PERFORMANCE ASSESSMENT OF TWO STORMWATER BEST MANAGEMENT PRACTICES FOR INFILTRATION, WATER QUALITY, AND VEGETATIVE GROWTH

A REPORT COMPLETED FOR THE CITY OF OMAHA, NEBRASKA

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EXECUTIVE SUMMARY

Bioretention gardens examined by the City of Omaha in 2011 demonstrated unexpected results. Infiltration rates were slower than expected in the native soils, and much more rapid than expected in the amended sand-compost soil mix used at both sites. The results of this assessment of Best Management Practice (BMP) performance indicate that changes in design parameters need to be considered closely with attention to small details that can dramatically affect their performance, and that adjustments to existing BMPs may be appropriate to improve function and performance to achieve the intended goals of stormwater control and water quality improvement.

The purpose of this assessment was to examine infiltration and percolation of stormwater in and near established BMPs during the growing season. The original intent of this assessment grew during the project time to assess overall performance of one particular bioretention garden that demonstrated initial results different from what had originally been assumed; that being that stormwater was effectively infiltrating into the native soils as well as percolating through an infiltration cell comprised of a sand-compost mix. During the course of this project, this assessment included examination of water quality improvements and vegetative growth of the garden in addition to infiltration.

Two sites were selected for the BMP assessment: a bioretention garden constructed at Orchard Park in north-central Omaha in 2009, and a series of bioretention gardens constructed at the Under the Sink facility in west Omaha in 2008. The bioretention gardens at the two sites have different designs that allowed examination of variability in bioretention garden performance. The bioretention garden at Orchard Park consisted of two gardens separated by a sidewalk, but connected by pipes extending under the sidewalk. The gardens were established in native silty clay loam soil, with 20 foot long by 5 foot wide by 2 foot deep infiltration cells filled with a sand-compost mix, and drained through perforated 4-inch PVC pipe. The bioretention gardens at the Under the Sink facility were constructed in native silty clay loam soils with a sand-compost mix filling the entire structure to a depth of 2.5 feet. Each garden is drained by flexible, perforated pipes laid in an oval shape near the perimeter of the gardens. All of the gardens are vegetated with vegetation native or adapted to the eastern Nebraska region.

Infiltration was measured using double ring infiltrometers and mini-infiltrometers three times during the growing season (May, July, and September). In addition to measurement of infiltration using the double ring infiltrometers and mini-infiltrometers, the Orchard Park bioretention gardens were flooded three times during the summer to simulate actual stormwater conditions and infiltration. After the first series of infiltration measurements in May, valves were installed at Orchard Park to control the rate of discharge through the underdrain system. No alterations to the structures at the Under the Sink facility were made as these gardens already had valves on the underdrains.

The results of this assessment of BMP performance include the following:

1. The sand/compost soil mix used for BMPs – whether for the entire base of the BMP, or for individual infiltration cells – is very permeable, with infiltration rates typically more than 40 inches per hour
2. Native soils in most locations are slowly permeable and highly prone to compaction that will slow infiltration even more. Root growth in the native soils at Orchard Park varied by location within the bioretention garden, with the roots in some areas of the garden deep with strong vertical growth, while in other parts of the garden, the root growth was stunted by very dense soils.

3. Infiltration in native soils is enhanced in very close proximity to plants and their associated roots. Infiltration through vegetated native soil was found to be approximately 3.0 to 3.5 inches per hour. On soil without vegetation, even if only several inches away from vegetation, infiltration was very slow.

4. During stormwater simulations, water quality data show release of nitrogen and phosphorous with water percolating through the sand-compost soil mix of the infiltration cell with uncontrolled flow through the BMP (short retention time). This finding is consistent with other water quality measurements conducted around the U.S. and in a study conducted at the University of Minnesota. A reduction of nitrate nitrogen, total Kjeldahl nitrogen, and total phosphorous was observed in samples collected after water was resident in one BMP for 24 hours when compared to the samples collected after no retention time in the same BMP.

5. Vegetation performance of the BMPs was found to be good. Native plants at both sites showed vigorous, healthy growth. Root growth and extension into the sand-compost mixes was observed to be very good, and root growth into the native soils was also very good, with root depths to 12 inches. Even in compacted soils root growth extended to depths of near 8 inches below the ground, although the roots of plants growing in the compacted soil were not as thick as roots in the non-compacted soils.

6. The total time of inundation plays a significant role in plant performance. During the first two seasons of the Orchard Park bioretention gardens, no valve was on the underdrain systems; as a result they drained excessively and dried in a short period of time. The addition of a valve and adjustment of flow out of the garden to extend residence time to 24 hours stressed the little and big bluestem plants that were located in the frequent inundation area. Those plants above that level performed better, emphasizing the need to site plants appropriately within the garden.

7. The combination of these extremes highlights the importance of fine details in installation, limiting compaction during construction, and in design, detailing a valve assembly to control the flow out of the underdrain system.

1.0 INTRODUCTION

According to the U.S. Environmental Protection Agency, "The best way to mitigate stormwater impacts from new developments is to use practices to treat, store, and infiltrate runoff onsite before it can affect water bodies downstream. " In keeping with this philosophy, the City of Omaha conducted an assessment of stormwater Best Management Practices (BMPs) performance as represented by two bioretention garden systems in 2011.

1.1 Purpose

The purpose of this study was to assess infiltration and percolation of stormwater in and near established BMPs during the growing season, and determine if improvements or adjustments in the BMPs are needed.

A primary goal of the study was to determine differences in infiltration between the established BMP and nearby (non-BMP) soil conditions, and potential changes in infiltration and percolation during the growing season. The study measurements are intended to provide data that will help designers more effectively estimate the volume of stormwater that can be treated in these BMPs. Because infield observations and measurements elucidated unexpected BMP performance issues, the original intent of this study shifted from looking at infiltration differences between BMPs and the surrounding areas, and instead became focused on infiltration management and adjustment in bioretention gardens with different design elements. Through the process of evaluating BMP performance, the project had the opportunity to examine:

- Infiltration
    - in separate native and manufactured soil types
    - in simulated conditions and manipulated drainage
- Water quality
- Vegetation performance

Data quality in this study is limited to direct measurements of observed or manipulated field conditions to test BMP performance and infiltration rates.

1.2 Background

To comply with requirements of the U.S. EPA for stormwater management, the City of Omaha requires capture and treatment of the first one-half inch of stormwater runoff to improve water quality and reduce stormwater runoff peak volumes on renovation projects and new developments. One of the best methods for accomplishing this goal is the implementation of stormwater BMPs that capture and detain rainfall runoff, promote infiltration into the soil within 24 hours, and slowly conveying excess stormwater through and out of the garden. The depth of the BMP and the infiltration rate of both the native soil and any amended soil used are intrinsically related. Shallow BMPs can function properly with slower infiltration rates, with a minimum rate of at least 0.5 inches per hour. Deeper BMPs require more rapid infiltration and drainage to assure drawdown necessary to empty the BMP above ground storage in a 24-hour period.

2.0 SITE DESCRIPTIONS

Two sites were selected for study: a bioretention garden constructed at Orchard Park in 2009, and bioretention gardens constructed at the Under the Sink (UTS) facility constructed in 2008. Orchard Park is located in north-central Omaha at North 66th Street between Sorenson Boulevard and Hartman Street, consisting of approximately 14 acres bisected by Cole Creek. Orchard Park is set in a dominantly suburban residential area, and the park is used for active and passive recreation. The Orchard Park bioretention garden investigated for this study is part of a two-cell structure that collects and treats stormwater runoff from N. 66th Street. Stormwater enters the first cell through curbcuts along the street, and overflows through pipes into the larger cell that was the focus of this assessment (Figure 2-1).

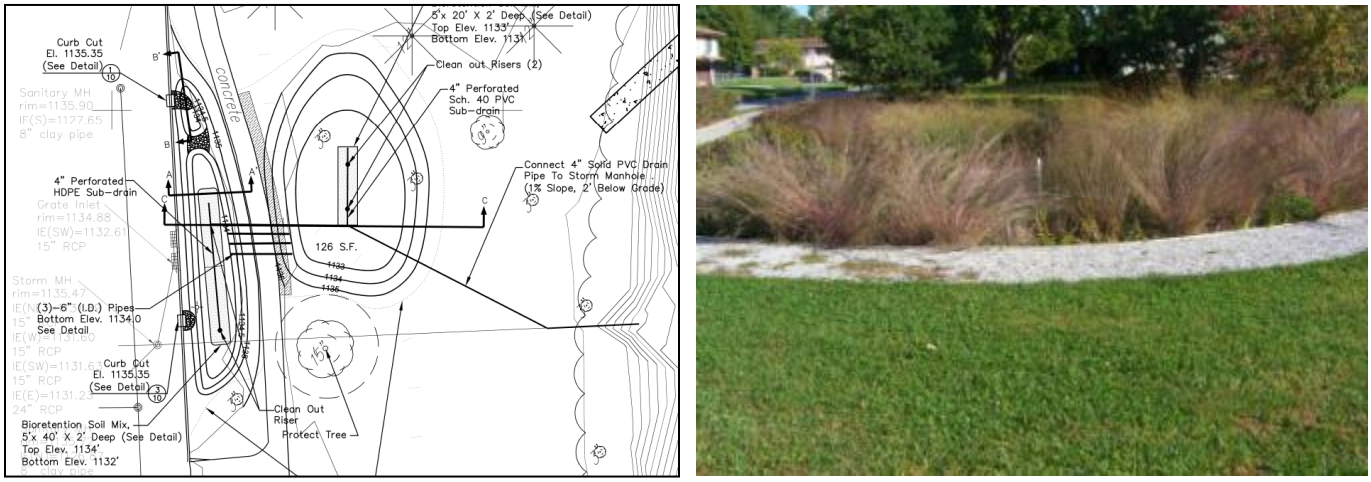

Figure 2-1: The Orchard Park Bioretention cell, with design features shown, and the primary structure showing plant growth in the third year of operation

The primary (larger) garden examined for this project averages approximately 50 feet in diameter and is approximately 30 inches deep, with a ponding depth of approximately 18 inches. Most of the garden is established in the native silty clay loam soil, with an "infiltration cell" that consists of a sand/compost soil mixture in a trench 5-feet wide, 20 feet long, and 24 inches deep, and that is drained by perforated 4-inch PVC pipe.

The Orchard Park bioretention garden exhibits very good vegetative establishment and growth. In 2011, the garden was entering its third year of growth. Grasses planted in the garden including big blue stem, switch grass, Indian grass, little blue stem, bulrush, and herbaceous plants such as black-eyed susan, liatrus, monarda, and prairie cone flower, were well-established. Little blue stem on the north and west sides of the garden does not exhibit growth vigorous as grasses on the south and east sides of the garden, and grasses in the middle of the garden, within the "infiltration cell" demonstrate excellent growth and establishment.

The Under the Sink facility is a household hazardous waste collection facility operated by the City of Omaha located at 4001 South 120th Street, occupying approximately 5.5 acres. The land has moderate slope to the west, and consists primarily of the building, parking lots, and turf lawn. A series of 15 bioretention gardens were constructed in 2008 at the site along the west and south boundaries of the property, adjacent to 120th Street (Figure 2-2).

Figure2-2: Under the Sink Bioretention Gardens (aerial photo source: Google Earth)

The bioretention gardens are generally about 20 feet in diameter, and were constructed in a silty clay loam soil. The bioretention gardens were constructed with flexible, perforated drainage pipe installed in an oval configuration at the bottom of each garden, connected with a solid four inch drainage pipe that runs to the nearest storm sewer inlet. Pea gravel was installed over the perforated pipe, geotextile laid over top of the aggregate and stapled down, and then backfilled with a compost/sand mixture. The ponding depth of each garden is approximately six inches. Vegetative growth in the bioretention gardens was observed to be good at the time of sampling, with some sparsely vegetated areas in two of the gardens. Vegetation in the gardens included Helen's Flower, New England Aster, Bee Balm, Spiderwort, and Golden Alexanders.

3.0 DATA COLLECTION AND RESULTS

Infiltration measurements were collected using double ring infiltrometers and mini-infiltrometers. Double ring infiltrometers have long been used by soil scientists and engineers to determine infiltration rates in soils. The device consists of two concentric rings, one inside the other, that are filled with water, with the drop of the water level in the inner ring measured with time (falling head measurement). The mini-infiltrometer is a smaller version of the double ring infiltrometer. When possible, subsoil conditions and root development of plants were examined to help understand the flow rates in the BMPs.

Infiltration and percolation measurements were conducted three times during the growing season: early May; mid-July; and September. Samples were initially collected within the BMP structures and from areas nearby the BMPs, but as initial data demonstrated variable characteristics within the BMPs, the subsequent measurement periods focused on the bioretention garden structures to determine if seasonal changes with plant growth or changing soil conditions might occur. Infiltration testing was initiated on May 9, with subsequent testing completed on July 12/13, and September 21, 2011. At both locations, measurements included infiltration within the gardens, and from nearby turf lawns.

In addition to measurement of infiltration using double ring infiltrometers and mini-infiltrometers, the Orchard Park bioretention garden was flooded three times during the summer season to simulate actual

storm runoff conditions. The objective was to measure the 24 hour infiltration rate of the garden from a staff gauge placed in the center of the garden. After the 24 hour infiltration readings were taken, the valves on each garden were opened one at a time to assess the rate of flow out of the garden through the underdrain system. Concurrent to the second and third simulations, water quality samples were collected and analyzed to assess the bioretention garden's performance in removing pollutants.

Vegetation condition was observed and noted during each sampling period at both sites. Along with observation of vegetation conditions, infiltration related to bioretention garden vegetation was measured twice at Orchard Park using the double ring infiltrometer in which the center ring of the infiltrometer was placed over a stalk of native grass (little bluestem both times), and measurements of infiltration rate recorded from the center ring.

4.1 Orchard Park

The original intent of infiltration measurement at Orchard Park was to measure the differences in infiltration within the bioretention garden compared to infiltration outside the garden and if infiltration would increase with plant growth through the summer. During the first testing period in May, it was observed that infiltration in most areas within the bioretention garden and outside of the infiltration cell was very slow; generally less than 0.5 inches per hour (see Section 3.0). Infiltration within the garden and within the footprint of the infiltration cell was excessively fast, measured at a rate in excess of 24 inches per hour.

4.1.1 Infiltration

Infiltration measurements were collected at Orchard Park at varying locations within the bioretention garden in approximately similar locations, or in locations to determine if amendments to soil conditions or plantings affected infiltration. Approximate testing locations are shown in Figure 4-1.
At Orchard Park, the premise that the infiltration rates for the bioretention garden may increase with new vegetative growth through the summer was a constant measurement objective. After the first

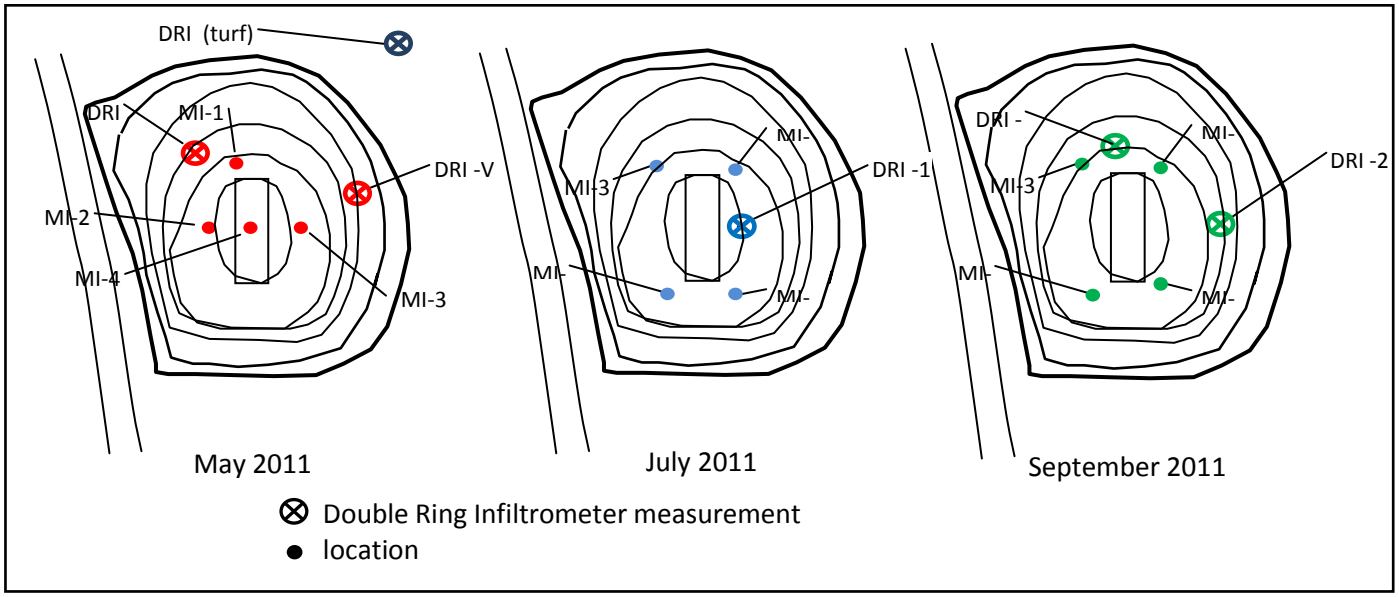

Figure 4-1: Infiltration measurement locations – Orchard Park Bioretention Garden

measurements in May the native soil condition was examined for bulk density to determine if this factor could be influencing infiltration rates. The bulk density of the bioretention garden was measure as high as 1.8 grams per cubic centimeter (g/cc) from the surface to approximately eight inches below the surface, reflecting a high degree of compaction. The project approach was amended to determine if remedial actions to break compacted, dense soils would improve infiltration.

Throughout the measurement periods, the infiltration tests using the double ring infiltrometers demonstrated very slow infiltration. Infiltration rates measured at Orchard Park are provided in Table 4-1. To determine if infiltration were equally slow near or with vegetation, infiltration was measured on soil occupied by native grass (little bluestem).

Table 4-1: Infiltration Measurement Results
Orchard Park, May-July-September 2011

Measurement Location	May 9	July 12	Sept 21
DRI – Turf	0.38 in/hr	No Measure	No Measure
DRI	0.25 in/hr	<0.10 in/hr	<0.10 in/hr
DRI – Vegetation	3.00 in/hr	No Measure	3.50 in/hr
MI – 1	0.38 in/hr	0.62 in/hr	8.20 in/hr
MI – 2	0.75 in/hr	1.12 in/hr	0.13 in/hr
MI – 3	0.81 in/hr	0.18 in/hr	0.76”/hr
MI – 4	>40 in/hr *	0.00 in/hr	9.75”/hr

In general, the infiltration rates in the native soil of the Orchard Park bioretention garden ranged from 0.38 inches per hour on the north side of the infiltration cell, to 0.75 to 0.81 inches per hour on the west and east sides of the cell, and greater than 40 inches per hour within the sand/compost mix of the infiltration cell. The infiltration rate in native soil between plants averaged approximately 0.41 inches per hour, or 1.65 inches per hour including the two very rapid infiltration measurements shown in Table 4-1. The average infiltration rate excluding the two very rapid measurements is nearly equal the rate measured in the nearby park turf grass area (0.38 inches per hour). The data show that infiltration incorporating vegetation in the measurement showed a rate of 3.0 inches per hour.

The data show very slow infiltration rates, with variability in the rates of infiltration measured at different locations in the garden. Measurements from the south end of the bioretention garden had faster infiltration than readings collected on the north (0.62 – 1.12 in/hr on the south end compared to 0.00 to 0.18 in/hr on the north end in July. The garden also had typically faster infiltration on the west side (southwest and northwest corners) of the infiltration cell compared to the east side of the infiltration cell.

4.1.2 Stormwater Drainage Simulation

Valve assemblies were installed on both of the bioretention garden underdrains in May, 2011 when it was realized that drainage through the infiltration cells was too fast. To assess the infiltration of the garden as a whole, three simulated rain events were conducted by closing the underdrain valves and then flooding the garden with water from a nearby fire hydrant. These simulations took place on May

25th, June 30th, and August 17th. During the first simulation, the drop in water elevation of ponded water in the larger, primary garden was less than 3 inches over a 24-hour period. When the valve was open, the garden drained within 75 minutes, or 10.92 inches per hour, showing the affect of the infiltration cell on the performance of the bioretention garden. The second and third simulations were 12.12 and 14.64 inches per hour respectively.

During the storm event simulations, the valves were shut completely and the outfall was capped to ensure no loss of water. The 24 hour infiltration rate of water into the native soil of the primary bioretention garden was consistent for the May 25th, June 30th, and August 17th simulations, with measured infiltration rates of approximately 0.10 to 0.125 inches per hour (Table 4-2). The data indicate slight movement upward in the infiltration rate over the course of the growing season, but not significantly.

Table 4-2: Bioretention Garden Flooding Infiltration Results June and August 2011

	Water Elevation 0 hr (ft)	**Water Elevation 24 hr** (ft)	**Drop** (ft)	**Drop** (inches)	**Infiltration Rate** (in/hr)
June 30, 2011					
24 hr infiltration (ft):	1.7	1.47	0.23	2.76	0.115
August 17, 2011					
24 hr infiltration (ft):	1.465	1.22	0.245	2.94	0.123

4.1.3 Water Quality Analysis

Water samples were collected at Orchard Park during the second and third rainfall flooding simulations to provide a preliminary assessment of BMP performance for water quality improvement. Composite samples were collected for the influent entering the first curb-side garden and grab samples were collected as water first entered the larger, primary bioretention garden. Effluent grab samples were taken from both gardens independently to assess each gardens performance. Water samples were then collected from the effluent discharged from the primary garden at 0 hour, and again after 24 hours of residence time.

Samples were analyzed for nitrate/nitrite nitrogen, Total Kjeldahl Nitrogen (TKN), total phosphorous (TP), total dissolved phosphorous (TDP), heavy metals, and hydrocarbons. E coli, total suspended solids (TSS), and total solids (TS) were also tested, but due to errors in the field and lab, usable data was not obtained.

Water quality analytical results are shown in Table 4-3. The data show increases in nitrogen and phosphorous concentrations as the simulated stormwater filters through the bioretention garden. This is not unexpected, as microbial activity will free nitrogen and phosphorus from its bound form in organic matter, making it susceptible for leaching with incoming water. These results are consistent with the findings of other infiltration BMPs listed on the U.S. BMP Database maintained by the U.S. EPA in which similar BMPs show slight increases of nitrogen and phosphorous in effluent.

Table 4-3: Water Quality Analytical Results Orchard Park – June 2011					
	Nitrate/Nitrite Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorous	Nitrite	Total Dis. Phosphorous
Influent (mg/l)	0.03	2.39	0.44	0	0
0-hr effluent (mg/l)	0.52	2.54	0.71	0	0.62
24-hr effluent (mg/l)	0.90	2.00	0.76	0.02	0.63
U.S. median influent (mg/l)[a]	0.59	01.80	0.25	NA	0.09
U.S. median effluent (mg/l)[a]	0.60	1.51	0.34	NA	.044
a. Median of 57 infiltration BMPs nationwide. Source: USEPA National BMP Database, May 2011					

It may be reasonable to assume that the pollutant removal capabilities of the Orchard Park and other BMPs in Omaha will show similar results for effective filtering of sediments, metals, and hydrocarbons. Bioretention gardens have been reported to effectively remove metal pollutants and hydrocarbons from stormwater under simulated conditions, while also releasing consistent concentrations of phosphorous. A study conducted at the University of Minnesota showed good uptake of cadmium, zinc, and copper by compost-amended sand in bioretention gardens, while releasing phosphorous at rates of approximately 0.29 mg/l through several hundred simulated rainfall infiltrations (Morgan, Gulliver, and Hozalski, University of Minnesota, Science and Engineering Update, Nov. 2011)

4.1.4 Vegetation

The plant material within the primary garden has performed quite well since its installation in early 2009 and has continued to perform well in 2011. Observations during the course of this study include:

- Root growth was good, with plants within the infiltration cell showing excellent root growth and structure. Plants growing in the native silty clay soil also showed very good growth, with roots found as deep as 12 inches below the ground surface. Roots of little bluestem growing in areas of the garden that have compacted soils also showed root growth to depths of 6- to 8 inches below the ground surface (bgs), demonstrating the hardiness of these plants to grow even in difficult soil conditions (Figure 4-2).

- Little bluestem grass that encompasses the majority of the north, east and south sides of the primary bioretention garden exhibited stunted growth where inundation occurred more frequently, typically toward the bottom of the garden. It is likely that while root growth was observed as deep as 8 inches bgs, high bulk density of the native soil and poor drainage contributed to stunted growth of the plant and its roots.

Figure 4-2: Root growth in uncompacted native soil (left) and compacted native soil (right)

- In late August, a 4- to 7-inch rainfall occurred in the Omaha area. Both gardens that comprise the bioretention structure were filled to capacity, with 12" of ponding in the first garden and 26 inches of ponding in the primary garden. The valve in the primary garden was partially closed to allow for a slow drawdown. In the bottom of the garden, Big Blue Lobelia had been performing well, but prolonged submersion during this event led to die-back of this plant. Lobelia plants that were able to stay above the ponding level remained viable and approximately two weeks after this event, new growth was noted at the base of the plants.

- New England Aster has exhibited strong colonization throughout the gardens and into the adjacent naturalized areas.

- Black-eyed susans and prairie cone flowers exhibited less vigorous growth than the first two years. This is not unusual, as the typical growth pattern of these plants is two years, followed by new growth from seed. The overall population of black-eyed susans and prairie cone flowers was lower in 2011, but improvements are expected in 2012.

- Penstemon and Prairie Blazing Star growth improved in the smaller, curb-side garden from decreases in populations in 2010 primarily the result of extensive vole damage.

The original design for the Orchard Park bioretention garden included drier, upland vegetation such as little bluestem in the bottom of the garden with the expectation of dry conditions during mid- to late-summer. The rapid drainage of the garden due to the highly permeable infiltration cell kept conditions dry and allowed the upland plants to do well. After the drain valves were installed in the garden, and

drainage slowed, the dryland vegetation such as little bluestem and great blue lobelia suffered due to the wetter conditions.

4.2 Under the Sink

Infiltration measurements were collected at the Under the Sink facility in the four bioretention gardens in the northwest corner of the property. Whereas the initial infiltration measurements at Orchard Park demonstrated very slow movement of water into the soil, infiltration into the Under the Sink bioretention garden soils was very fast. Observation of the four gardens showed that the first garden (BG-1) has a layer of silt over the top of the amended soil mix approximately 1.5 to 2 inches thick. It was determined to measure infiltration through the silt, as well as with the silt scraped aside. The remaining three gardens (BG-2, BG-3, and BG-4) were not covered with discernable silt. Measurements were collected in each garden as shown in Figure 4-3.

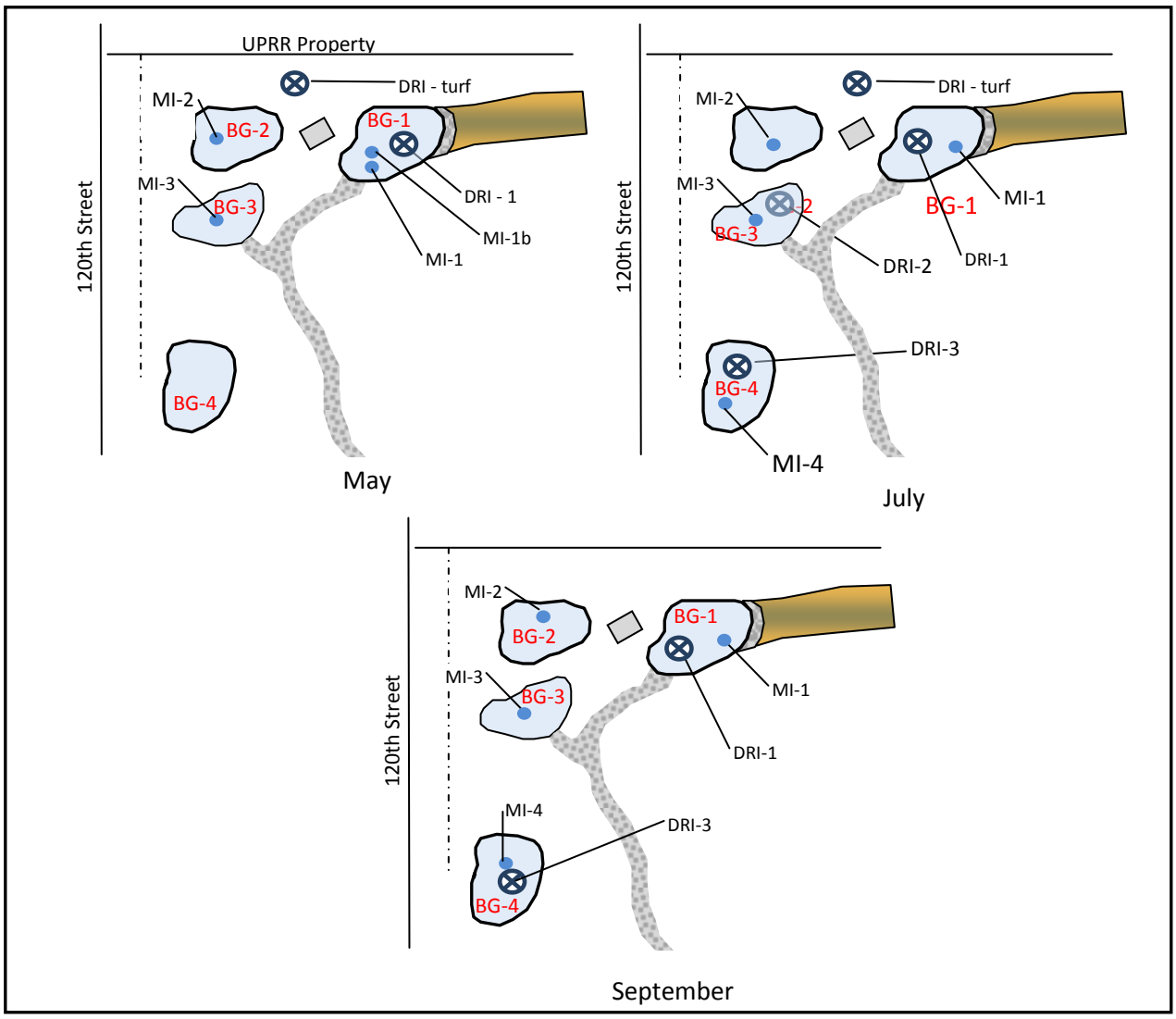

Figure 4-3: Infiltration Measurement Locations at the Under the Sink Bioretention Gardens

Because of the very porous nature of the bioretention amended soil at the Under the Sink facility, infiltration measurements from May through September were conducted to determine if there would be changes in infiltration rates with increased plant growth through the summer (including root mass) and/or possible silt deposition that could occur with rainfall runoff. Infiltration measurements were also collected in the turfgrass area near the BMPs at the Under the Sink facility. Infiltration rate measurement results are shown in Table 4-4.

Table 4-4: Infiltration Measurement Results Under the Sink, May-July-September 2011

Measurement Location	May 9	July 12	Sept 21
DRI – Turf	1.00 in/hr	0.90 in/hr	No Measure
DRI – 1	3.9 in/hr *	16.2 in/hr*	9.10 in/hr
DRI – 2	No Measure	>40 in/hr*	No Measure
DRI – 3	No Measure	>40 in/hr*	>40 in/hr*
MI – 1	2.31 in/hr	3.50 in/hr	6.50 in/hr
MI – 1b	>40 in/hr *		
MI – 2	21.5 in/hr*	28.0 in/hr*	5.50 in/hr
MI – 3	>40 in/hr *	>40 in/hr*	>40 in/hr*
MI – 4		>40 in/hr*	>40 in/hr*
*interpolated infiltration rate from last time measurement			

Infiltration measurements collected at the Under the Sink facility in May included examination of the northeast-most bioretention garden (BG-1) that had been covered with approximately 1.5 – 2 inches of silt. Infiltration measurements in this garden, collected with the silt in place, demonstrated reasonable infiltration rates (3.9 in/hr using the double ring infiltrometer, and 2.3 in/hr using the mini-infiltrometer). Infiltration rates in this same garden in July and September showed variable infiltration rates through the silt-covered material, including rates of 16.2 in/hr and 9.1 in/hr with the double ring infiltrometer, and 3.5 in/hr and 6.5 in/hr with the mini-infiltrometer. The variability in these measurements likely reflects varying thickness of the silt as well as possible edge effects from water seeping along the sides of the infiltrometer tools used. An additional measurement of infiltration into the garden with silt scraped away (MI-1b) resulted in an excessively rapid rate, greater than 40 in/hr.

Infiltration measurements collected in the two adjacent gardens, where silt had not accumulated were 21.5 in/hr in BG-2 (MI-2 in Figure 4), and greater than 40 in/hr in BG-3. Infiltration remained rapid in July and September in BG-2 (28 in/hr and 5.5 in/hr, respectively) and BG-3 (>40 in/hr in both July and September). The fourth garden (BG-4) had infiltration rates greater than 40 in/hr for both mini-infiltrometer and double ring infiltrometer measurements in July and September.

The two infiltration readings collected on the turf area at the Under the Sink facility were generally consistent between the two readings, with infiltration approximately 0.90 to 1.0 inches per hour. The data show, then, that the rapid rate of infiltration in the Under the Sink bioretention gardens is substantially greater than the existing turf, and even infiltration through the silt-covered garden was more rapid than infiltration into the existing turfgrass areas.

5.0 DATA INTERPRETATION AND DISCUSSION

When the bioretention gardens are considered as complete structures, information obtained during this assessment demonstrates that BMPs improve drainage of stormwater by diverting water away from storm sewer inlets and slowing its discharge. From this study, it was observed that variability in design and construction significantly affects the rates of stormwater infiltration and drainage in the bioretention gardens and their performance.

Infiltration rates on turf grass lawn areas near BMPs studied ranged from 0.38 inches per hour to approximately 1.0 inches per hour, based on a limited number of measurements collected. Typically, infiltration rates in the BMPs studied ranged from 0.125 inches per hour during storm event simulations at the Orchard Park primary bioretention garden, to an average of 6.9 inches per hour in the silt-covered bioretention garden at the Under the Sink facility, and to greater than 20 inches per hour in the other three gardens examined at Under the Sink.

5.1 Stormwater Infiltration at Orchard Park

While data collected at Orchard Park demonstrated increased stormwater drainage rates overall when compared to background conditions, the data does not indicate an increased rate of infiltration of stormwater into the natural soil at this location. The data showed that the sand/compost soil mix used for the infiltration cell is excessively permeable, with infiltration rates greater than 40 inches per hour based on interpolation of timed infiltration within the limits of equipment used. Infiltration in the native soil surrounding the infiltration cell averaged 1.6 inches per hour, however, two infiltration measurements were extraordinarily high (9.75 and 8.2 inches per hour) skew this average. Without these measurements, the average infiltration rate into the native soil averaged 0.4 inches per hour, with a range (excluding the two high measurements) from 0 to 1.12 inches per hour. The infiltrometer measurements were consistent with the results of a simulation in which the BMP was flooded with water from a fire hydrant. When the underdrain system was closed at the Orchard Park gardens, the 24 hour infiltration rate into the surrounding native soils was very slow, approximately 3 inches, or 0.125" per hour. When the underdrain valves were open, the bioretention garden completely drained in 70 minutes.

The measured variability in infiltration rates on the native soil likely reflects differences in soil density and/or proximity of the measurement to vegetation. The influence of vegetation on infiltration rates in the bioretention garden, however, was demonstrated with two measurements showing rates of 3.0 to 3.5 inches per hour. This highlights the importance vegetation plays in the overall function of bioretention gardens. It also brings notice that their influence on excessively compacted and poor soil conditions is slow to evolve, with infiltration rates between plants showing little increased infiltration as compared to those taken directly over the plant material.

5.2 Under the Sink

The 50/50 fine sand and compost mix used as the base soil of the bioretention gardens at the Under the Sink facility exhibited very high infiltration rates in all four of the gardens studied during all of the measurement periods. Only a covering of silt on BG-1 modified and slowed the infiltration into the garden. The extent of root growth in the Under the Sink bioretention gardens was not examined to

determine if the roots have extended into the native subsoil and may be promoting infiltration into the deeper soil depths.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The results of this study did more to expose potential design and construction flaws that can occur with bioretention gardens than to observe changes or improvements in stormwater infiltration over the course of the growing season. The results of this study will contribute to improved BMP design to enhance infiltration and water quality.

Essential findings of this study include:

1. The sand/compost soil mix used for BMPs – whether for the entire base of the BMP, or for individual infiltration cells – is very permeable. The rate of measured infiltration into this soil mix is typically more than 40 inches per hour. Root growth into the sand/compost mix at Orchard Park was inspected, with plants roots within the infiltration cell showing excellent growth (approximately 24 inches or more).

2. Native soils in most locations are slowly permeable and highly prone to compaction that will exacerbate slow infiltration even more. Root growth in the native soils at Orchard Park overall was good but varied by location within the bioretention garden, with the roots in some areas of the garden deep with strong vertical growth, while in other parts of the garden, the root growth was acceptable, but stunted by very dense soils.

3. Infiltration in native soils is enhanced in very close proximity to plants and their associated roots. Infiltration on soil without vegetation, even if only several inches away from vegetation, was very slow, whereas infiltration measurements that incorporated native grasses within the infiltrometer demonstrated higher rates of infiltration.

4. Water quality data show release of nitrogen and phosphorous when water percolates through the sand-compost soil mix of the infiltration cell. This finding is consistent with other water quality measurements conducted around the U.S. and in a study conducted at the University of Minnesota. It's reasonable to assume, based on other studies conducted on bioretention gardens that other pollutants such as sediments, metals, and hydrocarbons will be removed from stormwater in bioretention gardens, but nitrogen and phosphorous will be released with water discharged from the gardens. No data was found to determine if higher concentrations of nitrogen or phosphorous in water entering the garden would be reduced in concentration in discharged water.

5. The total time of inundation plays a significant role in plant performance. During the first two seasons of the Orchard Park bioretention gardens, no valve was on the underdrain systems; as a result they drained excessively and dried in a short period of time. The addition of a valve and adjustment of flow out of the garden to extend residence time to 24 hours stressed the little

and big bluestem plants that were located in the frequent inundation area. Plants above that level performed better, emphasizing the need to site plants appropriately within the garden.

The findings of this study should be considered in the future design elements of new stormwater BMPs, as well as the management of existing BMPs in Omaha. Observations and measurements of infiltration at Orchard Park and the Under the Sink facility, combined with knowledge of the BMP structures, provides the following design and construction recommendations for BMPs:

1. Because of the high infiltration and permeability rates of the sand/compost infiltration mix, this material should be limited in application for bioretention gardens. Three strategies for design with the manufactured soil mix include:

    a. Limit the extent of sand/compost mix to areas immediately above drainage pipes. The areal extent of the sand/compost mix can be determined by calculation of the volume or column of water that can pass into and through the infiltration cell assuming an infiltration/percolation rate of at least 20 inches per hour. The BMP designer should determine the true infiltration rate of the sand/compost mix prior to conducting calculations. It must be noted that bench-scale tests of sand/compost mix infiltration rates indicated infiltration rates of approximately 3.5 inches per hour, far less than what was measured in the field.

    b. Install a valve at the discharge point of the drainage pipes of the BMP that can be open and closed as appropriate to control drainage from the BMP.

    c. Install a reducer (1-2”) between the perforated and solid drainage pipes to restrict the flow out of the system if a valve is not utilized.

2. Water quality benefits are likely greater with longer residence time of water within the soil, which can be controlled with slower drainage through a valved underdrain system. The valve can be adjusted to slow or increase flow rate out of the system as needed. It can also be adjusted over time to account for increased infiltration into the native soils as a result of plant root establishment, increasing the effectiveness of the garden.

3. Manage native soils in the BMP carefully. During construction, limit access over the base of the BMP by equipment and foot traffic when and where possible. If heavy equipment must be used within the BMP area, the soils should be tilled to a depth of 8- to 12 inches (minimum) to break any compaction, and compost worked into a depth of at least 6 inches at a rate of approximately 1 cubic yard per 100 square feet. If a rototiller is utilized for blending of compost into the native soils, randomly dig holes throughout the tilled area deeper than the tilling depth. This will help to reduce the potential of an impermeable layer forming where the depths of the tines of the tiller reach to. Smearing and compacting of native soils can occur with tines striking at the same consistent depth during operation.

4. In existing or new BMPs, where compaction is found to be a problem, the compaction can be broken between plants using either an auger or a hand shovel to a depth of at least 12 inches, and backfill the hole with the native soil and compost mixed at a 1:1 rate. This will enable plant roots to grow more freely, and will also help to reduce the compaction of nearby soils. Compaction must be broken as much as possible in as many locations in the BMP as possible.

5. Maximize plant density. Plants and their root growth are the single most important factor in maximizing water infiltration into the soil in the BMP. Plant density should be carefully considered, however, as too high of a planting density can stunt plant growth. Not enough plants, however, will reduce the effectiveness of the BMP. Consider targeted spreading of seed from established plants within the garden. This can help to establish a full garden sooner with plants germinating in desired locations.

6. Monitor BMPs for infiltration performance regularly. If infiltration is not occurring as planned, adjustments to the BMP structure, whether by the amending soil conditions, increasing plant density, or installing a valve to control discharge can remediate problems and increase the performance and function of the BMP.