SATURATED HYDRAULIC CONDUCTIVITY ASSESSMENT OF BIORETENTION AND RAIN GARDENS IN OMAHA, NEBRASKA

A REPORT COMPLETED BY THE CITY OF OMAHA, NEBRASKA

BY

JOHN O'DONNELL
AND
ANDY SZATKO

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Abstract

Bioretention systems and rain gardens are an effective measure for mitigating the effects of stormwater runoff in urban environments. Scheduled maintenance and continuous monitoring efforts are necessary to ensure these systems are performing properly. Additionally, measuring the hydraulic characteristics of these systems provides adequate information to determine their infiltration capacity and overall efficiency. A Modified Philip-Dunne (MPD) infiltrometer was used to estimate infiltration rates via saturated hydraulic conductivity (K_{sat}) measurements for rain gardens, bioretention systems, and turf lawns. A total of 112 samples were collected from nine sites in Omaha, Nebraska to assess the performance of both rain gardens and bioretention systems in comparison with adjacent turf areas. The mean K_{sat} values for the rain gardens and bioretention systems sampled ranged from 4.01 to 76.46 in/hr. Across all survey sites, average measurements of saturated hydraulic conductivity in rain gardens (55.31 in/hr) and bioretention systems (23.00 in/hr) were significantly higher than those acquired over adjacent turf grasses (2.53 in/hr).

1. Introduction

Stormwater runoff has significant impacts on the water quality of local streams and rivers in the United States (US EPA, 1996; US EPA, 2009). In an effort to mitigate these damaging effects, local governments (City of Omaha) have incorporated the use of green infrastructure as a best management practice (BMP) within their stormwater management programs. These BMPs significantly reduce stormwater volumes, peak flows, pathogens, sediment loading, erosion, and nutrient concentrations through infiltration into the soil subsurface (Winogradoff, 2002; Dietz and Clausen, 2005; Collins et al., 2010; Beutel and Larson, 2015).

Green infrastructure is a powerful and beneficial approach to stormwater management that aims to preserve natural areas and mimic natural processes through the use of local soils, native vegetation, and land features to capture and manage rain close to where it falls. Green infrastructure practices can range in scale from regional (floodplains and wetlands) to local (urban and residential) landscapes. Examples of more common green infrastructure practices include green roofs, bioswales, rain harvesting systems (rain barrels), rain gardens, and bioretention systems.

Within urban environments, bioretention systems are one of the most implemented green infrastructure practices (Hartsig and Rodie, 2016). These features are shallow vegetative depressions designed to capture and treat water collected from impervious surfaces by slowly infiltrating stormwater through amended soils and various root layers. Native vegetation is tolerant of local climate conditions and used to increase water absorption, filtration capacity, and permeability of soils within the system. Bioretention systems incorporate the use of an infiltration cell to collect water and promote slow drainage over a set period of time (Figure 1). The infiltration cell spans 90% of the length of the bioretention system bottom and is composed of a Bioretention Soil Mix (BSM) which facilitates drainage to the under-drain. The under-drain consists of an open-graded, washed aggregate that surrounds rigid piping which connects to the storm sewer system or another predetermined area, draining excess water that is not absorbed (Figure 1). The addition of a valve or outflow control device to the under-drain can provide flexibility in setting water retention times within the bioretention system (Figure 1). Finally, bioretention systems incorporate the use of an overflow and/or high flow structures in the event of excess stormwater volumes. If water is flowing through the bioretention system it is considered an inline system, but if water bypasses the system once it has reached capacity, it is considered an offline system.

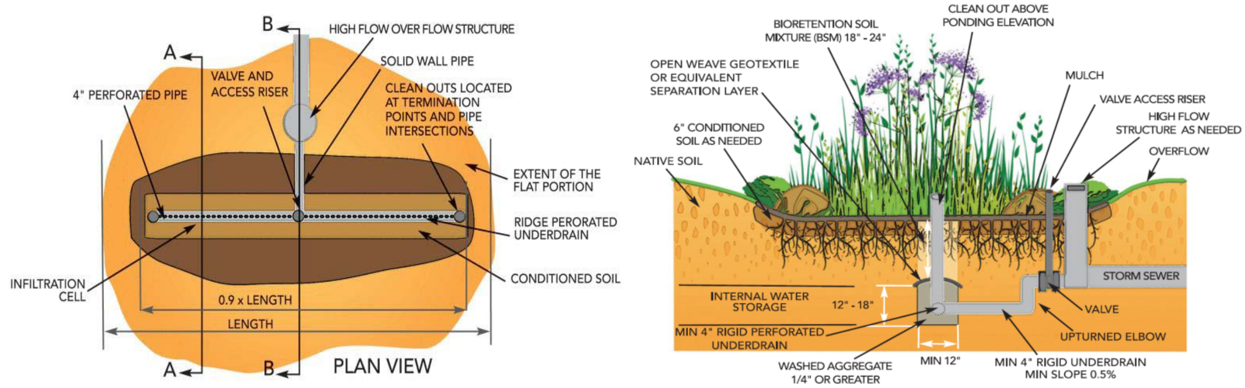

Figure 1. Schematic of bioretention system highlighting infiltration cell and under-drain (left) and cross-sectional profile of bioretention system showing upturned elbow and control valve (right).

Bioretention systems and rain gardens have proved a useful tool for mitigating stormwater impacts and improving water quality. In July 2008, the City of Omaha adopted their post-construction stormwater runoff ordinance which states that, at a minimum, low impact development (LID, often used interchangeably with the term green infrastructure) BMPs be utilized to provide water quality control of the first one-half inch of runoff from the site and shall maintain the peak discharge rates during the two-year storm event to baseline land use conditions. Today, there are over 1,800 post-construction BMPs within the Papillion Creek Watershed Partnership area, this includes those BMPs in design, construction and certified. Of those 1,800, over 490 of them are bioretention systems or rain gardens.

1.1 Purpose

The purpose of this study was to estimate infiltration rates via saturated hydraulic conductivity (K_{sat}) measurements within bioretention systems, rain gardens, and adjacent traditional turf areas. K_{sat} is a quantitative measure of the maximum water transmission rate of a saturated soil. Data generated from this study will provide current assessment of these projects and baseline measurements for comparison with future monitoring efforts of the sites measured and others. Understanding how these living systems function over time and seasons will help improve overall stormwater management.

An additional objective of this study was to create a Standard Operating Procedure (SOP) for measuring K_{sat} to be used in addition to visual inspections during annual assessments. Visual inspections of BMPs are necessary to identify any impediments to inlet and outlet structures, erosion within and around gardens, sediment accumulation, and vegetative health. However, visual inspections overlook actual infiltration rates, which dictate the amount/volume of stormwater that can be treated. Furthermore, examination of the spatial distribution of K_{sat} values can be used to determine areas of low permeability within a garden that require amending (Asleson et al., 2009).

Making regular observations of bioretention systems, rain gardens, and other green infrastructure practices help catch issues (erosion, vegetation health, sediment and debris build up, etc.) early. If not addressed promptly, issues can require significant effort to repair along with an increased expense. Therefore, proper maintenance and monitoring efforts are necessary for the longevity of these BMPs.

2. Site Descriptions

Nine sites throughout Omaha, Nebraska were selected for this study: Saddle Hills Park, University of Nebraska at Omaha (UNO) Welcome Center, Orchard Park, Florence Streetscape, The Benson East Gateway, Under the Sink Facility, Creighton Prep, South Omaha Industrial Area (SOIA) Lift Station, and Omaha Sewer Maintenance Facility (Figure 2). A quick summary of site details can be found in Table 1.

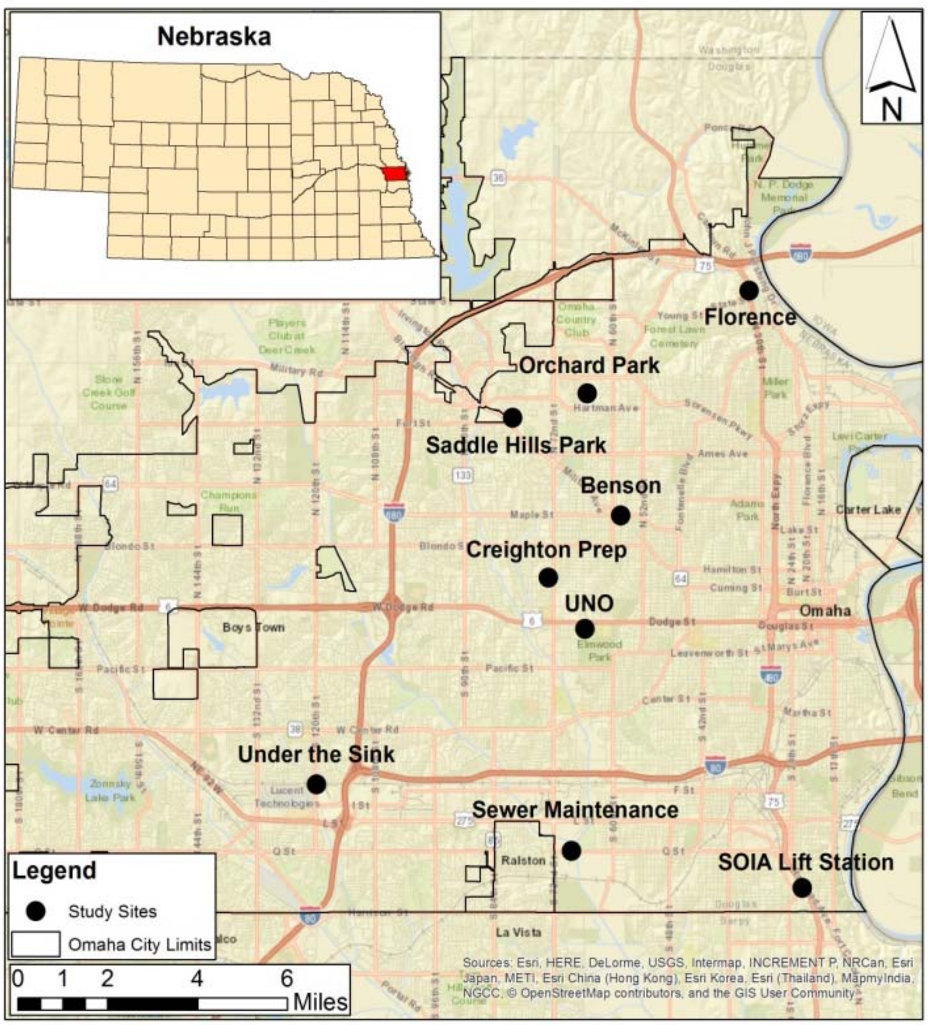

Figure 2. Map of the City of Omaha, Douglas County, highlighting the nine study sites in our study.

Table 1. Summary of project details for each of the nine study sites examined in this study.

Site	Install	Type*	Footprint (ft^2)	Contributing Area (acres)	% Footprint to Contributing Area	Design Volume (gal)	Pretreatment	Under-drain Outlet Control	Under-drain	Overflow	Bioretention Soil Mix
Saddle Hills Park	2014	RG	2,310	2.5	2.2	N/A	Utility box curb-wells	None	None	Soft weir in berm	Compost amended in-situ soils
University of Nebraska-Omaha	2012	B	1,345	0.6	5.5	2,469	None	4" Polyball valve	4" perforated HDPE	Soft weir in berm	50/50 sand/compost
Orchard Park	2009	B	3,180	0.8	9.2	14,270	Vegetated Forebay	2" Brass Curb-Stop Valve	4" perforated PVC	Offline system	50/50 sand/compost
Florence	2012	B	440	0.7	1.5	2,825	Stainless steel sediment trap w/ Permeable Base	2" Brass Curb-Stop Valve	4"perforated HDPE	Offline system	50/50 sand/compost
Benson	2013	B	1,225	1.0	2.8	5,535	2 Forebays & Dry Creek Bed	2" Brass Curb-Stop Valve	4" perforated PVC	High flow structure & soft weir	50/50 sand/compost
Under the Sink Facility	2008	B	1,540	2.5	1.4	9,620	Bioswale	4" Polyball valve	6" perforated HDPE	Soft weir in berm	50/50 sand/compost
Creighton Prep	2014	B	5,720	2.7	4.9	40,395	Permeable patio (East) & manhole sump w/Envirohood (West)	4" Slide Gate Valve	4" perforated PVC	Soft weir in berm	80/20 sand/compost
South Omaha Industrial Area	2014	B	3,400	0.7	11.5	25,430	Turf swale	4" Polyball valve	4" perforated PVC	High flow structure & soft weir	100% 1" washed limestone
Sewer Maintenance Facility	2014	B	2,200	0.95	5.3	39,085	Permeable paver parking lot (East) & Forebay (West)	4" Slide Gate Valve	4" perforated PVC	High flow structure	100% pea gravel

*RG = Rain Garden; B= Bioretention System

2.1 Saddle Hills Park

Saddle Hills Park (SHP) is located within the Saddle Hills Neighborhood near North 78th Street and Crown Point Avenue. The neighborhood consists of two distinct sub-watersheds (north and south) covering a total of 160 acres. Saddle Hills Park is set in the south watershed, a suburban residential area, and contains two rain gardens in the northeast corner of the park. These rain gardens, in conjunction with four others in the neighborhood, were completed in the fall of 2014 as part of a collaborative effort with the City of Omaha Stormwater Program, local residents, the Nebraska Department of Environmental Quality (NEDQ) 319 Program, the University of Nebraska at Omaha (UNO) Center for Urban Sustainability, and the Nebraska Statewide Arboretum (NSA) to improve water quality and reduce stormwater runoff volume and erosion through green infrastructure practices. The two rain gardens in Saddle Hills Park cover a combined area of 2,310 ft^2 (820 ft^2 east and 1,490 ft^2 west) and are connected via a 6-inch diameter PVC pipe (Figure 3). The east and west rain gardens contain a 1-foot max ponding depth and have a total contributing area of 2.5 acres. Stormwater runoff primarily flows down Arlington Drive and enters the east garden through a curb cut with pretreatment, a sump structure created with a modified utility vault box. After the east garden fills up, it then spills into the west rain garden through a PVC pipe that goes underneath the adjacent sidewalk. Both rain gardens have soft outlet weirs allowing excess water to spill out of the gardens during heavy flows.

Figure 3. Photographs at Saddle Hills Park showing the east rain garden with utility box curb-well pretreatment (left) and the west rain garden fully inundated during a rain event (right).

2.2 University of Nebraska at Omaha Welcome Center

The University of Nebraska at Omaha (UNO) bioretention system was constructed in 2012. The bioretention system is located on the west end of the University's campus, providing an interactive display with the University's Welcome Center (Figure 4). The project was part of a multi-institution collaboration with the City of Omaha Stormwater Program, UNO, and NSA to provide a teaching tool and an amenity to the UNO Campus. The bioretention system is split into two different bioretention systems allowing for significant volumes of landscape and rooftop rainwater to be captured. The North bioretention system covers approximately 625 ft^2, with the South bioretention system covering a larger footprint of 720 ft^2. Both systems contain an *in-situ* mixture of silty clay loam and fine-silty loess soil with 4-inch perforated PVC under-drains and a 4-inch Polyball valve. However, the south bioretention system is fitted with an upturned elbow (Figure 1). In total, the contributing area is 0.6 acres (north 0.25 acres and south 0.35 acres). The North and South bioretention systems have a ponding depth of 12 inches allowing a holding capacity of ~ 2,469 gallons. Stormwater runoff enters these bioretention systems via surface flow and storm drain outfalls on the east side of each system. Additional monitoring efforts at this site include soil temperature and soil moisture levels, water levels, and use of time-lapse photography (Figure 1A - Appendix).

Figure 4. Photographs of the bioretention systems in front of the UNO Welcome Center (left) and the North bioretention system entirely inundated (right).

2.3 Orchard Park

Orchard Park is located within a predominately residential area in northwest Omaha near North 66th Street and Sorensen Parkway. The site is a part of the Cole Creek restoration project which was implemented to improve habitat and water quality within Cole Creek through stream realignment and streambank stabilization. In addition, the project features five bioretention systems which are intended to capture and treat runoff from the adjacent residential areas and impervious surfaces within the park prior to entering Cole Creek. These bioretention systems were installed in 2009. This study only examined the bioretention system located at the north end of Orchard Park. This particular bioretention system consists of two cells (3,180 ft^2) and collects and treats stormwater runoff from a contributing area of 0.8 acres. Stormwater enters the first cell through a curb cut pretreatment forebay along North 66th Street and then spills into the larger cell through three PVC pipes. Both systems contain infiltration cells which are drained by a 4-inch perforated PVC pipe and fitted with a 2-inch brass curb-stop valve to regulate flow. Prior to 2011, the bioretention system did not have an under-drain valve installed, resulting in shorter retention periods. The larger cell has a ponding depth of 30 inches with a design volume capacity of 1,290 gallons (Figure 5). Current monitoring efforts at the site examine hydrologic flow through the use of a rain gauge, soil moisture probes, water pressure transducers, and periodic simulation of flooding events (Figure 2A).

Figure 5. Photographs of the bioretention system at Orchard Park exhibiting vigorous summer growth (left) and fully inundated during a rain event (right).

2.4 Florence Streetscape

The Florence Streetscape Project consists of seven bioretention systems along a two-block stretch of North 30th Street, from Clay to Willit Streets. The bioretention systems were finished in 2012 and designed to capture and treat runoff from surrounding street and sidewalk surfaces. The under-drain for the bioretention systems runs the length of the system and is composed of a dual-wall perforated HDPE pipe. A 2-inch curb-stop valve is installed on the downstream side to regulate the flow of the system. For this study, two of the bioretention systems were studied, located (1) on the west side of N 30th Street, at the southwest corner of N 30th Street and Clay Street and (2) on the east side of N 30th Street, parallel with the No More Empty Pots business, between Tucker and Willit Streets (Figure 6). Both bioretention systems use a stainless steel sediment trap with a permeable base as a pretreatment. This pretreatment allows water to gradually fill up and spill into the system causing sediment and debris to settle out and cleaner water to enter. Combined, the two bioretention systems have a footprint of 440 ft^2 with a contributing area of 0.7 acres, with a total design volume of 2,825 gallons.

Figure 6. The east (left) and west (right) bioretention systems from the Florence Streetscape Project showing the stainless steel sediment traps pretreatments.

2.5 The Benson East Gateway

The Benson East Gateway bioretention system was established in 2013 and is located in North Omaha at the intersection of Northwest Radial Highway, Maple, and 58th Streets. The bioretention system replaced a portion of 58th Street between Maple and Corby Streets, providing a beautiful landscape that filters, slows and infiltrates stormwater runoff before it enters the sewer system. Stormwater runoff from 58th street enters the system through two forebays capturing sediment and debris. Runoff then flows through a dry creek bed with layer of aggregate before slowly moving into the bioretention system (Figure 7). The bioretention system contains a 4-inch PVC under-drain and a 2-inch curb-stop valve. The Benson bioretention system occupies an area of 1,225 ft^2, draining 1-acre of the adjacent roads and residential landscape. With a maximum ponding depth of 18 inches, the bioretention system is capable of holding 5,535 gallons (Figure 7).

Figure 7. Photographs of the Benson East Gateway bioretention system showcasing the layered dry creek bed (left), strong summer growth (center), and inundated system (right).

2.6 Under the Sink

Under the Sink (UTS) is a city operated facility collecting household hazardous waste. Located at 4001 South 120th Street, the site occupies 5.1 acres with a primary recycling building, parking lots, drive lanes, and turf lawns. The Under the Sink facility is one of the earliest demonstration project showcasing stormwater best management practices through the incorporation of bioretention systems, bioswales, a level spreader, and rain barrels into the landscape. In 2008, 15 bioretention systems were installed on the property with the majority of them situated adjacent to South 120th Street. This study focused on the four bioretention systems located in the northwest corner of the Under the Sink facility (Figure 8). Each of these four systems has a ponding depth of 12 inches and are capable of holding a total of 9,620 gallons. Combined, the four bioretention systems have a footprint of 1,540 ft^2 and drain a 2.5-acre area. The bioretention systems are constructed out of a silt clay loam soil with 6-inch perforated HDPE pipe for the under-drain and fit with 4-inch Polyball valves. Stormwater flows into the bioretention systems via a bioswale lying to the northeast. During high runoff volumes, water spills into each bioretention system over a series of soft weirs. To the north of the UTS property is an 11.5-acre tract of land owned by the Union Pacific Railroad Company (UPRR) containing active railroad lines. A portion of this property, slightly northeast of the bioretention systems, has seen significant erosion of the subsoil underneath the track foundation (Figure 9a and 9b).

Figure 8. Photographs of the bioretention systems at the Under the Sink facility (left) and the bioswale that drains in bioretention system 1 (right).

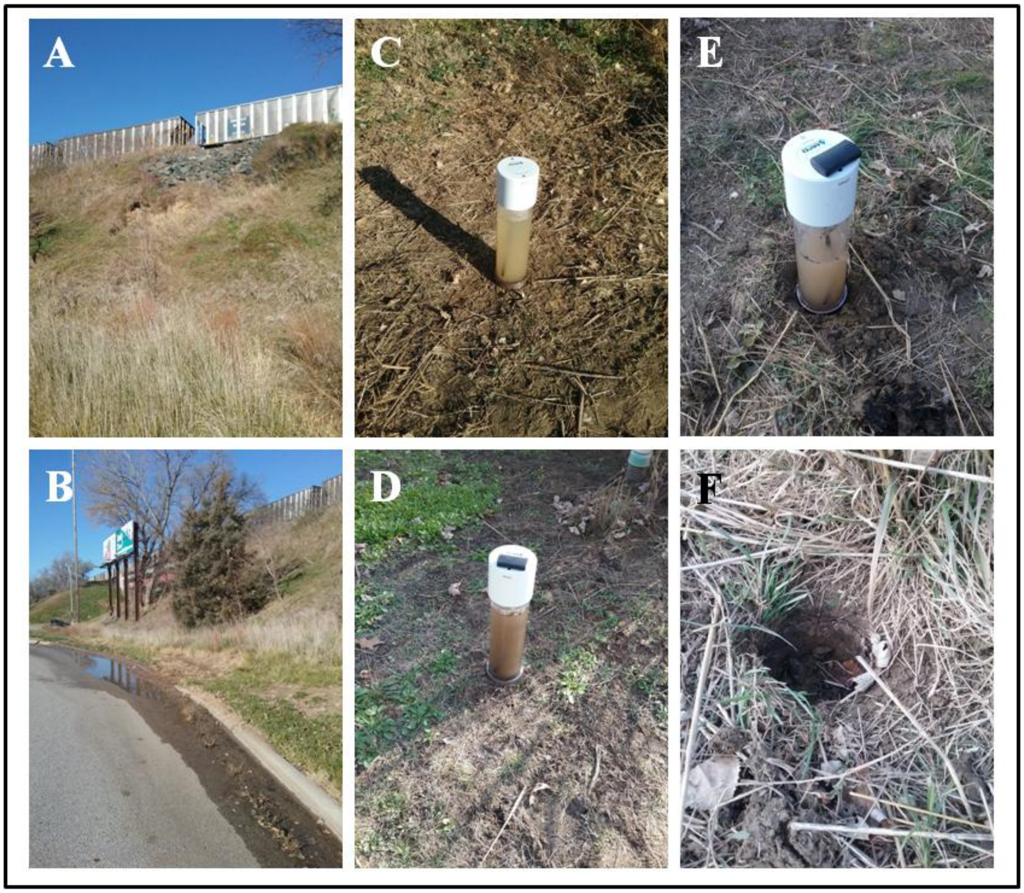

Figure 9. Photographs were taken at Under the Sink documenting A) erosion occurring on UPRR property, B) build up of sediment in gutter which flows to the bioretention systems, C) heavy silt in B 1, D) little to no silt in B 4, and E-F) example of removing silt layer to run infiltrometer test in B 2.

2.7 Creighton Prep

Creighton Prep High School is located in the center of Omaha at North 72nd Street and Western Avenue. The Creighton Prep bioretention system was construction in 2014 on the south end of the Creighton Prep Campus, running parallel with Western Ave. The bioretention system consists of an infiltration cell spanning the length of the system with a 4-inch perforated PVC under-drain and a 4-inch Slide Gate Valve. There are two points of entry where stormwater runoff flows into the system. First, stormwater enters from the west through a storm sewer that collects runoff from the adjacent parking lot and athletic fields. The second point of entry into the bioretention system is through a permeable patio located on the east side of the system, which also collects sheet flow from the athletic fields. Spanning a total of 5,720 ft^2, with a max ponding depth of 18 inches, the Creighton Prep bioretention system drains 2.7 acres and is capable of holding 40,395 gallons. Monitoring equipment has been installed to assess the performance of the bioretention system regarding volume reduction, infiltration rates, water quality, and plant performance (Figure 3A).

Figure 10. Creighton Prep bioretention system exhibiting summer growth (left) and inundated during rain event (right).

2.8 South Omaha Industrial Area Lift Station

South Omaha Industrial Area (SOIA) Lift Station, located at 2214 Washington Street, is a project of the City of Omaha's Clean Solutions for Omaha (CSO) program. The SOIA Lift Station collects industrial waste from meat packing facilities, removing it from the combined sewer system. Once separated, the industrial waste is then sent to the Missouri River Wastewater Treatment Plant for treatment before entering the Missouri River. After completion of the SOIA Lift Station, a bioretention system was installed on the south end of the property. Completed in 2014, the bioretention system covers an area of 3,400 ft^2 and drains an area of 0.7 acres. The under-drain within the bioretention system contains a 4-inch perforated PVC pipe with a 4-inch Polyball valve. Stormwater runoff primarily enters the system on the northwest side and through the northeast most corners via turf swales. With a maximum ponding depth of 12 inches the bioretention system has a design volume capable of holding 25,430 gallons of stormwater runoff over a 24-hour period.

Figure 11. Photographs of the bioretention system at SOIA Lift Station exhibiting rapid growth from August 2014 (left) to August 2015 (right).

2.9 Omaha Sewer Maintenance Facility

The City of Omaha Sewer Maintenance Facility, located at 6880 Q Street, sits adjacent to the confluence of the Big Papillion and Little Papillion Creeks. The Sewer Maintenance Facility is home to a demonstration project which consists of a multi-agency collaboration between the Environmental Protection Agency (EPA) Office of Research and Development, the United States Geological Survey (USGS), the University of Nebraska, and the City of Omaha CSO and Stormwater programs incorporating the design and installation of green infrastructure practices through a pervious paver parking area and a bioretention system. Completed in 2014, the bioretention system covers an area of 2,200 ft^2, draining roughly 0.95 acres. With a maximum ponding depth of 12 inches, this system has a design volume of 39,085 gallons (Figure 12). The under-drain within the bioretention system contains a 4-inch PVC pipe regulated by a 4-inch Slide Gate Valve. Runoff flows into the bioretention systems through a forebay on the west side of the system and permeable pavement on the east side of the system. Additional monitoring efforts have been designed to evaluate system performance by studying water retention and infiltration over time with inflow and outflow flumes and soil moisture sensors (Figure 4A).

Figure 12. Bioretention system at Sewer Maintenance Facility partially inundated after a rain event (center), with West forebay (left), and permeable paver parking lot (right).

3. Data Collection

Measurements were collected at all sites using Modified Philip-Dunne (MPD) Infiltrometers (Upstream Technologies, Inc., www.upstreamtechnologies.us). The MPD infiltrometer is a falling head device used to measure the saturated hydraulic conductivity (K_{sat}) at the soil surface. K_{sat} is important for modeling infiltration rates within BMPs. The device consists of three parts; (1) a 3-inch long steel bottom or "collar," (2) 14.5-inch tall graduated cylinder, and (3) an MPD Head (Figure 13). The steel collar and graduated cylinder are connected with a silicone bead to eliminate leakage between the inner surface of the collar and the outer face of the cylinder. The MPD Head records pressure changes within the cylinder as the water level drops and then transmits that data via Bluetooth to an Android tablet. See Ahmed and Gulliver

(2010) for further details on MPD infiltrometer setup and equations used for the K_{sat} calculation.

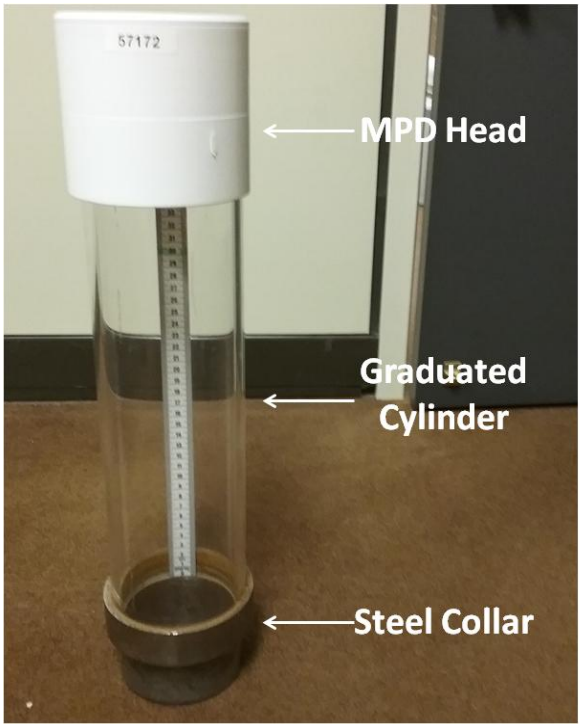

Figure 13. Modified Philip-Dunne Infiltrometer.

Samples were collected from mid-November through early December prior to the ground freezing. For each sample, the steel collar and graduated cylinder were inserted into the soil surface at a depth of 2 inches. Any mulch or plant materials were brushed aside before inserting the device into the soil. Soil moisture readings were collected pre and post test using a Rapitest Moisture Meter (Luster Leaf, www.lusterleaf.com). The graduated cylinder was filled with water to a predetermined height (~ 12 inches, 30 cm). An MPD Head was placed on top of the full graduated cylinder to record the water level drop over time. After completion of each test, recorded data were uploaded to the Upstream Technologies website where it is run through an automated program to calculate K_{sat} values. K_{sat} calculation requires a minimum of 2-4 inches (5 - 10 cm) of drop in water level within the MPD infiltrometer. Therefore, if the test is stopped before the drop in water level occurs a NULL value is obtained. GPS coordinates (Garmin GLO, Garmin, Ltd, www.garmin.com) were collected at each sample location. Vegetation type and proximity to each sample location was noted across all sites.

Data generated were compared within site and against non-BMPs (nearby turf and landscape areas) adjacent to each site. Data were compared across sites for evaluation of pretreatment effect on K_{sat} within the bioretention systems, distribution of K_{sat} across the entire system, and plant influence.

4. Results and Discussion

4.1 Saddle Hills Park

The Saddle Hills Park site consisted of two rain gardens, containing a silty clay loam soil, located in the northeast corner of the park. Saturated hydraulic conductivity measurements were collected within both rain gardens and adjacent turf grass areas (Figure 2). A total of 22 samples were acquired at the site (Table 1A). The site average K_{sat} (for both gardens) was 55.31 in/hr with average K_{sat} values of 38.5 and 65.4 in/hr for the west and east rain gardens, respectively. Collectively, the Saddle Hills Park site had the second highest site average K_{sat} (Table 2A). Some of the highest observed K_{sat} values (65.65 – 152.59 in/hr) were obtained adjacent to Fox Sedge and Dogwood plant species. Additionally, these samples were located above inlet/ pretreatment areas.

The lowest observed K_{sat} values (5.77 and 5.27 in/hr) were in the east rain garden, near the inlet. Similarly, the west rain garden saw its lowest K_{sat} value (7.26 in/hr) adjacent to the inlet pipe connecting the East garden to the West garden. While there wasn't clear visual evidence, low K_{sat} values could be attributed to sediment accretion and/or soil compaction. During periods of high stormwater runoff, sediment can be carried over the inlet pretreatment and deposited within the rain garden. Annual site inspections have documented sediment build up in the pretreatment curb-well and litter debris clogging the connecting inlet pipe, thus stressing the importance of routine maintenance to keep these gardens functioning properly.

Comparative measurements of nearby soil conditions were taken adjacent to the west and east rain gardens. Samples were collected in areas with turf grass as representative measurements for the surrounding park and conditions prior to rain garden installation. Only one out of the six samples acquired on turf grass returned a valid K_{sat} value (0.09 in/hr), which was the lowest observed K_{sat} value across all turf grasses sampled within our study. The remaining five turf grass samples returned NULL K_{sat} values.

4.2 University of Nebraska at Omaha Welcome Center

Measurements of saturated hydraulic conductivity were collected within two bioretention systems in front of the University of Nebraska-Omaha Welcome Center and nearby turf grass areas (Figure 15). Six samples were collected from the bioretention systems and four from turf areas, ten tests in total (Table 3A). The site average K_{sat} value was 55.35 in/hr, which was the highest site average K_{sat} value across all nine sites sampled (Table 2A). Average K_{sat} values for the north and south bioretention systems were 76.46 and 34.25 in/hr, respectively. Samples ranged from 6.37 to 146.55 in/hr in the north bioretention system and 6.23 to 58.4 in/hr in the south bioretention system.

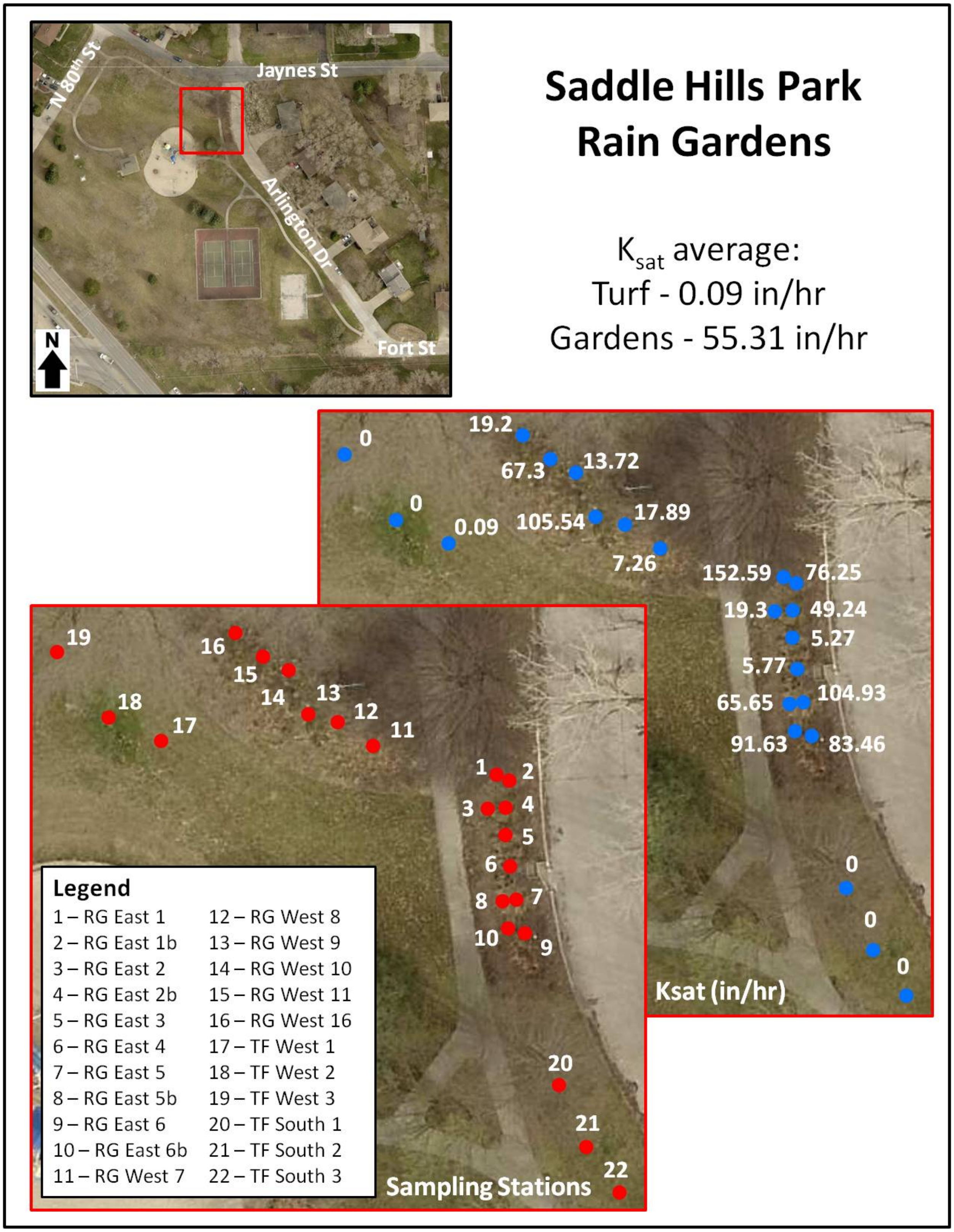

Figure 14. K_{sat} measurement locations and values at Saddle Hills Park. Note that NULL values are represented as zero (0).

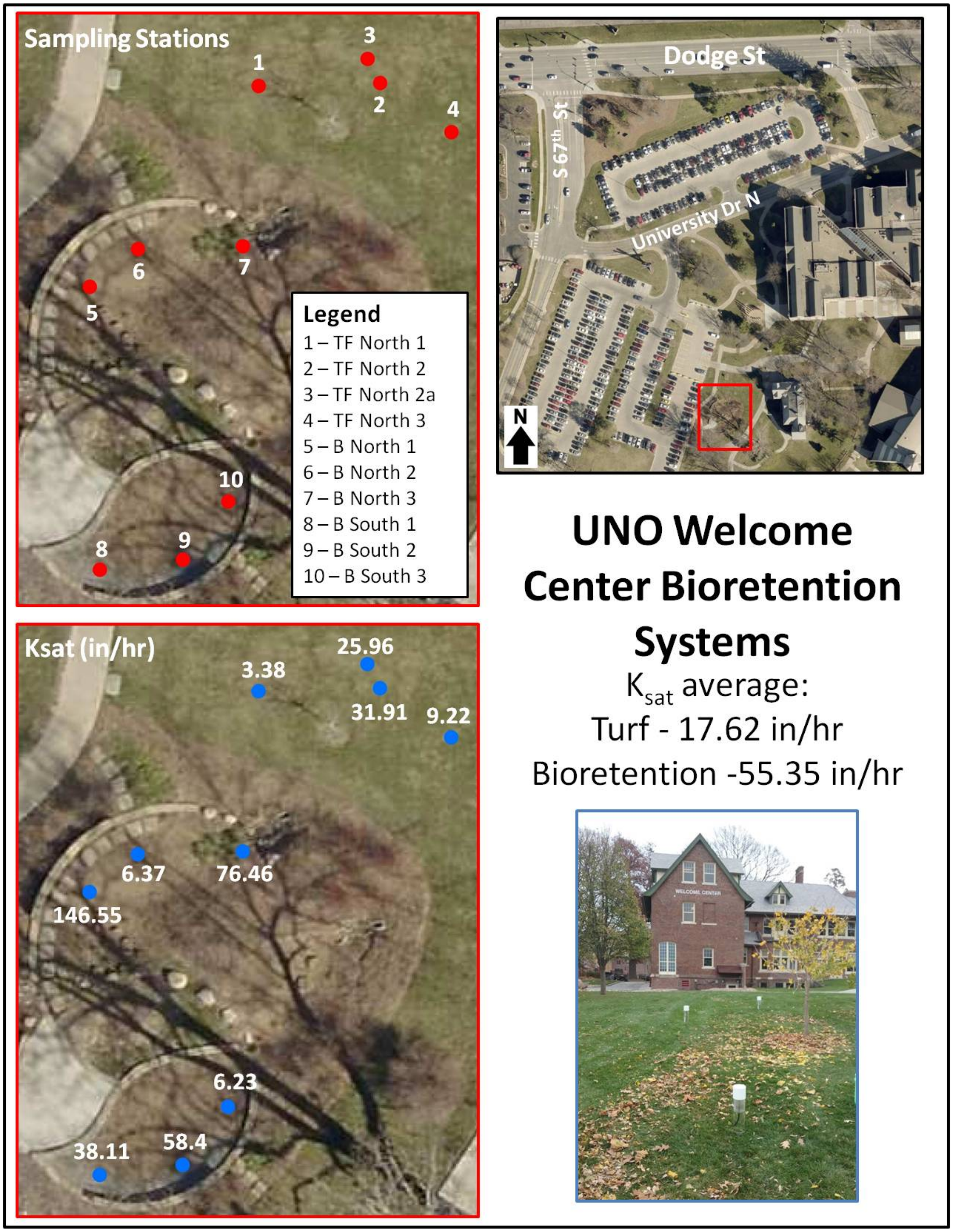

Figure 15. K_{sat} measurement locations and values at the University of Nebraska-Omaha Campus. Note that NULL values are represented as zero (0).

No spatial patterns of K_{sat} values were observed within the two systems.

Turf grass samples acquired north of the bioretention systems at UNO ranged from 3.38 to 31.91 in/hr. Turf K_{sat} values were highest at stations TF North 2 and TF North 2a (Figure 15). These stations fell within the closest proximity (~ 10 ft) to an adjacent tree, potentially falling within the tree's lateral root zone, which could lead to increased soil permeability. These were the highest observed K_{sat} values when compared to other turf grass samples across all nine sites.

4.3 Orchard Park

Saturated hydraulic conductivity measurements were collected at Orchard Park within the larger cell of northern bioretention system (Figure 16). A total of seven samples were acquired from both the bioretention system and adjacent turf grass area (Table 4A). The site average K_{sat} value for all four samples collected within the bioretention system was 11.77 in/hr, which ranked as the second lowest across all sites (Table 2A). Two samples, collected within the bioretention system, were taken adjacent to Little Bluestem (B 1 & B 4) and the remaining two samples were collected over bare ground (B 2 & B 3). Samples acquired next to native vegetation had higher K_{sat} values (16.53 and 22.3 in/hr) than those acquired over bare ground (1.68 and 6.58 in/hr). Native vegetation plays an important role in increasing infiltration rates as root structures break apart compacted soil layers. Three turf samples were acquired south of the bioretention system. Two of the three turf samples returned K_{sat} values averaging 1.81 in/hr.

4.4 Florence Streetscape

Measurements of saturated hydraulic conductivity were collected within two bioretention systems and adjacent tree planters from the Florence Streetscape Project on either side of North 30th Street between Clay and Willit Streets (Figure 17). The site average K_{sat} value, for both bioretention systems, was 18.28 in/hr, which was the fourth lowest site average K_{sat} value across all nine sites sampled (Table 2A). A total of 12 samples were collected at this site, three in each bioretention system and three in each adjacent tree planter (Table 5A). Tree planters were used as controls for nearby bioretention systems due to commercial development and limited access to turf grass. Collectively, the sampled tree planters outperformed both bioretention systems with a site average K_{sat} value of 33.30 in/hr. Higher K_{sat} values within the tree planters can be attributed to amended soils and no sediment loading. Samples were collected on the street side of each system to avoid sampling over the infiltration cell. The West bioretention system had the second lowest average K_{sat} value of 6.0 in/hr when comparing

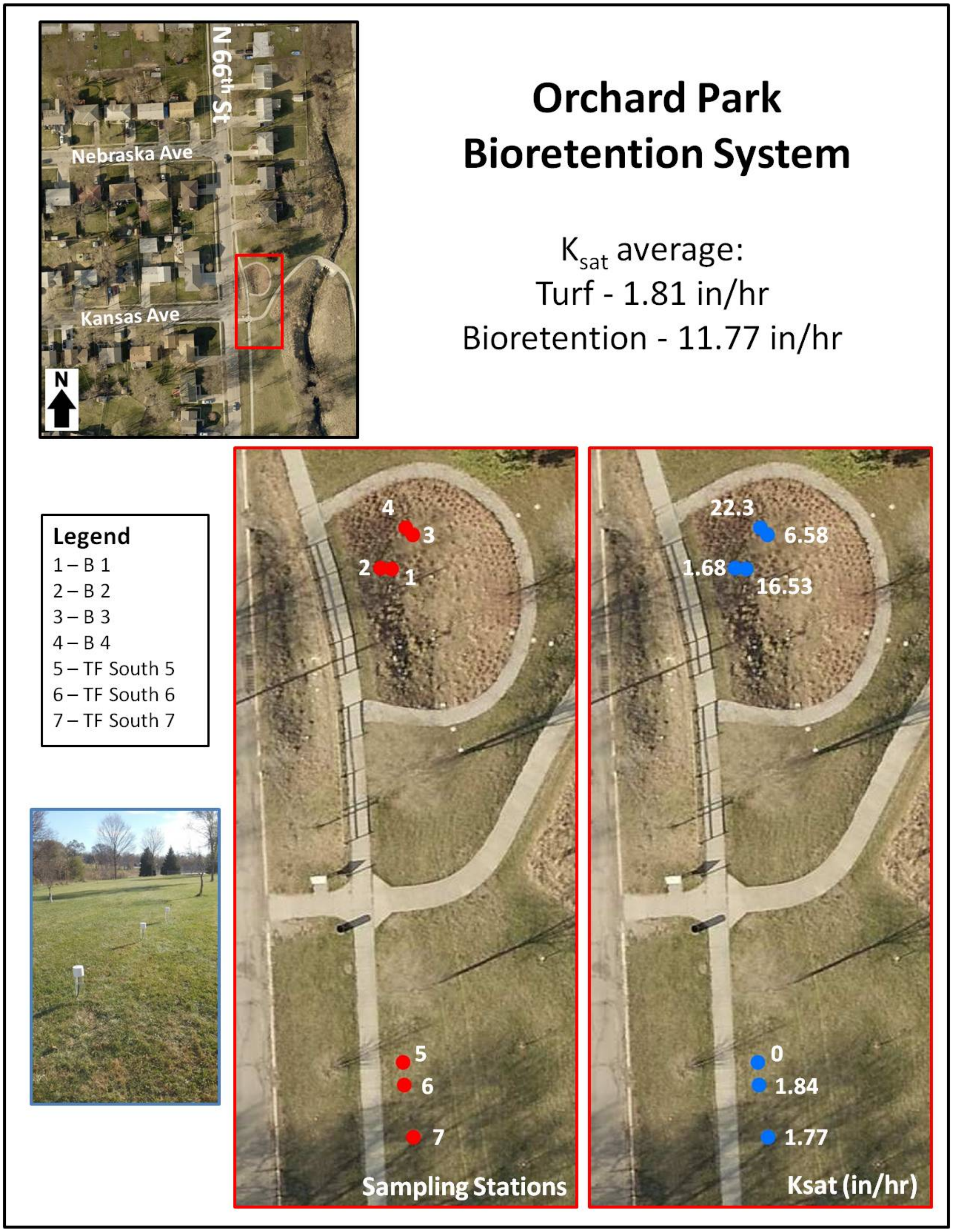

Figure 16. K_{sat} measurement locations and values at Orchard Park. Note that NULL values are represented as zero (0).

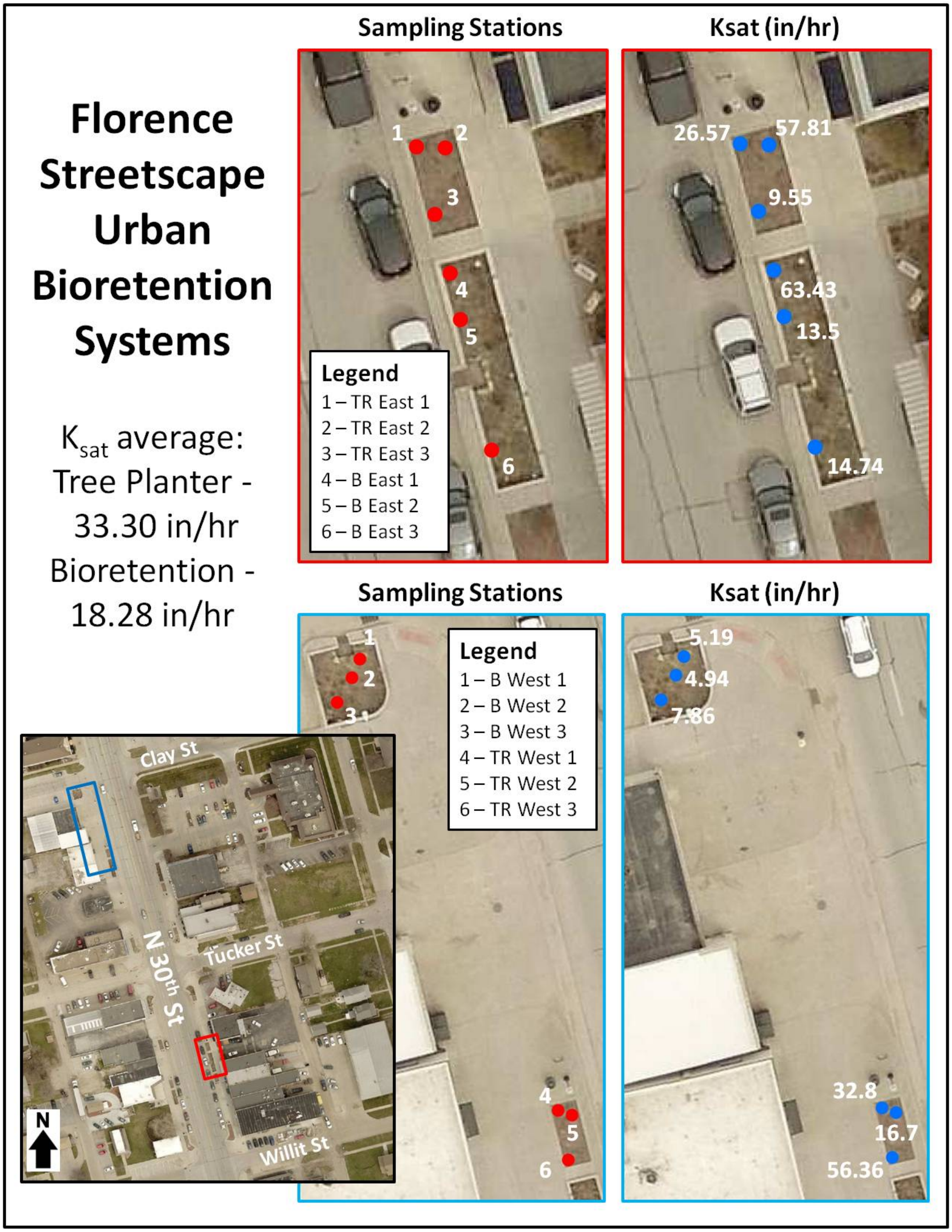

Figure 17. K_{sat} measurement locations and values at the Florence Streetscape Project.

each bioretention system and rain garden from all sites (Table 6A). The lowest K_{sat} values within the West bioretention system were near the inlet (Figure 17). These low K_{sat} values can be attributed to heavy sediment build up near the inlet, which was observed during sampling. The west system is located at the bottom of a hill on the corner of N 30th Street and Clay Street and experiences heavy sediment loading during high flows from an unimproved alleyway and vacant lot with little to no vegetative cover. Such influence caused severe build up of sediment within the bioretention system limiting infiltration rates/soil permeability. The East bioretention system had a higher average K_{sat} value (30.55 in/hr) compared to the west system (Table 6A). Again, the lowest observed K_{sat} values were located closest to the inlet in both systems (Figure 17).

4.5 The Benson East Gateway

Measurements of saturated hydraulic conductivity were taken within the Benson bioretention system, on the upper rim of bioretention system, and in an adjacent turf lawn (Figure 18). Eight samples were acquired at this site (Table 7A). The Benson bioretention system had a site average K_{sat} value of 27.55 in/hr, which was the fourth highest site average across all nine sites (Table 2A). K_{sat} values within the bioretention system ranged from 21.13 to 50.1 in/hr and were significantly higher than the adjacent turf and upper rim values. Lack of spatial trends within the bioretention systems could be attributed to the pretreatments installed above the system. The use of two forebays, a retaining wall, and a dry stream bed significantly reduces sediment deposition and water velocity prior to flowing into the bioretention system. The lowest K_{sat} value obtained (4.12 in/hr) was located on the edge of the bowl where soils were susceptible to compaction from construction and local foot traffic. Only one sample collected from the upper rim of the bioretention system returned a NULL value. The adjacent turf measurement was observed to have a K_{sat} value of 6.47 in/hr.

4.6 Under the Sink Facility

Saturated hydraulic conductivity measurements were collected from four bioretention systems located in the northwest corner of the Under the Sink property (Figure 19). In total, 14 samples were collected from the bioretention systems and adjacent turf grass areas (Table 8A). The site average K_{sat} for all four bioretention systems was 12.57 in/hr, which ranked as the third lowest K_{sat} value across all sites (Table 2A). This site was susceptible to heavy sediment build up (fine silt) from an eroding easement on the south side of the Union Pacific Rail Road (UPRR) Property and north of the bioretention systems (Figures 9 & 19). Bioretention systems 1 and 2 had the largest accumulation of sediment, which significantly impacted K_{sat} measurements resulting in NULL values (Figure 19). Within the second bioretention system, sample UTS B 2-3 produced a

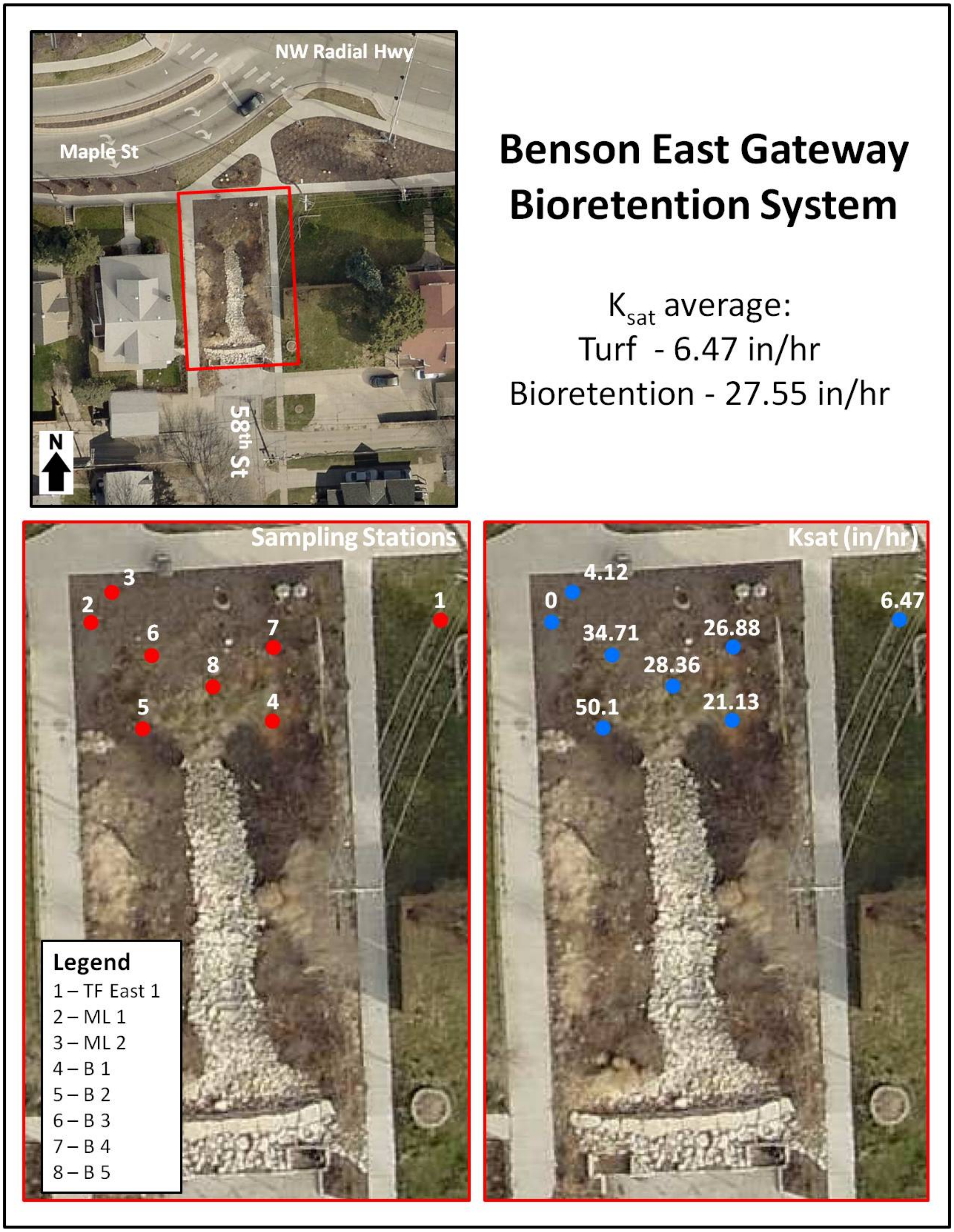

Figure 18. K_{sat} measurement locations and values at Benson East Gateway. Note that NULL values are represented as zero (0).

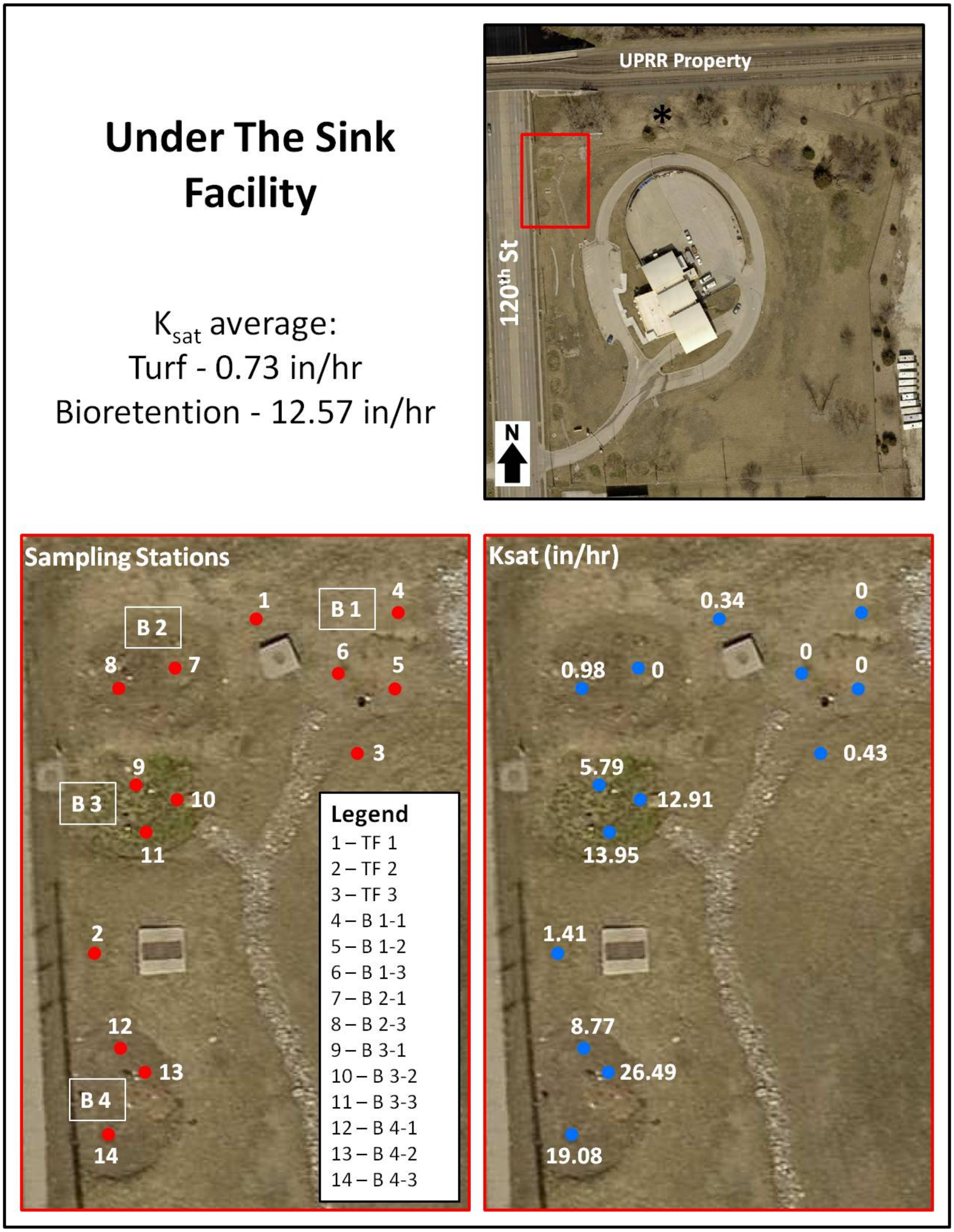

Figure 19. K_{sat} measurement locations and values at the Under the Sink Facility. Note that NULL values are represented as zero (0).* Denotes area of erosion causing silt accumulation in B-1 & B-2.

K_{sat} value of 0.98 in/hr, but only after 5 inches of the clogged top soil was removed (Figure 9c). Bioretention systems 3 and 4 did not have any observable impact from sediment build up and yielded average K_{sat} values of 10.88 and 18.12 in/hr, respectively (Table 6A). K_{sat} values for nearby turf measurements averaged 0.73 in/hr.

4.7 Creighton Prep

Saturated hydraulic conductivity measurements were collected on the west and east ends of the Creighton Prep bioretention system, located on the southern edge of the Creighton Prep campus (Figure 20). A total of 12 samples were collected at Creighton Prep, ten within the bioretention system and two in the adjacent turf lawn (Table 9A). Average K_{sat} values for the west and east bioretention samples were 3.09 and 4.93 in/hr, respectively. Two of the highest K_{sat} values (9.35 and 6.59 in/hr) collected within the bioretention system were adjacent to native vegetation (Switch grass and Fox sedge). The second highest measurement recorded for K_{sat} (6.75 in/hr) was adjacent to a Fox sedge plant, but located over the infiltration cell. The lowest K_{sat} value (0.81 in/hr) observed within the bioretention system was located closest to the inlet on the west side of the system, an area documented with heavy sediment build up and fine silt. Only one sample out of the 12 collected at Creighton Prep returned a NULL value. Turf grass measurements collected north of the bioretention system averaged 1.81 in /hr.

Creighton Prep's bioretention system had the lowest site average for K_{sat} at 4.01 in/hr (Table 2A). The presence of cattails was documented on the west side of the bioretention system and may be indicative of hydric soils resulting from periods of prolonged saturation. Observations made at the bioretention system noted significant sediment accretion on both the west and east ends. Heavy sediment accretion is a result of the nearby athletic fields which deposits infield topdressing into a nearby inlet that drains directly into the bioretention system (Figure 20). Infield topdressing is preventative measure used to reduce erosion on baseball fields but is often washed away during heavy rain events. It is important to note that this system has the largest drainage area when compared to the other sites that were sampled.

4.8 South Omaha Industrial Area Lift Station

In total, 17 measurements of saturated hydraulic conductivity were collected within the bioretention system and adjacent turf grass at the southern end of the SOIA Lift Station property (Figure 21, Table 10A). This site average K_{sat} value was 29.14 in/hr, which was the third highest site average across all nine sites (Table 2A). The lowest K_{sat} values (0.03 and 0.76 in/hr) observed at this site were those that were placed directly on top of native vegetation (Karl Foerster) within the bioretention system. However, samples collected adjacent to and between Karl Foerster plants saw anywhere from a 50 to 640-fold increase in K_{sat} values. Samples

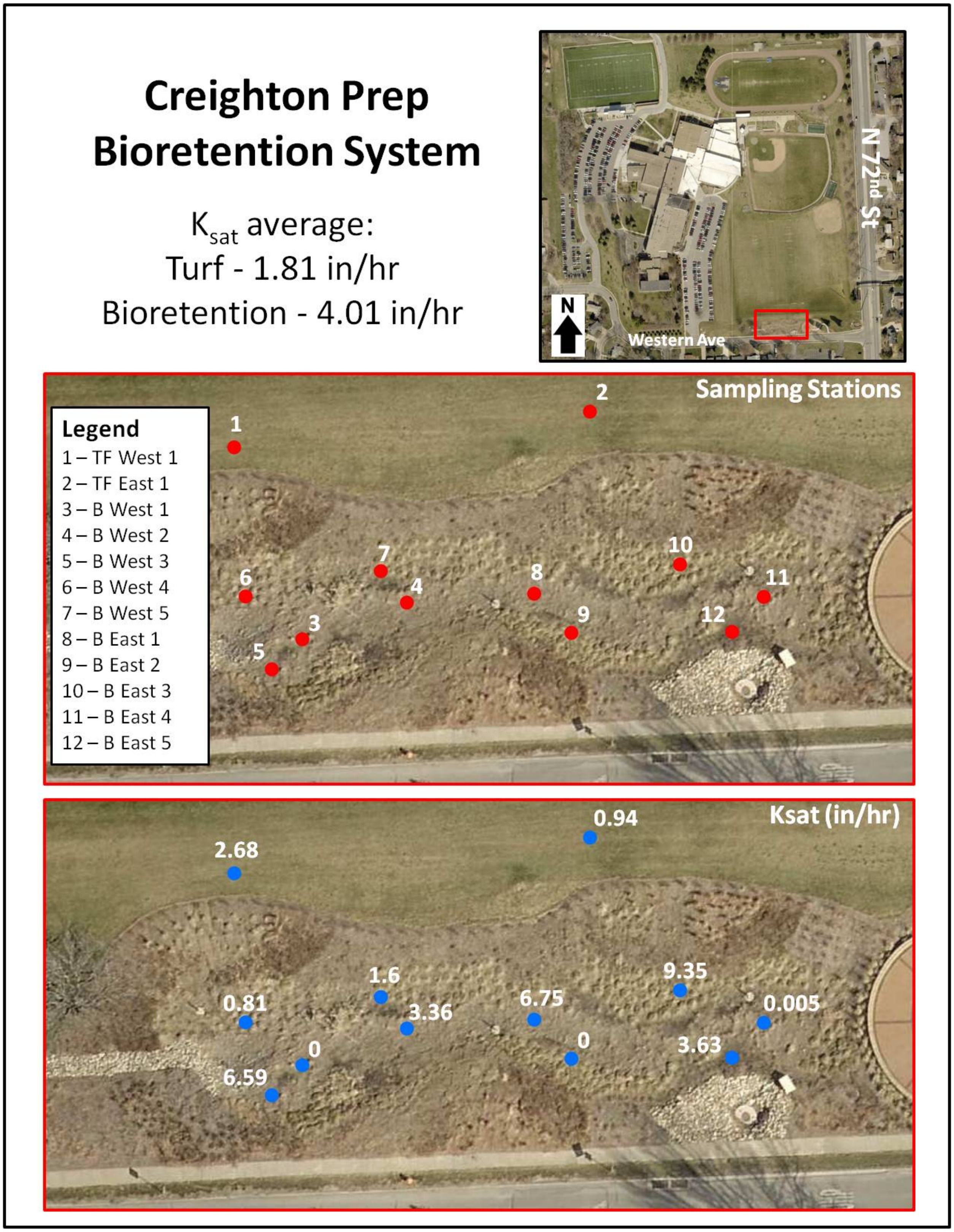

Figure 20. K_{sat} measurement locations and values at Creighton Prep. Note that NULL values are represented as zero (0).

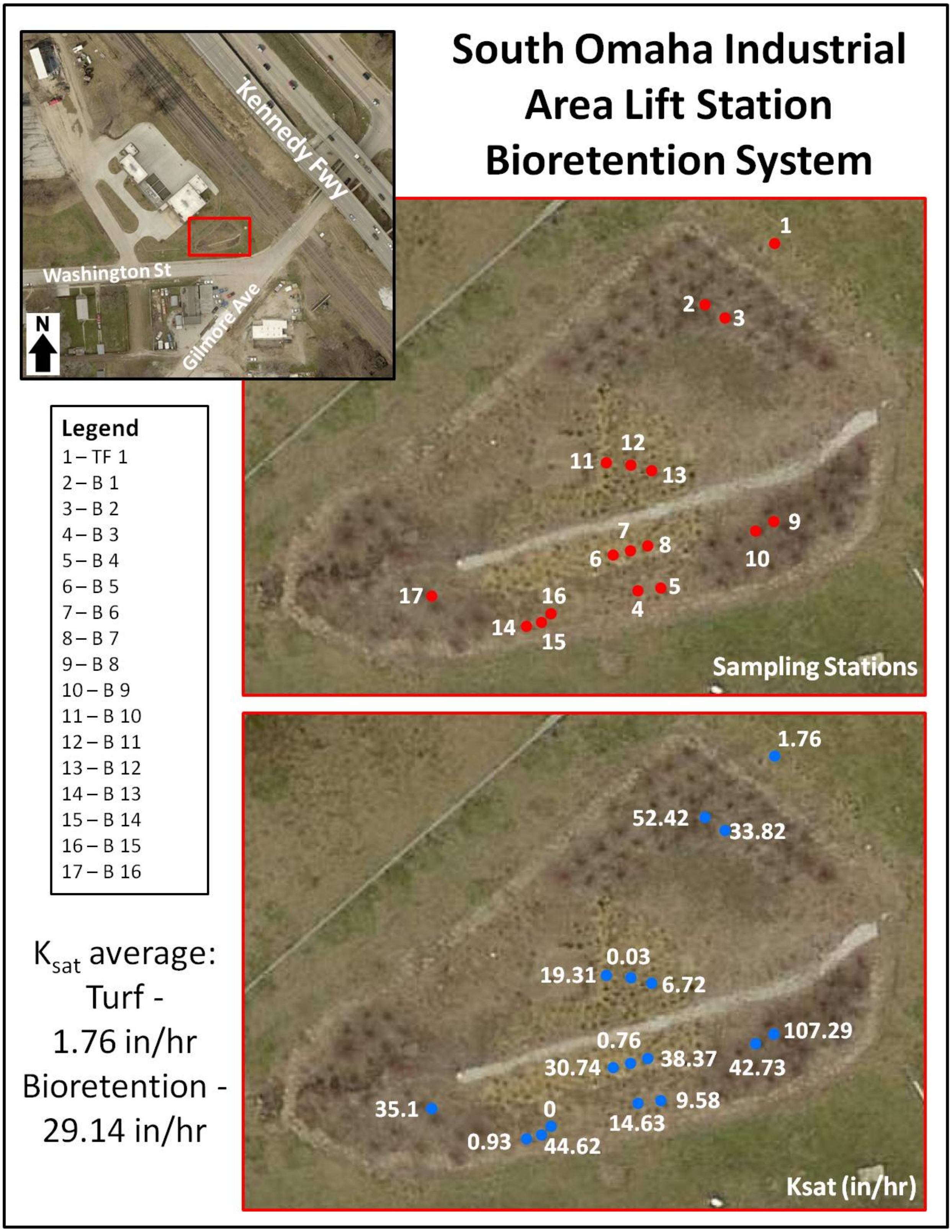

Figure 21. K_{sat} measurement locations and values at the South Omaha Industrial Area. Note that NULL values are represented as zero (0).

collected adjacent to or between Dogwood plants documented some of the highest K_{sat} values within site, ranging from 35.1 to 107.29 in/hr. One measurement of saturated hydraulic conductivity was acquired over turf grass, northeast corner above the bioretention system, with an observed K_{sat} value of 1.76 in/hr. Only one out of the 17 samples collected from the bioretention system returned a NULL value for unknown reasons. No observed spatial patterns of K_{sat} values were documented with respect to inlet structures (pretreatments) and stormwater entry into the bioretention system.

4.9 Omaha Sewer Maintenance Facility

Measurements of saturated hydraulic conductivity were collected at the Omaha Sewer Maintenance Facility (SMF) from within the bioretention system and an adjacent turf lawn composed of Buffalo Grass. In total, ten samples were collected from this site (Table 11A). The bioretention system had a site average K_{sat} value of 20.83 in/hr, which was slightly skewed from measurements obtained from stations 7 and 8 (Figure 22). The SMF site average was ranked the median value when compared across all nine sites (Table 2A). Stations 7 and 8, collected within the bioretention system, had the highest K_{sat} values with 100.17 and 25.88 in/hr, respectively. These samples were acquired over the infiltration cell which is constructed with pea gravel to promote rapid infiltration/high permeability. Observations made at station 8 during sample collection noted medium to heavy sediment build up and propagation of plants into the infiltration cell, which could attribute to reduced permeability and a lower K_{sat} value when compared to station 7.

Additional measurements collected on the rim and within the basin of the bioretention system ranged from 0.02 to 8.7 in/hr (Figure 22). The lowest observed K_{sat} values (1.22 and 1.32 in/hr) within the bioretention basin were located closest to the inlet in areas that have experienced build up of fine silt and sediment. This accumulation of debris is due to erosion of the inlet structure and accompanying vegetation. Measurements collected at stations 9 and 10 saw large discrepancies in K_{sat} values despite their close proximity. Observations noted in the field with respect to vegetation or soil conditions could not be attributed to the fluctuation of these values, concluding that soil compaction or an impartial seal when inserting the MPD infiltrometer was to blame.

Only one sample collected at this site (station 4) returned a NULL valve, which could be attributed to the samples proximity to the inlet structure and observed sediment build up noted at the sample location. Two turf measurements were acquired over native Buffalo Grass and observed an average K_{sat} value of 0.43 in/hr.

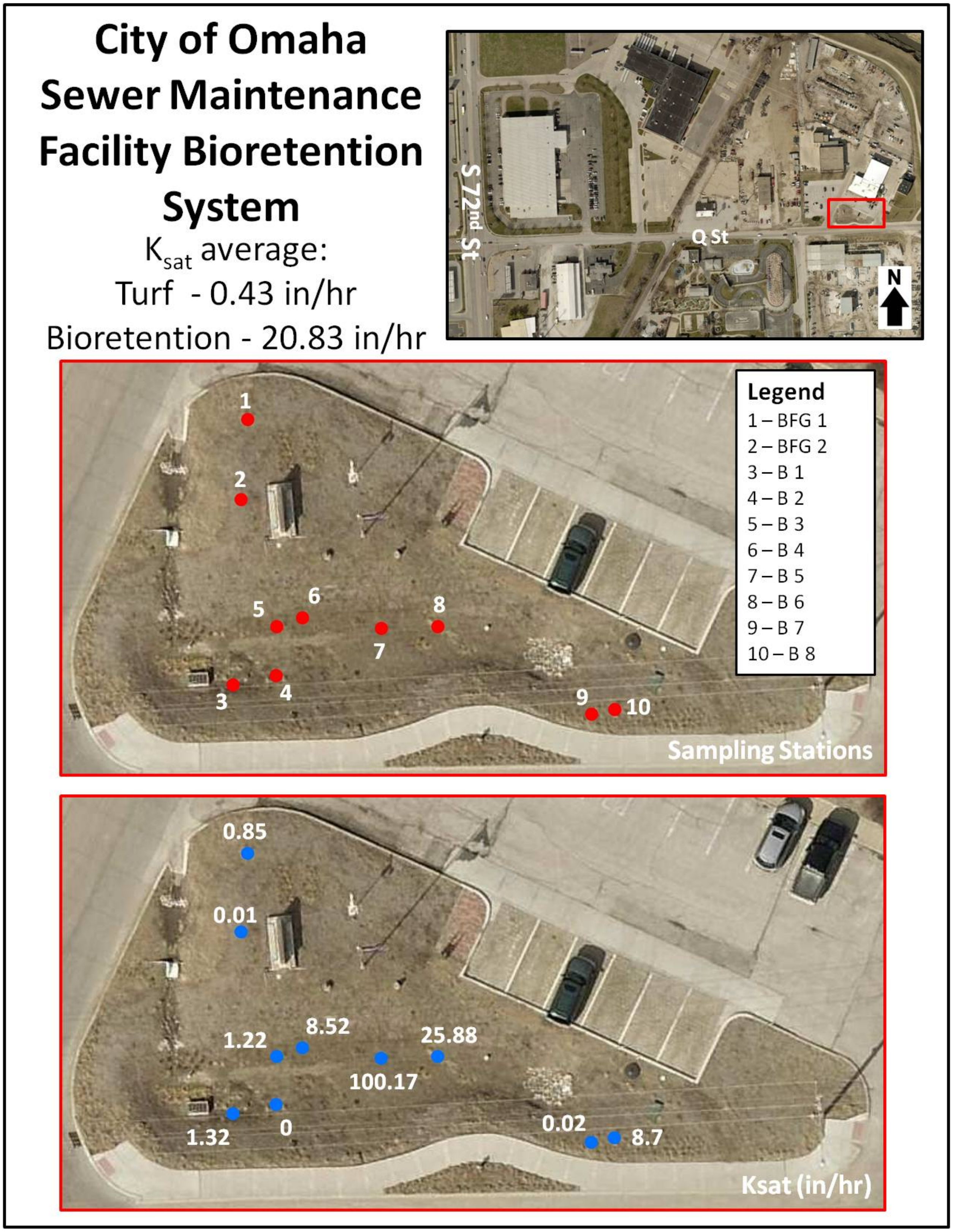

Figure 22. K_{sat} measurement locations and values at the Omaha Sewer Maintenance Facility. Note that NULL values are represented as zero (0).

5. Conclusion

Bioretention systems and rain gardens are an effective measure for mitigating the effects of stormwater runoff in urban environments. Emphasis can be placed on the increased filtration and permeability properties of these green infrastructure practices when compared to traditional turf areas or impervious surfaces (Table 12A). To ensure these systems are performing properly, regular inspection and testing of soil infiltration properties are necessary. MPD Infiltrometers provided useful and accurate information with respect to saturated hydraulic conductivity measurements collected at a site.

This study noted significant spread of saturated hydraulic conductivity measurements within and across sites. Due to the spatial and temporal variation of soil properties within rain gardens and bioretention systems it is recommended that larger sample sizes be obtained (appropriate to each system) and at regular intervals. Such information can easily identify spatial trends, seasonal variability, and identify areas with reduced permeability. Furthermore, increased sample size provides appropriate information for estimation of a system-wide (median) value for saturated hydraulic conductivity, accurately testing system performance.

While the MPD infiltrometer provides quick and accurate information, it is only designed to measure the saturated hydraulic conductivity of the top 8-12 inches of media. During construction of these green infrastructure practices typically 1-2 inches of compost is tilled into the *in-situ* soil to a minimum depth of 6 inches. Therefore, sampling these amended soils does not accurately reflect *in-situ* subsurface soil properties surrounding the system nor does it capture infiltration processes of the system as a whole. To better understand overall infiltration processes of rain gardens and bioretention systems it is recommended to test at various depths within the amended soils, but most importantly testing at different depths within the subsurface *in-situ* soils. Such sampling efforts would provide a greater understanding of amended and *in-situ* soil infiltration rates and how these properties could improve or diminish over time as a result of root propagation, freeze/thaw cycles, and soil compaction.

Vegetation has been shown to increase infiltration rates by increasing pore spaces within soil via root growth. This study noted several systems in which saturated hydraulic conductivity measurements were higher when collected adjacent to vegetation as opposed to measurements collected away from vegetation, which had slower rates of saturated hydraulic conductivity. Observations were pooled across all sites to identify plant specific saturated hydraulic conductivity measurements (Table 13A). Future work should focus on collecting measurements within proximity or adjacent to various plant species used in green infrastructure practices. This information would prove beneficial in understanding how plants could improve soil permeability and infiltration rates over time.

Finally, the results of this study highlight the significance of implementing pretreatment structures within inlet areas of rain gardens and bioretention systems. Several sites (Saddle Hills Park, Creighton Prep, & Under the Sink) yielded significantly lower k_{sat} values for samples collected within proximity of the inlet pretreatment structure. These observed values were attributed to the accumulation of fine silt and sediment. Pretreatment structures vary in design but are significant in reducing sediment loads and other debris from entering rain gardens and bioretention systems. Effective pretreatments significantly reduce sedimentation from occurring within structures and mitigating clogging potential of the soils. With proper maintenance and installation, pretreatment structures will properly trap sediment and decrease water velocity, reducing erosion within the system. Pretreatment structures can include bioswales, filter strips, "curb-wells", other sump structures, and forebays.

Results from this study helped with the overall assessment of these established bioretention systems and rain gardens and will provide the necessary baseline data for future monitoring efforts.

Essential findings of this study:

1. MPD Infiltrometers provide quick and quantifiable measurements of saturated hydraulic conductivity (K_{sat}). These infiltrometers allow for rapid generation of site-specific K_{sat} values. In addition, MPD Infiltrometers provide necessary data required to evaluate and monitor stormwater infiltration practices seasonally.
2. Amended soils and vegetation within rain gardens and bioretention systems demonstrated better infiltration properties (saturated hydraulic conductivity) than adjacent turf grasses.
3. Measurements acquired within proximity to inlet structures showed lower values of saturated hydraulic conductivity when compared to other measurements in the same system. Installation and proper maintenance of pretreatment structures in inlet areas is essential for eliminating the build up of fine silt, sediment, and other debris that reduces the saturated hydraulic conductivity within rain gardens and bioretention systems.
4. Measurements acquired adjacent to vegetation in bioretention systems exhibited larger K_{sat} values compared to samples collected over bare ground. Data were aggregated to generate species-specific values of K_{sat} (Table 13A).

Recommendations for future:

1. Continue monitoring with MPD Infiltrometers to better characterize the spatial distribution of K_{sat} values across all sites. Additional sampling can be done throughout the growing season to better identify (if any) seasonality in K_{sat} with response to vegetative growth.

2. While using MPD Infiltrometers care should be taken when inserting cylinders into the soil in order to avoid settings that allow for inaccurate or NULL tests.
3. Use of soil core monitoring to determine rates of sedimentation within rain gardens and bioretention systems. Additional focus could be placed on installation of horizon markers and/or erosion pins to document rates of sediment accretion or erosion within these systems. Both options provide a low cost, efficient, and quick means of measuring sedimentation rates and effectiveness of pretreatment.
4. Further examination of the relationship between observed K_{sat} values and adjacent plant species. Identify which plant species (if any) significantly increase infiltration rates through development of their rhizosphere.
5. Monitor rain gardens and bioretention systems saturated hydraulic conductivity rates and performance seasonally. If saturated hydraulic conductivity rates are falling below acceptable performance levels, adjustments to the structure should be made. Structure adjustments can include modification of soil conditions (sediment removal, tilling, and plowing), increasing plant density and diversity, or further inspection of the system to determine a site-specific issue.

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Appendix

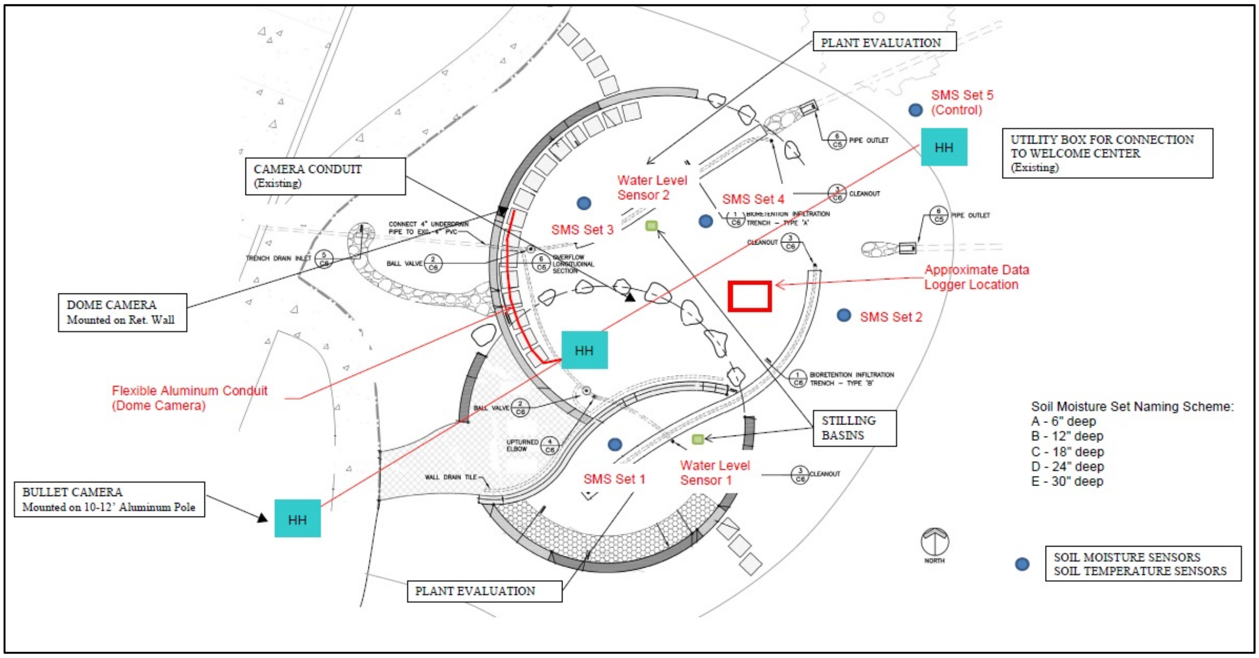

Figure 1A. Site plan for UNO bioretention system monitoring equipment.

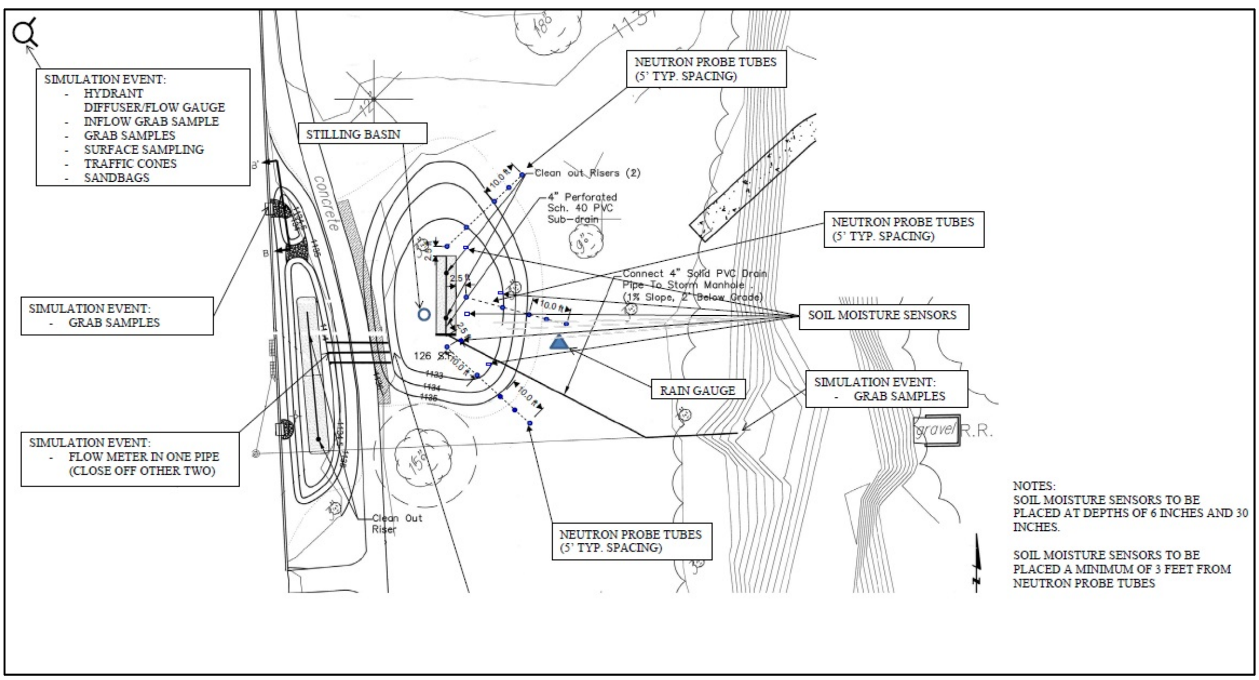

Figure 2A. Site plan for Orchard Park bioretention system monitoring equipment.

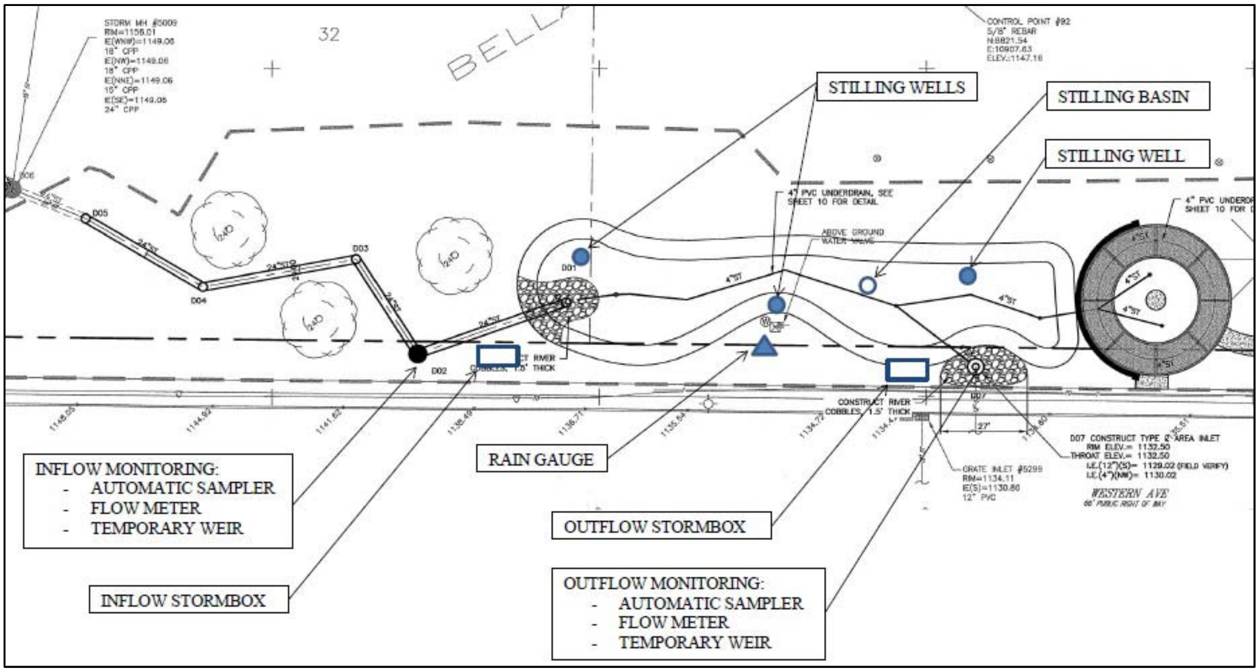

Figure 3A. Site plan for Creighton Prep bioretention system monitoring equipment.

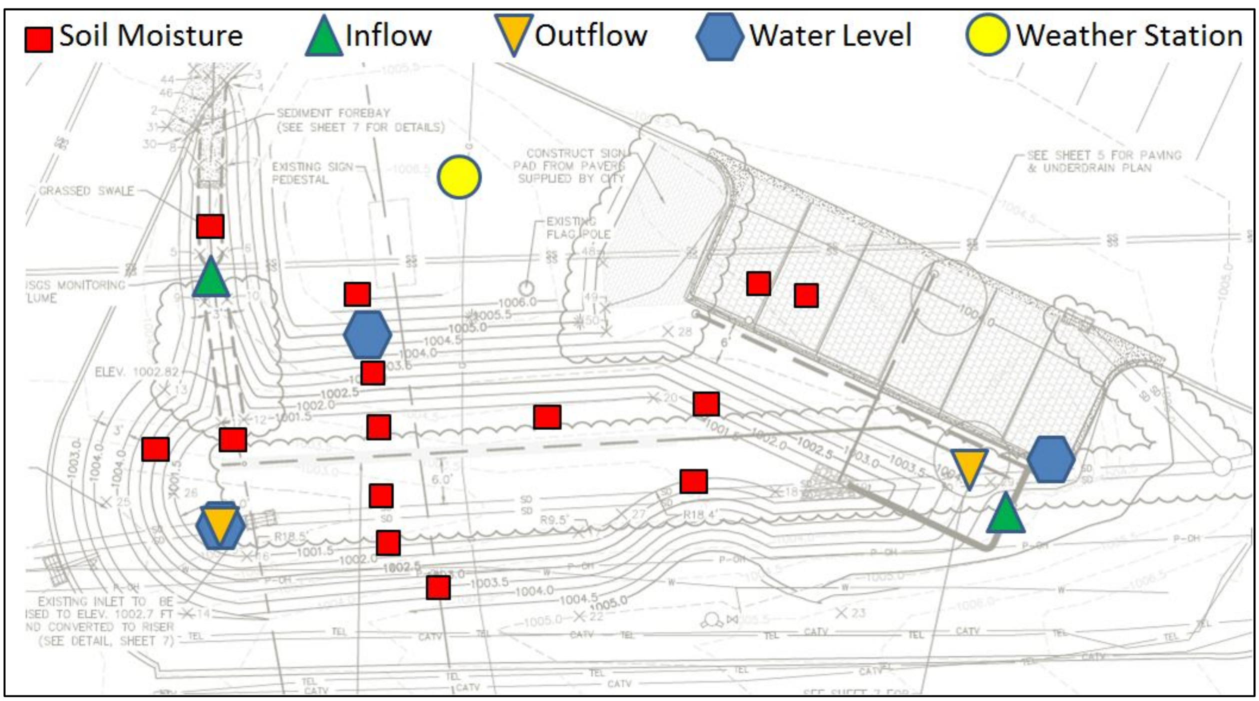

Figure 4A. Site plan for Sewer Maintenance Facility bioretention system monitoring equipment.

Table 1A. Summary of saturated hydraulic conductivity measurements collected from the Saddle Hills Park (SHP) Rain Gardens.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
SHP	16	55.31	44.93	5.27	152.59	147.32
SHP RG East	10	65.41	46.97	5.27	152.59	147.32
SHP RG West	6	38.49	39.27	7.26	105.54	98.28
SHP TF	1	0.09	-	-	-	-

*RG = Rain Garden; TF= Turf grass

Table 2A. Ranked mean site values for saturated hydraulic conductivity for bioretention systems and rain gardens from all nine study sites.

Site	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
UNO	6	55.35	52.69	6.23	146.55	140.33
SHP	16	55.31	44.93	5.27	152.59	147.32
SOIA	15	29.14	27.85	0.03	107.29	107.27
Benson	6	27.55	15.17	4.12	50.10	45.98
SMF	7	20.83	36.10	0.02	100.17	100.15
Florence	6	18.28	22.50	4.94	63.43	58.49
UTS	7	12.57	8.50	0.98	26.49	25.52
OP	4	11.77	9.35	1.68	22.30	20.61
CRP	8	4.01	3.28	0.005	9.35	9.34

Table 3A. Summary of saturated hydraulic conductivity measurements collected from the University of Nebraska at Omaha (UNO) Bioretention Systems.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
UNO B	6	55.35	52.69	6.23	146.55	140.32
UNO B North	3	76.46	70.09	6.37	146.55	140.18
UNO B South	3	34.25	26.30	6.23	58.4	52.17
UNO TF	4	17.62	13.50	3.38	31.91	28.53

*B = Bioretention System; TF= Turf grass

Table 4A. Summary of saturated hydraulic conductivity measurements collected from the Orchard Park (OP) Bioretention System.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
OP B	4	11.77	9.35	1.68	22.3	20.62
OP TF	2	1.81	0.05	1.77	1.84	0.07

*B = Bioretention System; TF= Turf grass

Table 5A. Summary of saturated hydraulic conductivity measurements collected from the Florence (FL) Streetscape Bioretention Systems.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
FL B	6	18.28	22.50	4.94	63.43	58.49
FL TR	6	33.30	20.09	9.55	57.81	48.26
FL B East	3	30.56	28.48	13.5	63.43	49.93
FL B West	3	6.00	1.62	4.94	7.86	2.92
FL TR East	3	31.31	24.48	9.55	57.81	48.26
FL TR West	3	35.29	19.95	16.7	56.36	39.66

*B = Bioretention System; TR= Tree Planter

Table 6A. Summary of saturated hydraulic conductivity measurements collected from each rain garden and bioretention system.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
UNO B North	3	76.46	70.09	6.37	146.55	140.19
SHP RG South	10	65.41	46.97	5.27	152.59	147.32
SHP RG West	6	38.48	39.27	7.26	105.54	98.29
UNO B South	3	34.25	26.30	6.23	58.40	52.17
FL B East	3	30.56	28.48	13.50	63.43	49.93
SOIA B	15	29.14	27.85	0.03	107.29	107.27
Benson B	6	27.55	15.17	4.12	50.10	45.98
SMF B	7	20.83	36.10	0.02	100.17	100.15
UTS B 4	3	18.12	8.90	8.77	26.49	17.72
OP B	4	11.77	9.35	1.68	22.30	20.61
UTS B 3	3	10.88	4.44	5.79	13.95	8.16
FL B West	3	6.00	1.62	4.94	7.86	2.92
CRP B	8	4.01	3.28	0.00	9.35	9.34

*B = Bioretention System; RG = Rain Garden

Table 7A. Summary of saturated hydraulic conductivity measurements collected from the Benson East Gateway Bioretention System.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
Benson B	6	27.55	15.17	4.12	50.1	45.98
Benson B[1]	5	32.24	11.09	21.13	50.1	28.97
Benson ML	1	4.12	-	-	-	-
Benson TF	1	6.47	-	-	-	-

*B = Bioretention System; ML = Mulch; TF= Turf grass

[1] Removed outlier measurement Benson ML

Table 8A. Summary of saturated hydraulic conductivity measurements collected from the Under the Sink (UTS) Facility Bioretention Systems.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
UTS B	7	12.57	8.49	0.98	26.49	25.51
UTS[1]	6	14.50	7.43	5.79	26.49	20.70
UTS B 2	1	0.98	-	-	-	-
UTS B 3	3	10.88	4.44	5.79	13.95	8.16
UTS B 4	3	18.12	8.90	8.77	26.49	17.72
UTS TF	3	0.73	0.59	0.34	1.41	1.07

*B = Bioretention System; TF= Turf grass

[1] Removed outlier measurement from bioretention system UTS B 2

Table 9A. Summary of saturated hydraulic conductivity measurements collected from the Creighton Prep (CRP) Bioretention System.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
CRP B	8	4.01	3.28	0.005	9.35	9.35
CRP B West	4	3.09	2.56	0.81	6.59	5.78
CRP B East	4	4.93	4.04	0.005	9.35	9.35
CRP TF	2	1.81	1.23	0.94	2.68	1.74

*B = Bioretention System; TF= Turf grass

Table 10A. Summary of saturated hydraulic conductivity measurements collected from the South Omaha Industrial Area (SOIA) Lift Station Bioretention System.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
SOIA B	15	29.14	27.85	0.03	107.29	107.26
SOIA TF	1	1.76	-	-	-	-

*B = Bioretention System; TF= Turf grass

Table 11A. Summary of saturated hydraulic conductivity measurements collected from the Omaha Sewer Maintenance Facility (SMF) Bioretention System.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
SMF B	7	20.83	36.10	0.02	100.17	100.15
SMF BFG	2	0.43	0.59	0.01	0.85	0.84

*B = Bioretention System; BFG= Buffalo grass

Table 12A. Summary of saturated hydraulic conductivity measurements from all nine sites sampled in this study.

	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
RG	16	55.31	44.93	5.27	152.59	147.32
B	59	23.00	28.86	0.005	146.55	146.55
TF	14	6.30	9.98	0.09	31.91	31.82
TF[1]	12	2.53	2.72	0.09	9.22	9.13
TR	6	33.30	20.09	9.55	57.81	48.26
BFG	2	0.43	0.59	0.01	0.85	0.84

* RG = Rain Garden; B = Bioretention System; TF= Turf grass; TR= Tree Planter; BFG= Buffalo grass

[1] Removed two outlier measurements sampled at UNO

Table 13A. Summary of species-specific saturated hydraulic conductivity measurements collected from all nine study sites.

Plant Species	N	Mean (in/hr)	Std Dev (in/hr)	Minimum (in/hr)	Maximum (in/hr)	Range (in/hr)
Dogwood	13	69.36	38.98	5.77	152.59	146.82
Pennsylvania Sedge	4	36.87	22.63	13.72	67.30	53.59
Fox Sedge	11	26.92	38.38	0.005	105.54	105.54
Blue Flag Iris	6	23.17	21.23	6.23	63.43	57.20
Palm Sedge	6	17.04	17.13	0.81	49.24	48.44
Karl Foerster	6	15.99	16.14	0.03	38.37	38.34
Little Bluestem	9	13.69	13.54	0.93	44.62	43.69
Switch grass	5	12.87	9.64	3.63	26.49	22.86
Turf Grass	14	6.30	9.98	0.09	31.91	31.82