depending on the slope of the ground the rain garden is to be built on; the steeper the slope, the deeper the garden (Bannerman & Considine, 2003). Basing the garden depth on the slope of the yard allows excavation to be kept to a minimum because the dirt from the excavated uphill side of the slope can be used to fill the downhill side of the garden, meaning that only half of the garden needs to be excavated. The area of the rain garden is determined by the area that drains to the garden. This area is multiplied by a size factor given in the WDNR guidance manual; this result gives the recommended surface area of the rain garden.

After a suitable location is found for the rain garden and it is designed, construction can take place. The garden is constructed by excavating the rain garden area to the desired depth and then using the excavated soil to create a berm around the perimeter of the garden. During this process, the bottom of the garden and the newly constructed berm are leveled (Bannerman & Considine, 2003). This leveling ensures that the rain garden will hold the entire depth of water that it has been dug for; it also stops stormwater from simply running out of the garden, which promotes infiltration.

The final step in rain garden construction is planting. Plantings should be native, and have well established root systems to help establish them in the garden. Variations in planting types are encouraged to help promote natural growing patterns (Bannerman & Considine, 2003). These plantings help remove water from the soil and promote infiltration.

These are general guidelines, and the construction of gardens can vary between locations and is affected by the soil the garden is built in, the area that is contributing to the garden, the rainfall in the area, and the desired infiltration into the soil. The fact is that there is no one way to install a rain garden at a location, which lends them well to residential use where yard layouts are generally not uniform.

Background

The purpose of this project was to determine if there is a difference between the infiltration rate of a newly constructed rain garden and a well-established one, and if there is a difference, how much of a difference there is. The reason there may be a difference in the infiltration rate is because two changes occur as a rain garden ages. The first change that occurs is the establishment of vegetation in the garden. The growth of vegetation introduces root structures into the soil, creating voids that promote greater infiltration in the soil, which would increase the infiltration rate of the garden (Johnston, 2011).

The second change that occurs is clogging of the surface soil in the garden. As stormwater runs from the roof, through the gutter system, and into the garden, it picks up fine particles which in turn get stuck on the surface of the garden as the stormwater infiltrates. The fine particles clog the voids in the surface of the garden’s soil, and can lower the rate at which stormwater can infiltrate (Jenkins, Wadzuk, & Welker, 2010). This lowers the infiltration rate of the garden. Because of these changes, there is the possibility for the infiltration rate of the garden to increase or decrease over its lifetime, depending on the influence each has on overall infiltration rate.

The reason it is important to understand how the infiltration rate of a rain garden may change over time is because rain gardens are becoming a larger part of urban stormwater management systems, with communities promoting the construction of rain gardens in both commercial and residential applications (Dovel, Kemp, & Welker, 2015). An example of this type of promotion is the city of Wauwatosa which gave homeowners $5 per square foot of rain garden constructed (City of Wauwatosa, 2010). The reason communities are promoting rain gardens is because urban areas have high amounts of impervious surfaces, which increases the amount of runoff that these areas contribute to their respective watersheds and streams (Dovel, Kemp, & Welker, 2015). Rain gardens help to mitigate the negative effects on hydrology and water quality caused by urban areas by limiting runoff and offering a certain degree of pollutant treatment of stormwater (Dietz & Clausen, 2005). These benefits, however, reduce as the infiltration rate of the rain garden decreases because the flow of water that the garden can handle is decreasing. Conversely, as the infiltration rate increases, the benefits of the rain garden increases.

Field Testing

Location

The rain gardens used in this study were located in a residential area in Wauwatosa, Wisconsin. The yard the gardens were built in is made up of a silt loam soil, which is the typical soil type in Wisconsin. Both gardens are located in the same yard, and started as roughly the same soil composition. One garden is approximately 11 years of age, and the other is approximately 1.5 years of age. Each rain garden receives flow from a different gutter system.

Both rain gardens were constructed by excavating the area of construction roughly six inches, and constructing a berm six inches tall around the garden area. The bottom and berm of the established rain garden were leveled during construction. This can be seen in Figure 1, which shows the currently established rain garden after its construction. Native plants were then planted and allowed to grow in each garden, and the results of these plantings are shown in Figure 2. Flow from the roof of the house on the property was routed to the established garden. Over its life, the established rain garden has maintained its initially level bottom and berm. The berm as a whole, however, has been compacted over time, bringing the garden to approximately nine inches in average depth, as opposed to the rain garden's initial 12-inch depth. The berm also has a few low spots which lowers the effective depth to approximately five inches. Overall, the established rain garden is approximately 136 square feet and can hold approximately 23 cubic feet of stormwater, which is equivalent to 0.015 inches of rainfall that can be held in the garden.

Figure 1. Construction of established rain garden.

Figure 2. Established rain garden.

Figure 3 shows the newer rain garden which the established rain garden is being compared to. Unlike the bottom of the established rain garden, the newer garden is on a slope, from both the fence line to the berm and along the entire length of the garden. The berm on the downhill end of the garden is also shorter in comparison to the rest of the berm. Flow to the newer rain garden is from a garage roof of another property. Because of the slope of the garden and the shorter berm on one end, this rain garden is approximately 58 square feet and can only hold approximately four cubic feet of stormwater, which is equivalent to 0.02 inches of rainfall that can be held in the garden.

Figure 3. Newer rain garden.

Equipment and Setup

There was a wide variety of equipment used during this experiment to determine the infiltration rates of the rain gardens. This equipment was used to measure stormwater flow into each garden, as well as the depth of water in each garden, and to record the intensity of rainfall events over the course of the experiment. This equipment included two flow measurement boxes equipped with pressure sensors, two perforated in-ground pressure sensor mounting tubes, a tipping bucket rain gauge, and a dual ring infiltrometer.

To measure the inflow into each rain garden, two flow measurement boxes were constructed. Pictured in Figure 4, these boxes were laser cut from quarter inch acrylic sheets, glued together, and sealed to ensure that flow could accurately be recorded. Flow from the roof gutters flowed directly into the rear chamber of each box. The stormwater then passed through an over-under weir to reduce the turbulence in the box; this system is pictured in Figure 5. After passing through the weir system, the water then entered the measurement chamber of the box. This chamber housed a pressure sensor which recorded the water pressure (in psi) of the water in the box every 30 seconds. From this chamber, the water left the box through a V-notch weir and entered the rain garden.

Figure 4. Flow measurement box.

Figure 5. Flow measurement box over-under weir.

A water level sensor was also installed approximately six inches below the surface of each garden. These sensors were used to track the water level in each garden, which, in conjunction with the flow measured entering the garden, was used to determine the infiltration rate of the soil for each rain garden. Each sensor was placed in a perforated PVC mounting tube, as seen in Figure 6, to ensure the sensor would be kept at a consistent depth and to prevent the hole from filling in, but not restrict groundwater flow.

Figure 6. Garden water level sensor mounting tube.

To measure the magnitude of rainfall events a tipping bucket rain gauge, pictured in Figure 7, was set up in an open area in the yard where the canopy was clear. The gauge logged the cumulative rainfall for each data collection period.

Figure 7. Tipping bucket rain gauge.

Several double-ring infiltrometer tests were also performed as spot tests for infiltration rates. This test was performed in an open area of the yard, as well as in each rain garden. The equipment used in this test was gathered in accordance with the ASTM D3385 standard (ASTM

International, 2009). For the infiltrometer test, two 20-inch-long pipes were used. These pipes had nominal diameters of 18 inches and 8 inches, with outer diameters of 18.25 and 8.125, and inner diameters of 17.75 and 7.875, respectively. These sizes were chosen based on the two-to-one ratio between the pipes called for by the standard. The larger of the two pipes was driven approximately six inches into the ground and the smaller pipe was driven approximately four inches into the ground, with the smaller of the pipes centered inside the larger pipe; this setup can be seen in Figure 8. Flow was delivered to each ring by a garden hose. A flow meter, pictured in Figure 9, was attached to the hose so that the flow into the rings during the test could be monitored.

Figure 8. Double-ring infiltrometer.

Figure 9. Hose mounted flow meter.

Methodology

The inflow to each garden was measured using the flow measurement boxes described in the Equipment and Setup section of this report. To determine the flow into the garden, the raw pressure data from the box sensors were first converted from psi to inches of water, the ambient pressure was converted to a depth of water, and then the ambient depth was subtracted from the sensor depth to determine the depth of water in the box. Equation (1) features the method:

$$D = \left(p_b * \frac{2.31\,ft}{psi} * \frac{12in}{ft}\right) - \left(p_a * \frac{2.31\,ft}{psi} * \frac{12in}{ft}\right), \tag{1}$$

where “D” is the depth of water in the box (in inches), “p_b” is the pressure data from the sensor (in psi), and “p_a” is the ambient pressure (in psi).

This depth was then converted to a flow rate (Q) using Equation (2) the general weir flow equation, and Equation (3) the general orifice flow equation (Bendient, Huber, & Vieux, 2013, p. 372):

$$Q_{Weir} = \frac{8}{15} * \sqrt{2g} * C_d * \tan\left(\frac{\theta}{2}\right) * H^{\frac{5}{2}}, \tag{2}$$

$$Q_{Orifice} = C_d * A * \sqrt{2g * (H - Offset)}, \tag{3}$$

where “Q” is the flowrate through either the weir or the orifice (in cfs), ”g” is acceleration of gravity (in feet per second squared), “C_d” is the discharge coefficient, “θ” is the angle of the V-notch weir (in degrees), “H” is the depth of water above the bottom of the weir or the orifice (in feet), “A” is the area of the orifice (in feet squared), and the “Offset” is the depth of the center of flow for the orifice (in feet).

Both of these equations needed to be used because the V-notch weir only went 5.4375 inches up the side of the box. This means that when the depth of water in the box rises above approximately 5.5 inches, the relationship between the depth of water in the box and the flow out of the box changes. As a result, the weir equation is used to determine the flow out of the box when the water depth is below 5.4375 inches, and the orifice equation is used when the depth is greater than 5.4375 inches. For this analysis, a discharge coefficient of 0.6 and 0.62 was used for the weir and orifice equations, respectively, the angle of the V-notch weir was 30 degrees, the area of the orifice was 16 square inches (0.11 feet squared), and the offset for the orifice was set at 3.625 inches. The dimensions of the V-notch weir can be seen in Figure 10. The depth of water in the box for each data point was then converted to flow out of the box using either the weir or orifice equation, depending on the depth of water.

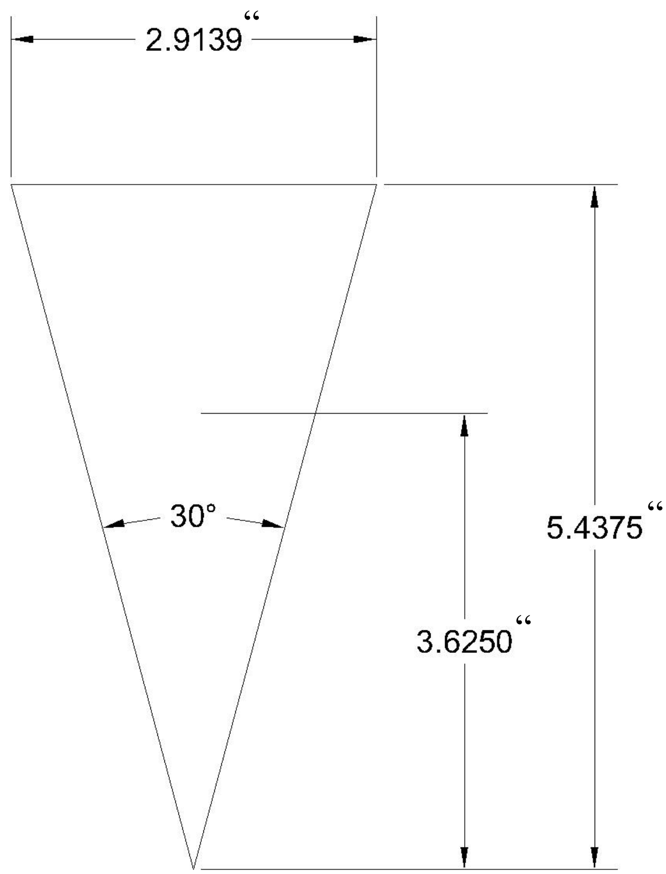

Figure 10. V-notch weir diagram.

The validity of the equations used above was confirmed using a scale model of the full sized flow box by measuring the flow rate out of the box at multiple depths, and then plotting those values against the flow rate values calculated by the equations. This can be seen in Figure 11.

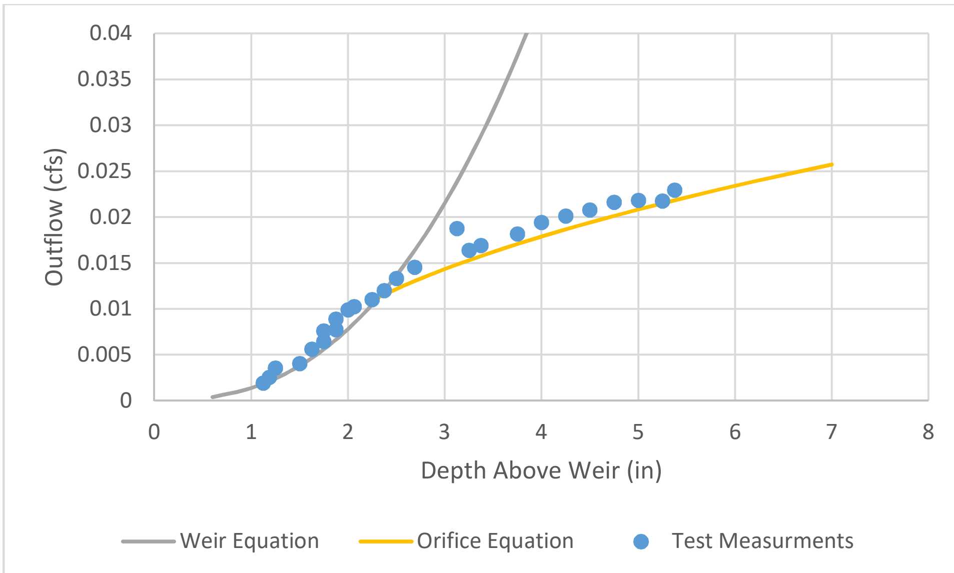

Figure 11. Weir and orifice equation applicability.

Since the calculated flow rate values from the equations matched the measured values taken during the model box test, the equations presented above accurately predict the flow leaving the box during the test.

The effect of direct rainfall on the gardens was taken into account by multiplying the ponded surface area of garden at each time step by the rainfall intensity of each time step. This value was added to the inflow calculated from the contributing roof areas to determine the total inflow to each garden.

The water infiltration, or outflow, was measured using the pressure sensor described in the Equipment and Setup section of this report and the inflow measured from the flow measurement boxes. The depth of water in the garden was determined the same way that it was determined in the flow boxes. A topographical survey of each garden was then performed, the results of which can be seen in Figure 12 and Figure 13. Both figures represent the height of the garden above its lowest point. In Figure 12, the established rain garden is oriented 90 degrees clockwise to how it is oriented in Figure 2, meaning that the left side of Figure 12 is the bottom of Figure 2. As can be seen from Figure 12, the majority of the berm of the established rain garden has a height of approximately 0.6 to 0.8 feet, but there are two low points in the berm (on the top of the figure) where the berm has a lower height. The lowest point on the berm has a height of 0.38 feet, which can be seen on the top end of Figure 12 at the 11 foot length marker. The lowest spot on the berm is the effective height of the garden, because once the water level rises above that point, it flows out of the garden.

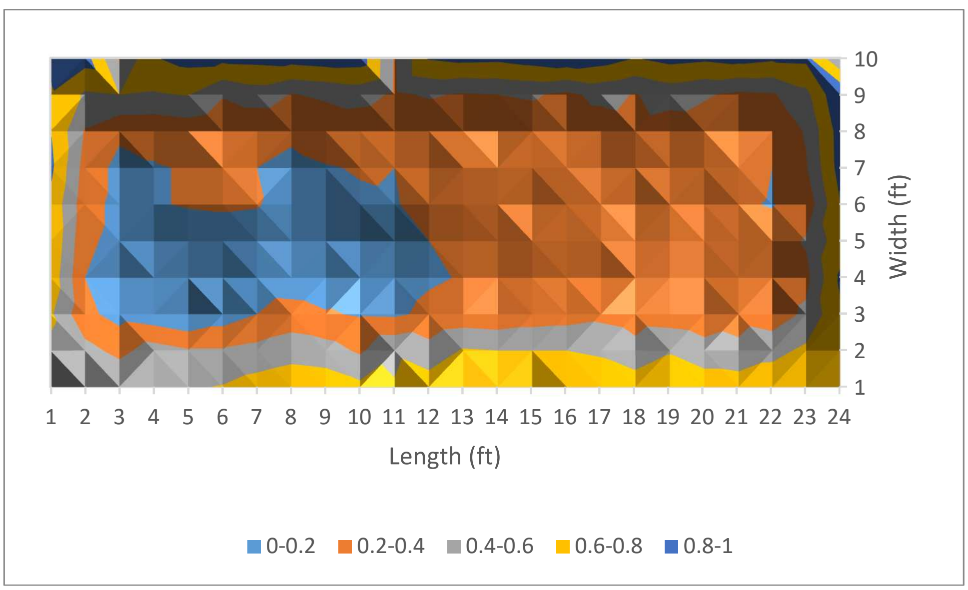

Figure 12. Topographic map of established rain garden.

In Figure 13, the newer rain garden is oriented the same way as it is in Figure 3, meaning that the left side of Figure 13 is also the left side of Figure 3. As can be seen in Figure 13, the berm starts out on the left side of the figure at a height of approximately 0.6 to 0.8 feet, and steadily decreases along the length of the garden. The lowest point on the berm has a height of 0.24 feet, which can be seen on the right end of Figure 13 at the seven foot width marker.

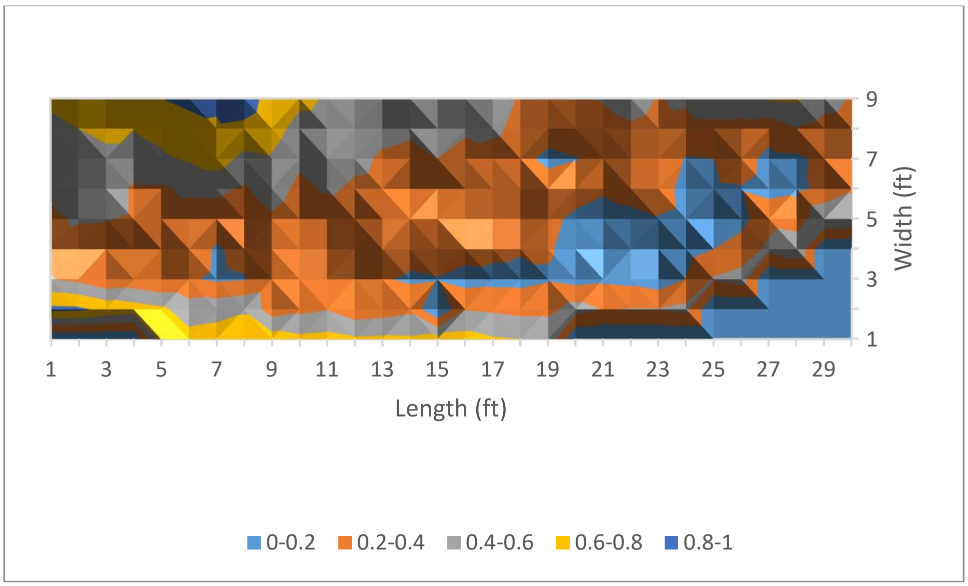

Figure 13. Topographic map of newer rain garden.

The survey data were then used to relate the ponded surface area in the garden to the depth of water present. These relationships can be seen in Figure 14 and Figure 15.

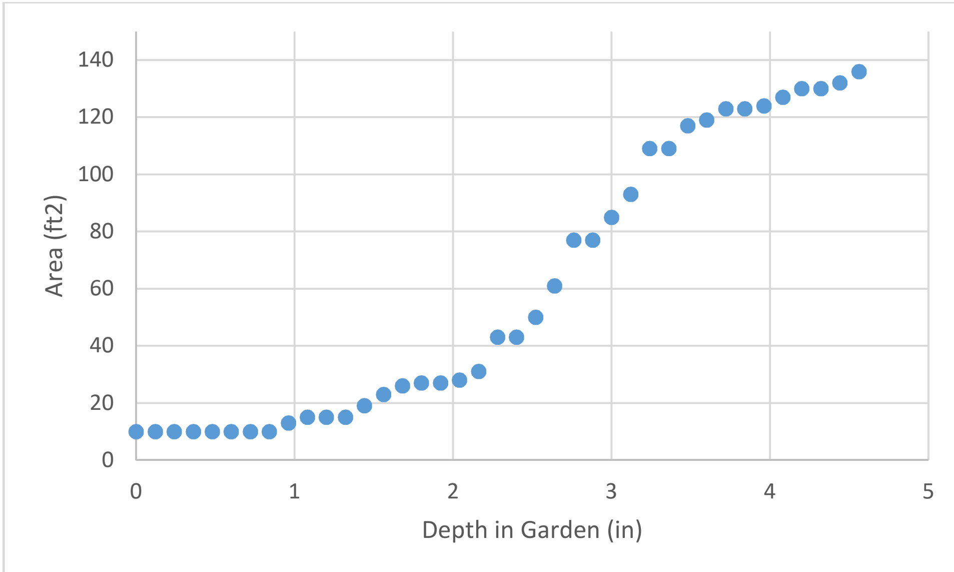

Figure 14. Established rain garden depth to ponded surface area curve.

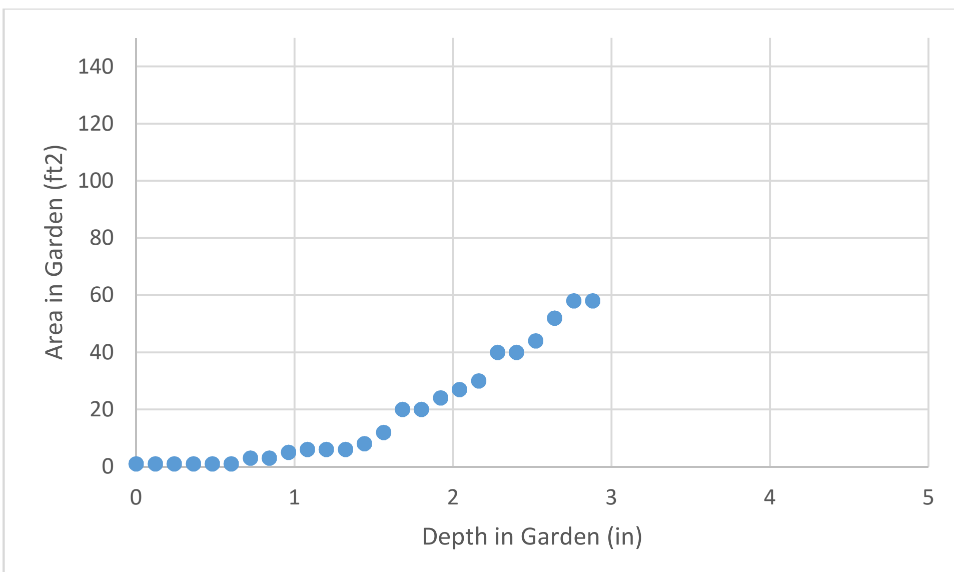

Figure 15. Newer rain garden depth to ponded surface area curve.

The change in storage in the garden was then found between each set of data points and then cumulated to relate the volume of stormwater stored in each rain garden to the depth of water present. These relationships can be seen in Figure 16 and Figure 17.

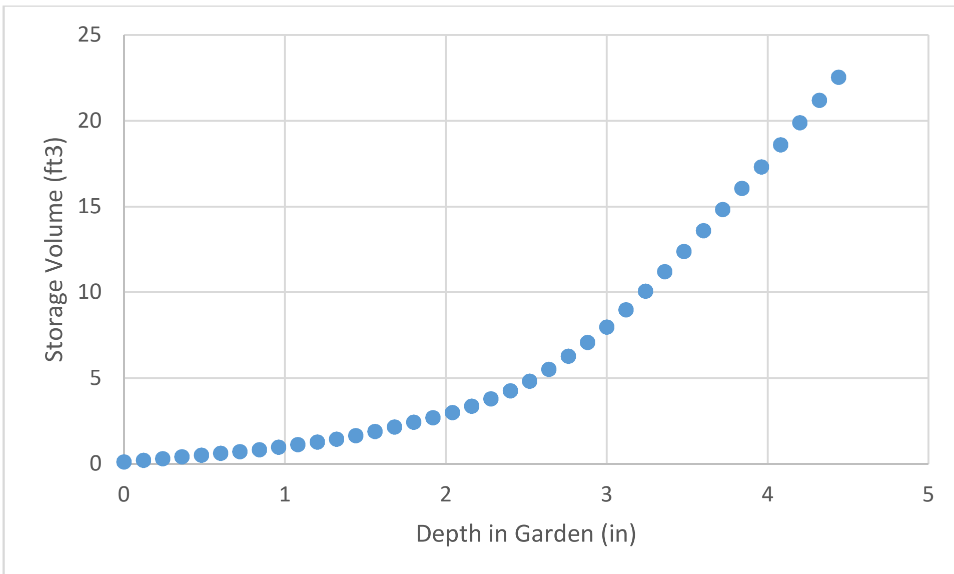

Figure 16. Established rain garden depth to storage curve.

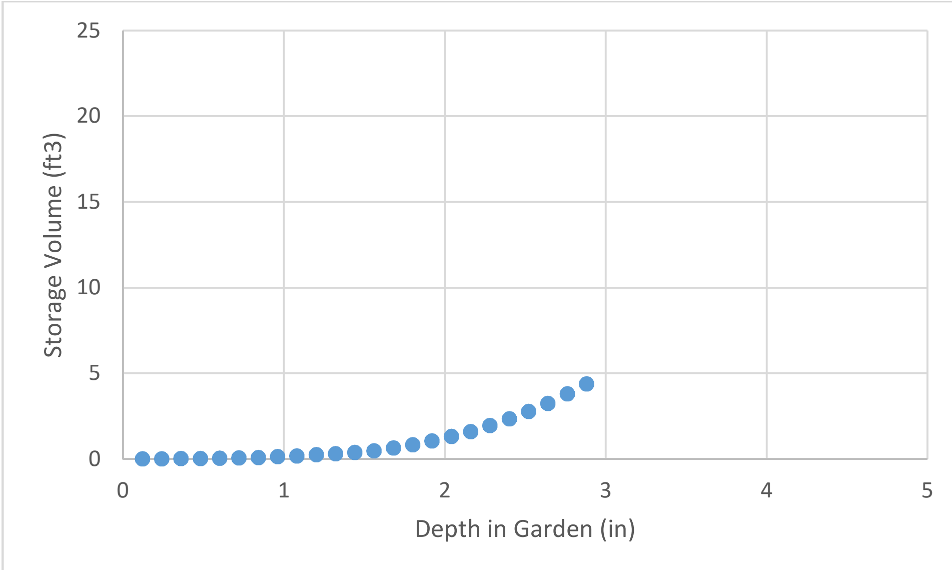

Figure 17. Newer rain garden depth to volume curve.

With this information, the infiltration rate out of the garden was determined using the storage routing equation -- Equation (4) -- assuming that the only outflow from the rain gardens was infiltration. Because the gardens never overtopped during the experiment and the evaporation and transpiration during the measured storm events is negligible, this is a reasonable assumption. Thus,

$$Infiltration\ Rate = \frac{I - \frac{\Delta s}{\Delta t}}{Average\ Area}, \tag{4}$$

where "Δs" is the change in storage between a set of data points (square feet), "Δt" is the time between a set of data points (which for this analysis is always 30 seconds), "I" is the inflow rate (in cfs), and "Average Area" is the average area between a set of data points.

In addition to the data collected and analyzed for each garden, a double-ring infiltrometer test was conducted in accordance with the ASTM standard D3385 on an area of undisturbed soil and both rain gardens to develop a baseline infiltration rate for the area to compare to the collected data (ASTM International, 2009). To conduct this test, the rings were set up in the manner described in the Equipment and Setup section of this report. Once the rings were installed, both the inner and outer rings were filled until the water level stabilized at approximately six inches. The water to the outer ring was then maintained at a constant level while the inner ring was allowed to drop over 15-minute intervals. The inner ring was refiled at the beginning of each interval, with the volume of water needed to fill the ring recorded for each interval. To determine the infiltration rate (inches per hour), Equation (5) was used:

$$Infiltration\ Rate = \frac{\Delta V * \frac{0.035\ ft^3}{l}}{A * \Delta t} * \frac{12\ in}{ft} * \frac{60\ min}{hr}, \quad (5)$$

where "ΔV" is the change in volume for each time interval (liters), "A" is the cross sectional area of the inner infiltrometer tube (square feet), and "Δt" is the length of the time interval (minutes).

Results

Figure 18 through Figure 24 show the calculated infiltration rates of the established rain garden during various recorded events. These events were chosen because they had a long enough duration to produce a significant ponded area in the rain garden, leading to more accurate infiltration values. For all graphs, infiltration values (blue) are read from the left vertical axis, and cumulative precipitation values (orange) are read from the right vertical axis. The precipitation values shown are cumulated over a seven-day period, the actual rainfall during a single event is the difference between the cumulative rainfall at the start of the event, and the cumulative rainfall at the end of the event. For example, in Figure 18, the rainfall during the event was approximately 0.4 inches, because there was 0.6 inches of cumulative rainfall before the event, and one inch of cumulative rainfall after the event.

In Figure 18 through Figure 24, there are drastic changes in the infiltration rate values shown, followed by periods of relatively even infiltration rate values. The reason for the large variances in the infiltration rate values is because the infiltration rate calculation is based on the ponded surface area of the garden. Because the measurements for this experiment were taken at 30-second intervals, there are intervals at the beginning and end of a rainfall event when the garden has a very small pond, but a relatively large inflow, which causes the infiltration rate for that interval to be significantly higher than what it actually is. As a result, the infiltration rate for an event from Figure 18 through Figure 24 is read from the portion of each figure when the data level off and remain relatively steady for a period of time. The data from these sections of the events were then averaged to determine the overall infiltration rate for the established rain garden, which can be seen in Table 4.

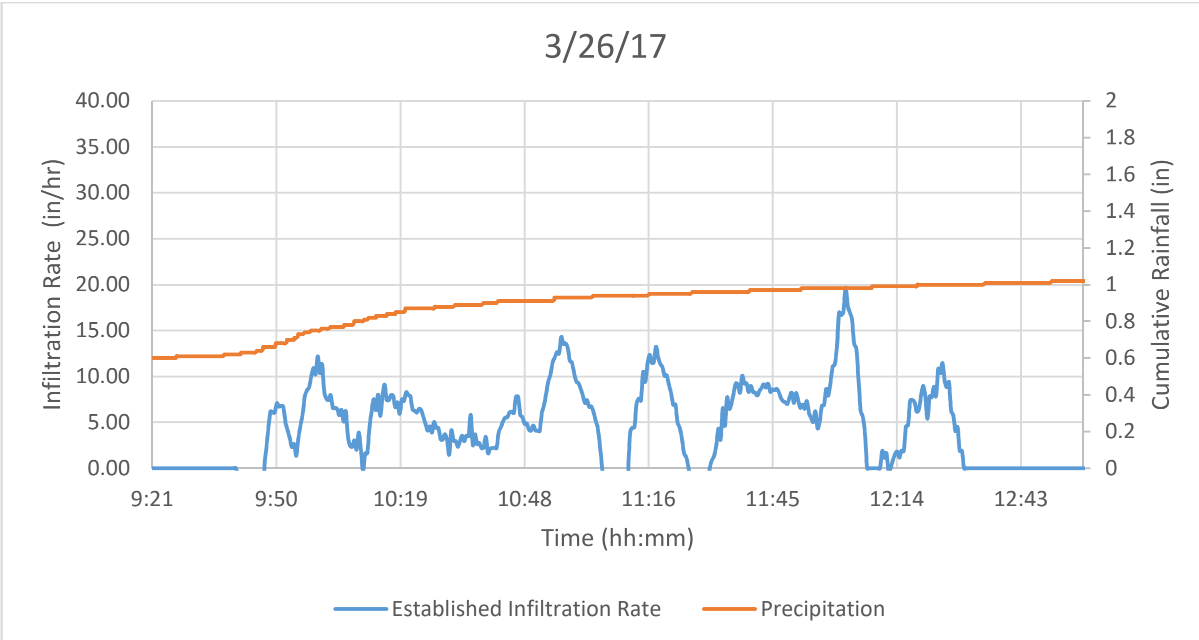

Figure 18. Rainfall event from March 26th.

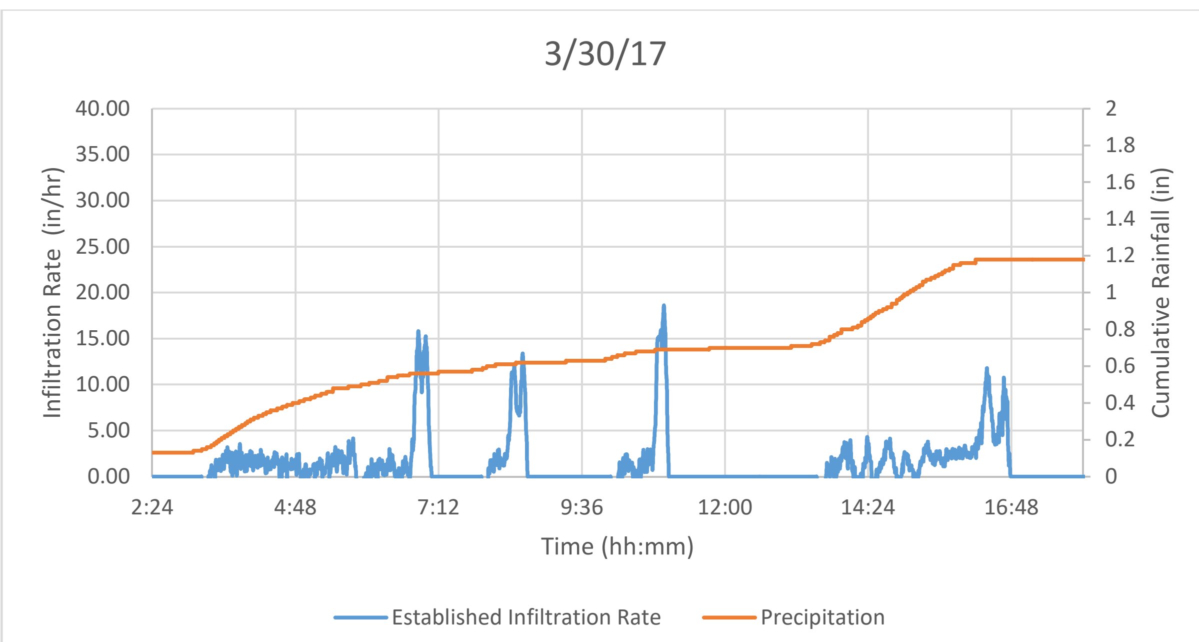

Figure 19. Rainfall event from March 30th.

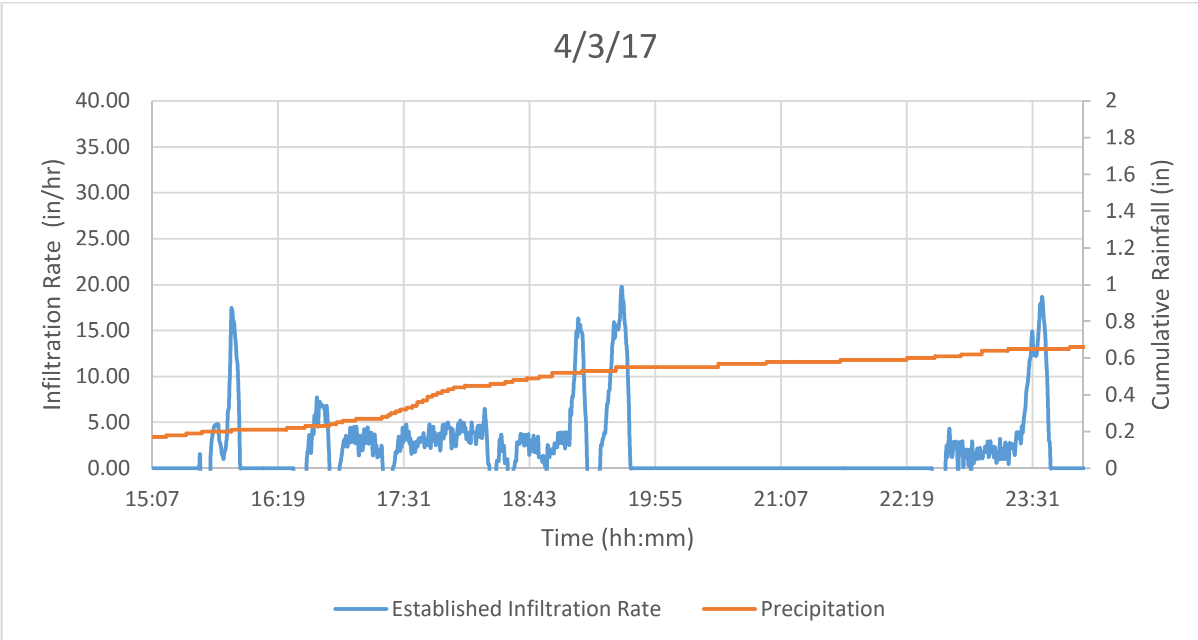

Figure 20. Rainfall event from April 3rd.

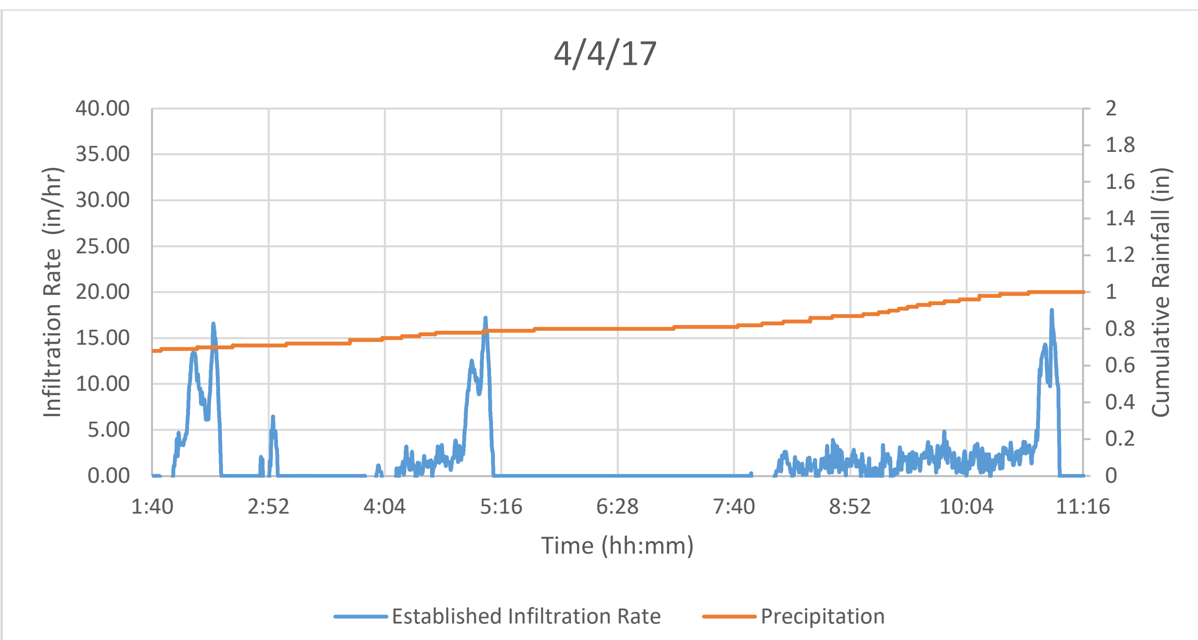

Figure 21. Rainfall event from April 4th.

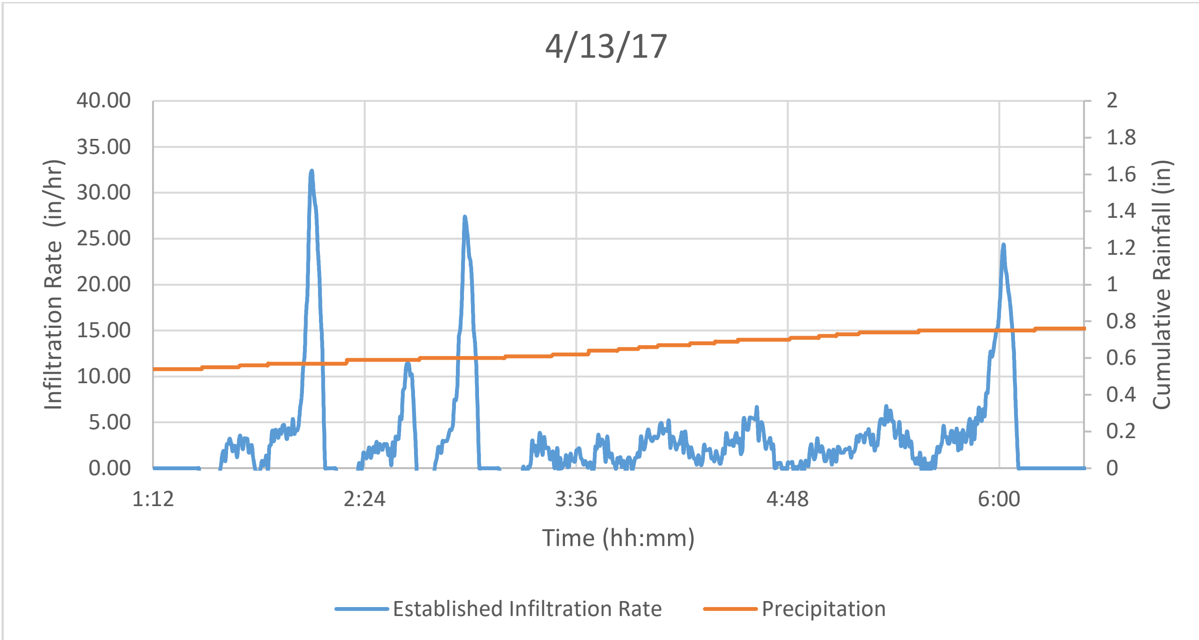

Figure 22. Rainfall event from April 13th.

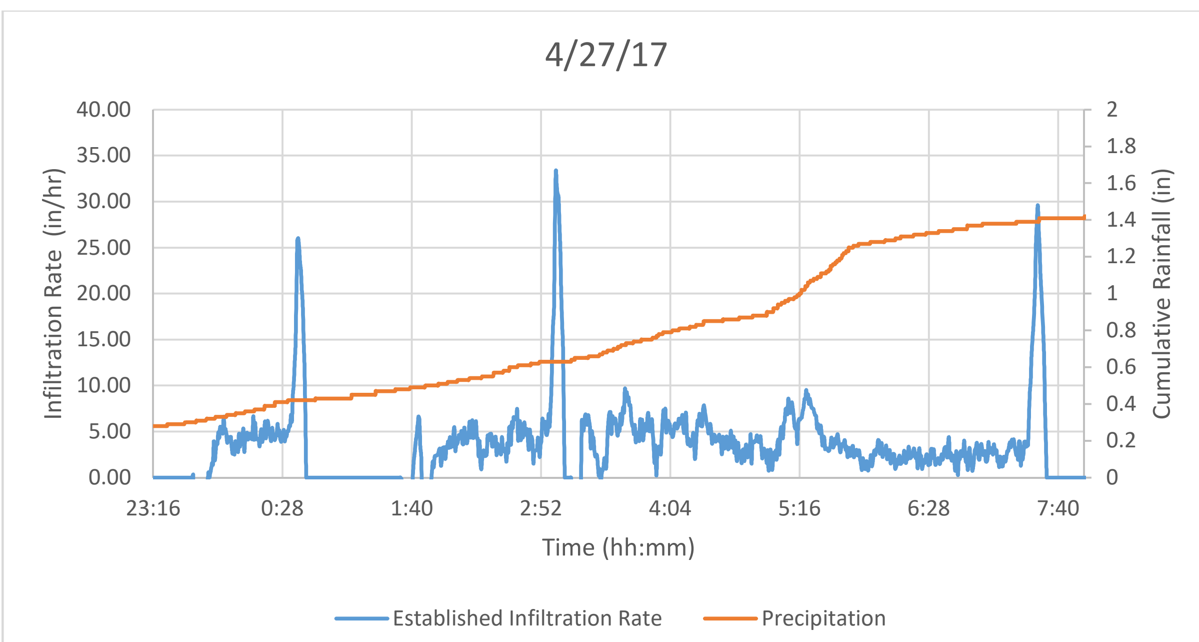

Figure 23. Rainfall event from April 27th.

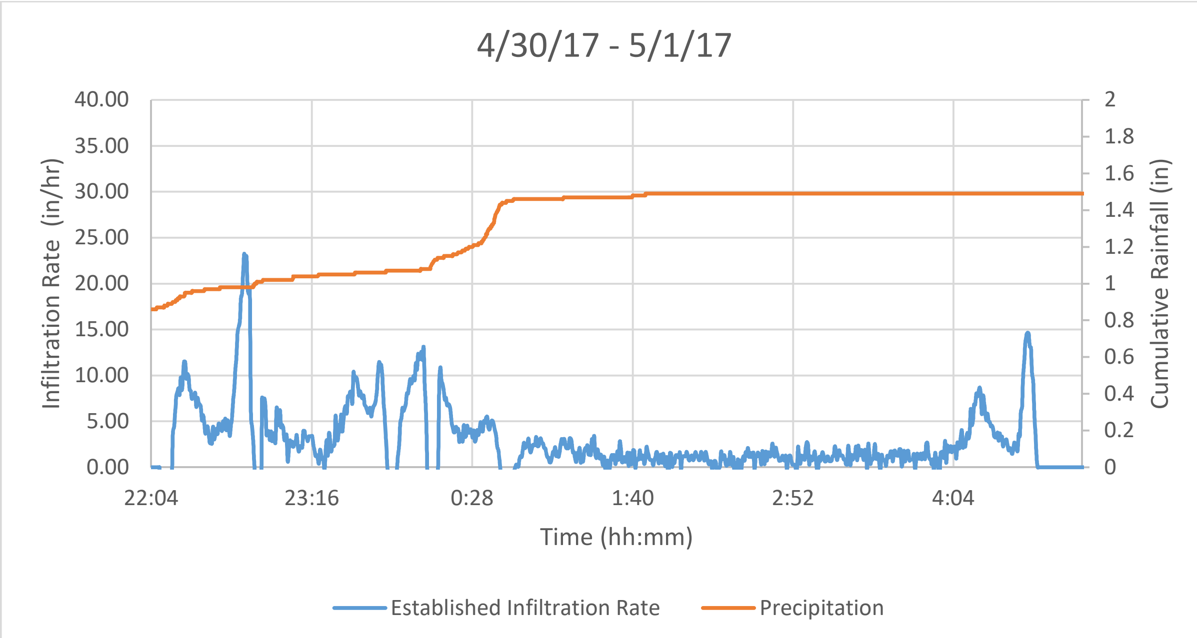

Figure 24. Rainfall event from April 30th and May 1st.

Table 1 through Table 3 show the results from the double-ring infiltrometer tests performed. The locations for this test were chosen based on the levelness of the test area, how representative the test area was of the overall location, and the absence of obstructions preventing the rings from being driven in correctly. The open yard area was located on the west side of the yard, where the terrain was most level and where there were no pits or holes which could skew the test results. The rain garden locations were chosen similarly, with the newer rain garden being more difficult to place the rings because of tree roots.

The trial number column indicates each time the rings were refilled, with the start time ("S") being when the rings were full and the end time ("E") being when the rings were refilled, and the volume needed to refill them was measured. The volume column shows the volume required to fill the rings to their initial depth; this was read directly from the flow meter readout. The infiltration rate column shows the calculated infiltration rate based on the volume required to fill the rings and the elapsed time during the trial run. In both the volume and infiltration rate columns, inner ring refers to the area inside the center eight-inch pipe, and annular area refers to the area between the inside of the 18-inch pipe and the outside of the eight-inch pipe; these infiltrometer results were also plotted in Figure 25.

Table 1

Open Yard Infiltrometer Test Results

Cumulative Elapsed Time (min)	Date		Time	Elapsed time	Volume (L)		Infiltration Rate (in/hr)	
					Inner Ring	Annular Area	Inner Ring	Annular Area
15	5/14/2017	S	11:59	15	3.06	11.27	14.86	13.47
	5/14/2017	E	12:14					
30	5/14/2017	S	12:17	15	3.21	9.74	15.59	11.64
	5/14/2017	E	12:32					
45	5/14/2017	S	12:34	15	2.86	7.51	13.89	8.98
	5/14/2017	E	12:49					
60	5/14/2017	S	12:51	15	2.86	7.39	13.89	8.83
	5/14/2017	E	1:06					
75	5/14/2017	S	1:08	15	2.34	6.95	11.36	8.31
	5/14/2017	E	1:23					
90	5/14/2017	S	1:25	15	2.37	6.64	11.51	7.94
	5/14/2017	E	1:40					
105	5/14/2017	S	1:42	15	2.83	6.55	13.74	7.83
	5/14/2017	E	1:57					
120	5/14/2017	S	1:59	15	2.52	5.89	12.24	7.04
	5/14/2017	E	2:14					
135	5/14/2017	S	2:16	15	2.27	6.12	11.02	7.32
	5/14/2017	E	2:31					
150	5/14/2017	S	2:33	15	2.43	5.26	11.80	6.29
	5/14/2017	E	2:48					
165	5/14/2017	S	2:51	15	2.34	6.31	11.36	7.54
	5/14/2017	E	3:06					
180	5/14/2017	S	3:08	15	2.42	5.80	11.75	6.93
	5/14/2017	E	3:23					
195	5/14/2017	S	3:25	15	2.55	5.25	12.38	6.28
	5/14/2017	E	3:40					
210	5/14/2017	S	3:42	15	2.38	5.85	11.56	6.99
	5/14/2017	E	3:57					

Table 2

Newer Rain Garden Infiltrometer Test Results

Cumulative Elapsed Time (min)	Date		Time	Elapsed time	Volume (L)		Infiltration Rate (in/hr)	
					Inner Ring	Annular Area	Inner Ring	Annular Area
15	5/21/2012	S	10:42	15	1.88	3.00	9.13	3.59
	5/21/2012	E	10:57					
30	5/21/2012	S	11:03	15	1.65	5.75	8.01	6.87
	5/21/2012	E	11:18					
45	5/21/2012	S	11:19	15	1.83	5.76	8.89	6.89
	5/21/2012	E	11:34					
60	5/21/2012	S	11:36	15	1.36	4.82	6.60	5.76
	5/21/2012	E	11:51					
75	5/21/2012	S	11:52	15	1.41	5.08	6.85	6.07
	5/21/2012	E	12:07					
90	5/21/2012	S	12:10	15	1.27	4.25	6.17	5.08
	5/21/2012	E	12:25					
105	5/21/2012	S	12:27	15	1.55	3.97	7.53	4.75
	5/21/2012	E	12:42					
120	5/21/2012	S	12:44	15	1.05	3.80	5.10	4.54
	5/21/2012	E	12:59					
135	5/21/2012	S	1:00	15	1.16	3.81	5.63	4.55
	5/21/2012	E	1:15					
150	5/21/2012	S	1:17	15	1.02	3.57	4.95	4.27
	5/21/2012	E	1:32					
165	5/21/2012	S	1:33	15	1.45	3.79	7.04	4.53
	5/21/2012	E	1:48					
180	5/21/2012	S	1:50	15	1.28	3.66	6.22	4.37
	5/21/2012	E	2:05					
195	5/21/2012	S	2:07	15	1.41	3.09	6.85	3.69
	5/21/2012	E	2:22					
210	5/21/2012	S	2:24	15	1.18	2.52	5.73	3.01
	5/21/2012	E	2:39					

Table 3

Established Rain Garden Infiltrometer Test Results

Cumulative Elapsed Time (min)	Date		Time	Elapsed time	Volume (L)		Infiltration Rate (in/hr)	
					Inner Ring	Annular Area	Inner Ring	Annular Area
15	5/22/2017	S	9:08	15	1.87	2.35	9.08	2.81
	5/22/2017	E	9:23					
30	5/22/2017	S	9:24	15	1.56	2.11	7.58	2.52
	5/22/2017	E	9:39					
45	5/22/2017	S	9:40	15	1.58	2.06	7.67	2.46
	5/22/2017	E	9:55					
60	5/22/2017	S	9:57	15	1.42	1.87	6.90	2.24
	5/22/2017	E	10:12					
75	5/22/2017	S	10:14	15	1.21	2.07	5.88	2.47
	5/22/2017	E	10:29					
90	5/22/2017	S	10:30	15	1.35	1.87	6.56	2.24
	5/22/2017	E	10:45					
105	5/22/2017	S	10:47	15	1.30	1.72	6.31	2.06
	5/22/2017	E	11:02					
120	5/22/2017	S	11:03	15	1.21	1.70	5.88	2.03
	5/22/2017	E	11:18					
135	5/22/2017	S	11:20	15	1.32	1.58	6.41	1.89
	5/22/2017	E	11:35					
150	5/22/2017	S	11:36	15	1.22	2.00	5.92	2.39
	5/22/2017	E	11:51					
165	5/22/2017	S	11:53	15	1.35	1.86	6.56	2.22
	5/22/2017	E	12:08					
180	5/22/2017	S	12:09	15	1.26	1.39	6.12	1.66
	5/22/2017	E	12:24					
195	5/22/2017	S	12:25	15	1.37	1.59	6.65	1.90
	5/22/2017	E	12:40					
210	5/22/2017	S	12:42	15	1.41	1.72	6.85	2.06
	5/22/2017	E	12:57					

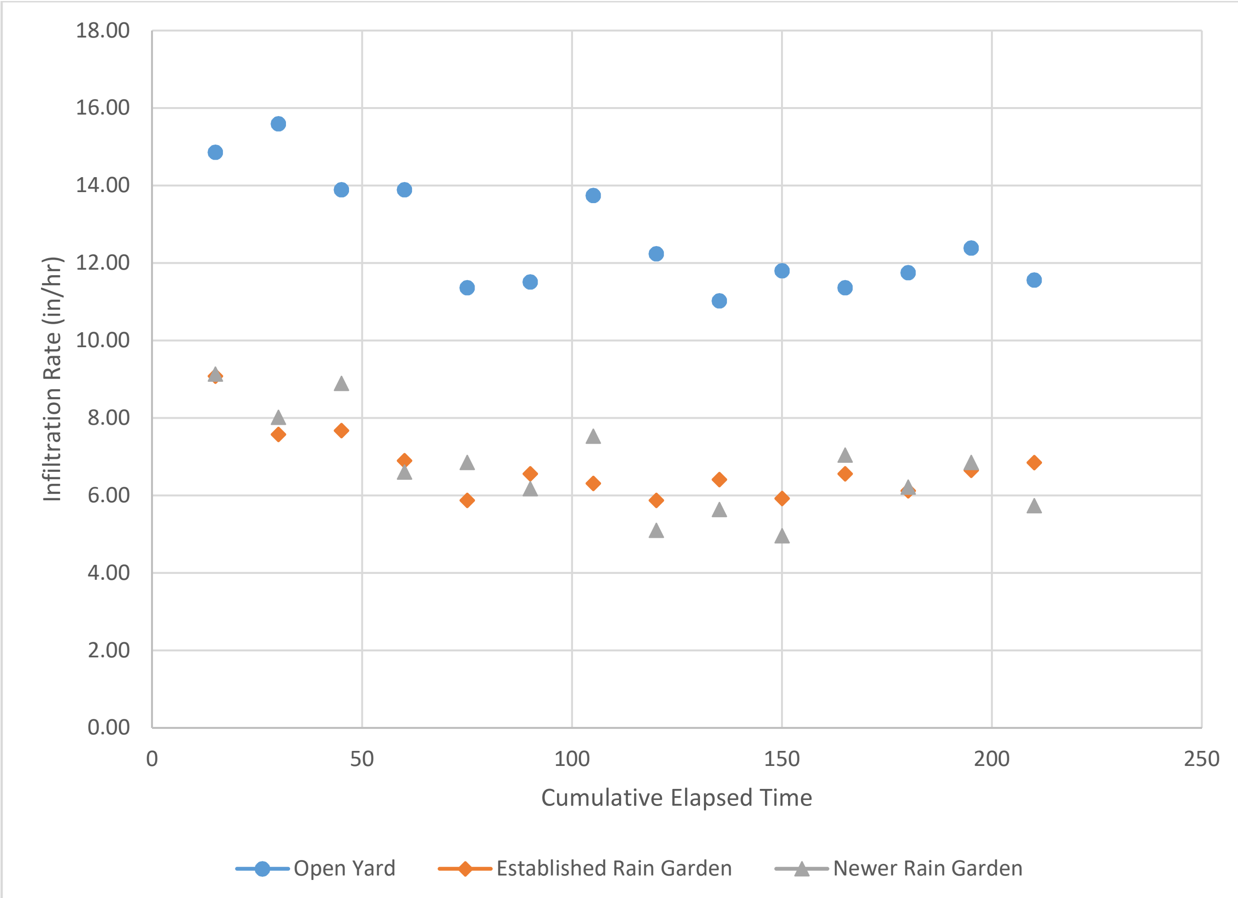

Figure 25. Plotted infiltrometer test results.

Table 4 is a summary of the average infiltration rates calculated during this experiment from the various locations used and test methodologies.

Table 4

Calculated Infiltration Rate Summary

Location	Test Type	Average Calculated Infiltration Rate (in/hr)
Established Rain Garden	Rainfall Analysis	6.00
	Infiltrometer	6.74
Newer Rain Garden	Infiltrometer	6.76
Yard	Infiltrometer	12.64

Analysis

The data collected during the various rainfall events suggest that the established rain garden has an average infiltration rate of approximately six inches per hour. Compared to the infiltrometer test performed in the yard, it would appear that the established garden has a lower infiltration rate than that of the rest of the yard, which was approximately 12.64 inches per hour. Although there was no calculated infiltration data for the newer rain garden, comparing the calculated infiltration data for the established garden to the infltrometer test results of the newer garden would suggest that the established rain garden has an infiltration rate about equal to that of the newer rain garden, which was approximately 6.76 inches per hour.

The results from the established rain garden infiltrometer test also agree with the results of rainfall event analysis. The infiltrometer test showed an average of approximately 6.74 inches per hour, which is about equal to that of the newer rain garden and still less than that of the yard. These results would suggest that the infiltration rate of rain gardens does not change over their lives.

Discussion

One important note about the infiltrometer tests presented in this report is that the condition of the soil was different between the test of the yard and the tests performed on the rain gardens. The infiltrometer tests in both rain gardens were performed within 24 hours of each other, and there were several heavy rainfall events in the day prior to those tests, which thoroughly saturated the soil. In the case of the yard infiltrometer test, however, there had not been any significant rain events in the week prior to the infiltrometer test. The fact that there were no major rain events prior to the yard infiltration test means that the soil was significantly less saturated than it was during the rain garden infiltrometer tests, which meant that the soil in the yard had a greater ability to store water during the test than the soil in the rain gardens. This may explain the drastically higher infiltration rates of the yard compared to the garden; however, there are many other possible explanations that could explain the difference between the two test results. More investigation is necessary to definitively determine the reason(s) for the difference in these test results.

The infiltrometer tests for this experiment were also only performed at one point in each location. This may also explain the high infiltration rate calculated for the yard because the area tested may have been more permeable than the rest of the yard, but without other tests to verify or to disprove the results of this infiltrometer test, there was no way to know whether this particular test was representative of the entire yard or not. To increase the accuracy of this particular test in future experiments, multiple points should be tested with the infiltrometer.

Another aspect to note about the data above was that although there were infiltrometer test results for both rain gardens, there were no results for the newer rain garden from rainfall events. This was due to an error in the placement of the sensors in the gardens. Initially, it was assumed that the gardens were relatively level, both in their bottoms and along their berm. As a result, the pressure sensors in the gardens were placed close to where the flow was entering the garden, which would help ensure that flow data were recorded during the experiment. However, after the topographic survey was performed on both gardens, it was determined that the sensors were not in the lowest area of their respective gardens. In the case of the established garden, the garden was relatively level, and the sensor was in an adequate position to still record data. In the newer rain garden, however, it was discovered the garden was on a slope, meaning that where the sensor was placed was above and far away from where stormwater would pond in the garden, so the sensor did not record any accurate storage data. This type of error could be easily remedied in future experiments by performing topographical surveys of the rain gardens prior to sensor placement.

Although the misplacement of the newer garden pressure sensor meant that no data could be presented for the newer rain garden, it lent a solution to an issue with adjusting the pressure data from the other sensors. Initially, data from a nearby weather station were used to adjust the pressure data from the sensors. However, this proved to be inaccurate and gave almost exclusively negative box depth measurements, which is impossible, since the sensor was always submerged, even if there was no flow through the box. This is most likely due to the fact that the weather station took data approximately every 15 minutes, as opposed to the pressure sensors on site which took readings every 30 seconds. Also, since pressure can vary greatly with location, the fact that the weather station was not in the same location as the rest of the sensors likely attributed to the error. This was remedied in this analysis of data shown above by utilizing the pressure data recorded by the newer rain garden sensor because that sensor spent the majority of the experiment in the open air. In future experiments, however, a fifth pressure sensor would be needed to record the pressure in the area at time steps equal to those of the other sensors.

While the purpose of this experiment was to determine if there was a difference between the infiltration rates of new and established rain gardens, the data collected during this experiment was also compared to the WDNR Technical Standard 1002, which is the standard for site evaluation for stormwater infiltration (Wisconsin Department of Natural Resources [WDNR], 2004). According to Standard 1002, the design infiltration rate for a silt loam soil, which is the soil present in the area, is 0.13 inches per hour. Even the lowest infiltration rates calculated during this experiment were significantly higher than that design infiltration rate. This would suggest that the WDNR design infiltration rates are underestimating the actual performance of rain gardens, but to make any definitive conclusions on this point, further tests on a large sample of rain gardens built in silt loam soil would need to be performed. If, however, there is an underestimation in the performance of rain gardens, it could mean economical savings for developers because rain gardens could be made smaller and still meet runoff requirements. It also means that rain gardens could be placed in spaces originally thought too small to have any significant benefit to runoff reduction, meaning that places where open space is limited could also see benefits from rain gardens. Finally, the underestimation of rain garden performance could mean that currently installed rain gardens are actually contributing more to runoff reduction than originally anticipated.

Conclusion

Based on the results of this experiment, it appears that there may be no change in the infiltration rate of rain gardens over their life. To say for certain, however, more examples of this type of experiment would need to be conducted and errors in the data collection of this experiment would need to be improved upon.

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Civil Engineering

Capstone Report Approval Form

Master of Science in Engineering – MSCVE

Milwaukee School of Engineering

This capstone report, titled "A Comparison of New and Established Rain Garden Infiltration Rates" submitted by the student Michael S. Anaszewicz, has been approved by the following committee:

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