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Soils Investigation for Infiltration-based Green Infrastructure for Sewershed Management (Omaha, NE)

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Soils Investigation for Infiltration-based Green Infrastructure for Sewershed Management (Omaha, NE)

by

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Foreword

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Cindy Sonich-Mullin, Director
National Risk Management Research Laboratory

Abstract

Infiltration-based green infrastructure and related retrofits for sewershed-level rainfall and stormwater volume capture (e.g., rain gardens, cisterns, etc.) are increasingly being recognized as management options to reduce stormwater volume contribution into combined sewer systems. A hybrid approach with green and grey infrastructures playing to their respective strengths may allow for downsizing or elimination of some ageing grey infrastructure CSO controls. Since CSO activity is typically greater in urban core areas, opportunities to leverage vacant land mass, park land, and other transitional land uses are abundant. However, little is known about urban soils or how these soils may store and transmit water resources. We, therefore, developed an established protocol to characterize soil taxonomic and hydraulic properties and deployed for field studies in Omaha, NE, July 2012. Parcels were selected by City of Omaha wastewater officials in areas where the local sewershed may benefit from additional detention capacity. Urban Omaha, NE, soils ranged in texture from silt-loams to silty clay loams with overall low measured surface infiltration rates. Subsoil permeability was slow, and drainage in the subsurface was limited. A modeling exercise was used to show how field data can be used to approximate GI performance in a large park setting (Fontenelle Park, Omaha, NE) and illustrate how larger land areas may be used to provide sufficient volume capture and capacity to compensate for the limitations of overall slow soil drainage rates. A discussion on how soils can be managed to set the stage for improved hydrologic services and effective land use planning for GI integration into existing wastewater management systems is provided.

Acknowledgements

The authors wish to thank staff from the United States Geological Survey for their assistance with soil borings. Pat Clark, ORD, EPA, assisted with field technical support, and Ted Hartsig, soil scientist (Olsson Associates), engaged in useful discussions with the authors on soil management matters.

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List of Acronyms

CCHP	Compact Constant Head Permeameter
CEC	Cation Exchange Capacity
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
ET	Evapotranspiration
GI	Green Infrastructure
HR	Hydraulically-Restrictive
HSG	Hydrologic Soil Group
NDEQ	Nebraska Department of Environmental Quality
SCM	Stormwater Control Measure
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Introduction

Soils are an important natural resource and can offer ecosystem services that include storage capacity for excess stormwater runoff that would otherwise contribute to combined sewer overflows (CSOs) (Shuster et al. 2011). The basis of infiltration-type green infrastructure (GI) (e.g., linked plant-soil ecosystems) is explicitly tied to the competence of soils to provide both a physical support for plants (enhancing evapotranspiration) and infiltration of rainfall (enhancing deep percolation and groundwater recharge). Measurement of infiltration rate (i.e., the rate at which water moves form the surface into the soil profile) and redistribution rate of water within the subsurface are important summary factors that can be used to describe gross site hydrology and, furthermore, to estimate overall site capacity to absorb a given stormwater runoff volume.

One way to increase confidence in the assessment of site conditions is to pair in-situ hydrologic measurements with correspondent soil morphologic cues (via standard methods in soil taxonomy) to determine historical hydrologic status. An assessment of this type would contribute to good practice in the selection, design, and construction of stormwater volume control measures. For example, Asleson et al. (2009) concluded that the incidence of rain garden failure would be markedly reduced if a prior identification of hydric (i.e., consistently wet) soils, poor drainage, and evidence of compaction had been determined in the planning stage of development. In order to address the question of GI suitability for improvements in combined sewer system (CSS) performance, this research effort includes: the assessment of urban soils from a hydrologic and morphological standpoint, recommendations on a modeling strategy to integrate the data and knowledge gained into existing models of wastewater-sewer system infrastructure, and outline monitoring needs and methods for the City of Omaha, Nebraska. The team conducted investigations at 14 areas that were identified by City of Omaha Public Works staff. These areas have either already been included in the Combined Sewer Overflow Long Term Control Plan (CSO-LTCP) for GI or were considered to have a high potential to keep excess stormwater runoff volume out of the CSS.

Data on co-located soil taxonomy and hydrologic measurements are especially rare for urban areas. The commonly available soil drainage data is limited to the county-level soil surveys that focused on rural areas. The traditional county-level soil surveys were foundational to understanding how soils were arranged across different landscapes and provided information on the proper use and management of soils for agriculture. Urbanized areas, however, were simply mapped as “complex” soil taxonomic units consisting of two or more dissimilar components, with one of the components being urban land that was mostly covered by streets, parking lots, buildings, and other impervious urban areas (Soil Survey Staff, 1993; US Department of Agriculture, 2010). Cities are dominated by urbanized, impervious or semi-pervious areas. In the process of development, urban areas often undergo both cutting and filling and often receive a great deal of imported fill soil material which can vary greatly in composition and consistency of placement. These same cities have considerable acreage in parks, back yards, and other neighborhood right-of-ways (e.g., the area under aerial utility lines) that can exhibit relatively low disturbance and may retain their original, pre-urbanization horizonation of native soils with favorable conditions for infiltration-type green infrastructure.

The idea of capturing excess runoff at the level of the park holding or vacant lot is relatively new and capitalizes on detaining modest runoff volumes in economical parcel-level stormwater control measures that are spread around a combined sewer drainage area (i.e., sewershed). This scalable, decentralized approach that couples stormwater and CSO management can be built on different types of GI (e.g., bioswales, bio-retention cells, pocket wetlands, rain gardens, green roofs, re-forestation, pervious pavements). Managed properly, GI applications can reduce, capture, and treat stormwater runoff at its source, before it can reach the sewer system. They are particularly appropriate for capturing low-volume, high-frequency storms. By using a combination of plant-soil systems and engineered approaches, green approaches can also maintain or restore the natural hydrology within a sewershed or watershed (i.e., moving the local water cycle from a runoff- to an infiltration-dominated system) by using practices that can be tailored to site-specific conditions. As long as detention does not present risks, such as groundwater mounding near basement structures, unintended contamination of groundwater via enhanced infiltration; flooding; or providing a habitat for disease vectors (i.e., mosquitoes, *Aedes* spp.), any opportunity to detain or store runoff volume and keep it out of the CSS has value.

Since there is little information on urban soils and their role in the urban hydrologic cycle, we intentionally designed an approach to surveying urban soils and use the accumulated field data to determine the hydrologic capabilities of the soils. There is a critical need to determine whether the type and storage capacity provided by GI techniques is adequate to mitigate CSOs and contribute to the restoration of degraded urban ecosystems. A thorough understanding of the soils and a quantification of site hydrology can then be used to parameterize accurate models of how GI might perform once installed, and suggest post-implementation monitoring needs. This approach front-loads the implementation for success by using actual field data to better know and understand risk at each step of the process; and can ensure that GI is either implemented properly or disqualified early in the planning phase.

We conducted an urban soil survey and characterized variability in soil taxonomic properties and gross hydraulic properties in Omaha, NE. The objectives of this study were: (1) to use standard soil taxonomic and hydrologic assessment methods to describe urban soils and (2) to assess surface soil- and sub-soil hydraulic properties in these urban landscapes. The objective of this research is to better understand the potential of park and municipal soils to support adjunctive management of stormwater quantity through GI, to determine soil restoration needs, and to further develop an established method to assess the distribution of soil series or phases and their properties in urban core areas.

Methods and Equipment

Background

The city of Omaha is located on the eastern border of Nebraska. The Missouri River serves as both the eastern boundary of the city and the division between Nebraska and Iowa. Council Bluffs, Iowa, is located across the river to the east. The population of the Omaha metropolitan area is approximately 800,000 individuals with about 75% of these citizens served by the Omaha sewer service area (United States Census Bureau, 2000). Included in the service area are the cities of Omaha, Bellevue, Papillion, La Vista, Ralston, Gretna, Bennington, Boys Town, and Carter Lake. The sewers in the older, eastern part of the sewer service area are combined rather than separate. The city operates over 850 miles of combined sewers in the CSS service area. This infrastructure services approximately 43 mi^2 (111 km^2); it extends from Harrison Street on the south to Interstate 680 on the north and from the Missouri River on the east to approximately 76th Street on the west.

There are currently 29 CSO outfalls in the Omaha CSS with 19 overflowing to the Missouri River and 10 overflowing to tributaries of Papillion Creek. Under existing conditions, which are representative of the CSS as it was in 2002 (the year of the city's first CSO permit), it is estimated that an average of 3.50 billion gallons (13.2 billion liters) per year of combined sewage overflows to receiving streams over an average of 86 CSO events. More than two-thirds of this total volume is estimated to overflow to the Missouri River, with the remainder overflowing from outfalls into the Papillion Creek system. The main pollutant of concern is *E. coli* bacteria.

The city, seeking to comply with the requirements of the Clean Water Act, the United States Environmental Protection Agency (USEPA) CSO Control Policy of 1994, and its Administrative Consent Order with the Nebraska Department of Environmental Quality (NDEQ), has developed a plan to control overflows from its CSS. Grey infrastructure retrofits and capital investments include extensive sewer separation throughout the CSS service area to reduce the flow of stormwater into the CSS. A new stormwater conveyance tunnel in the northeast Minne Lusa Study Basin will re-route stormwater so that it flows into the Missouri River rather than the CSS. In addition, a deep-tunnel will be used to capture combined sewage from several CSO outfalls along the Missouri River and convey it to the centralized wastewater treatment plant with additional flows possibly being routed to high-rate treatment units and storage tanks. As of 2012, the revised program cost estimate for these controls is approximately $1.66 billion (2009 dollars).

Study Area

All study sites were located in the Omaha, NE, combined sewer service area (Figure 1). The goal of the city-wide site investigation was to evaluate the type and hydrology of soils in parcels of land for their suitability to accept stormwater flows from their respective surrounding neighborhoods. The USEPA-led team assessed soils in each major landscape-hillslope position on a given site. Utility clearances were arranged for and executed by the City of Omaha prior to sampling. Upon arriving at each site, a banner was erected to identify the cooperative roles of USEPA, United States Geological Survey (USGS), and Cedarville Engineering in the project and state the purpose of our efforts in clear, proactive terms (Figure 2). Pictures of each site were taken from different vantage points and supplemented by sketched and written site descriptions. Measurements and samplings were made at multiple points within 15 distinct sites, the majority of which were city parklands. Geospatial data for approximate drainage areas were obtained from the city of Omaha, and exact sampling positions were located with a set of coordinates determined at the center of the site. The Trimble GeoExplorer 2008 Series GPS was connected to an Acumen GPS data logger (Trimble Navigation, Sunnyvale, CA) to record geographic coordinates.

Soil Physical, Hydraulic, and Chemical Assessment

A comprehensive approach was taken to the assessment of soils and soil-water relationships in both park and vacant lot settings. A tractor-mounted Geoprobe unit (Geoprobe Systems, Salina, KS) was employed to take soil cores to a maximum depth of 5-6 m (approx. 15-18'; in increments of 1.3 m [4'] increments) in each sampling site. Each core sample was nominal 6-cm diameter core with its length extending from the ground surface to 1.3 m (4') depth; the steel corer was advanced to depth by rapid percussion with a hydraulic hammer. In general, we observed full-recovery of soil core samples. The actual field depth measurement taken at the time of sampling was applied to correct for any differences in recovery due to compaction.

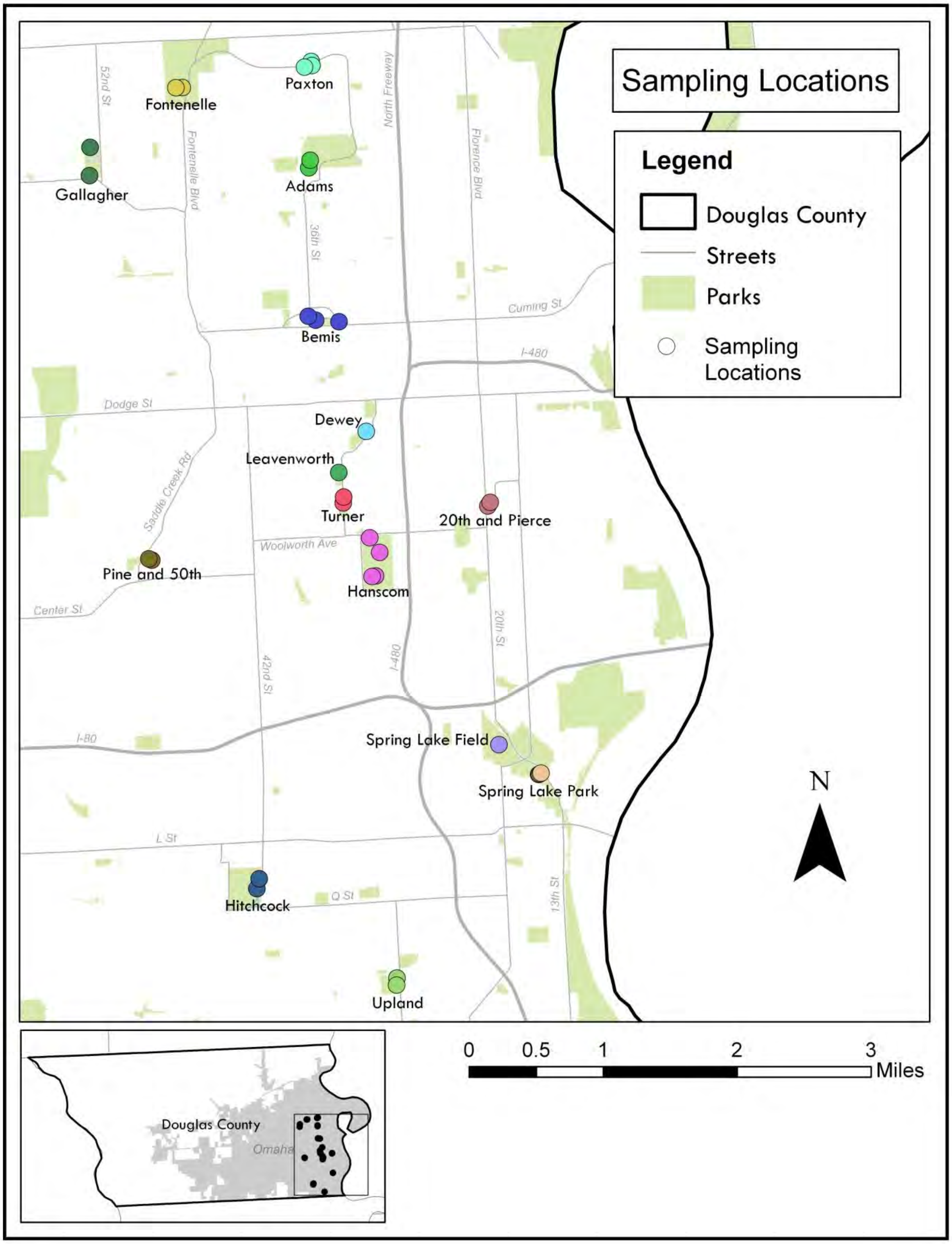

Figure 1. Study sites in the city of Omaha, NE, CSS service area (sites differentiated with color).

Figure 2. A typical deployment for soil study. Core sampling, soil taxonomy, and hydrologic assessment are performed. Omaha, NE, July 2012.

The corer consisted of a steel cylinder equipped with a threaded cutting shoe, transparent plastic liner, and drive head. The corer was cleaned and fitted with a new liner between samplings. The liner containing the soil sample was removed from the corer, labeled, and sealed with vinyl caps. Core samples were inspected (e.g., for change in color, texture, location of impeding layer, etc.) to qualitatively locate the transition between soil diagnostic horizons or layers by visual cues (Figure 3). Once measurements were complete, the bottom and top of the boreholes were sealed with a shallow layer of bentonite pellets and then packed with excess fill soil from borehole drilling.

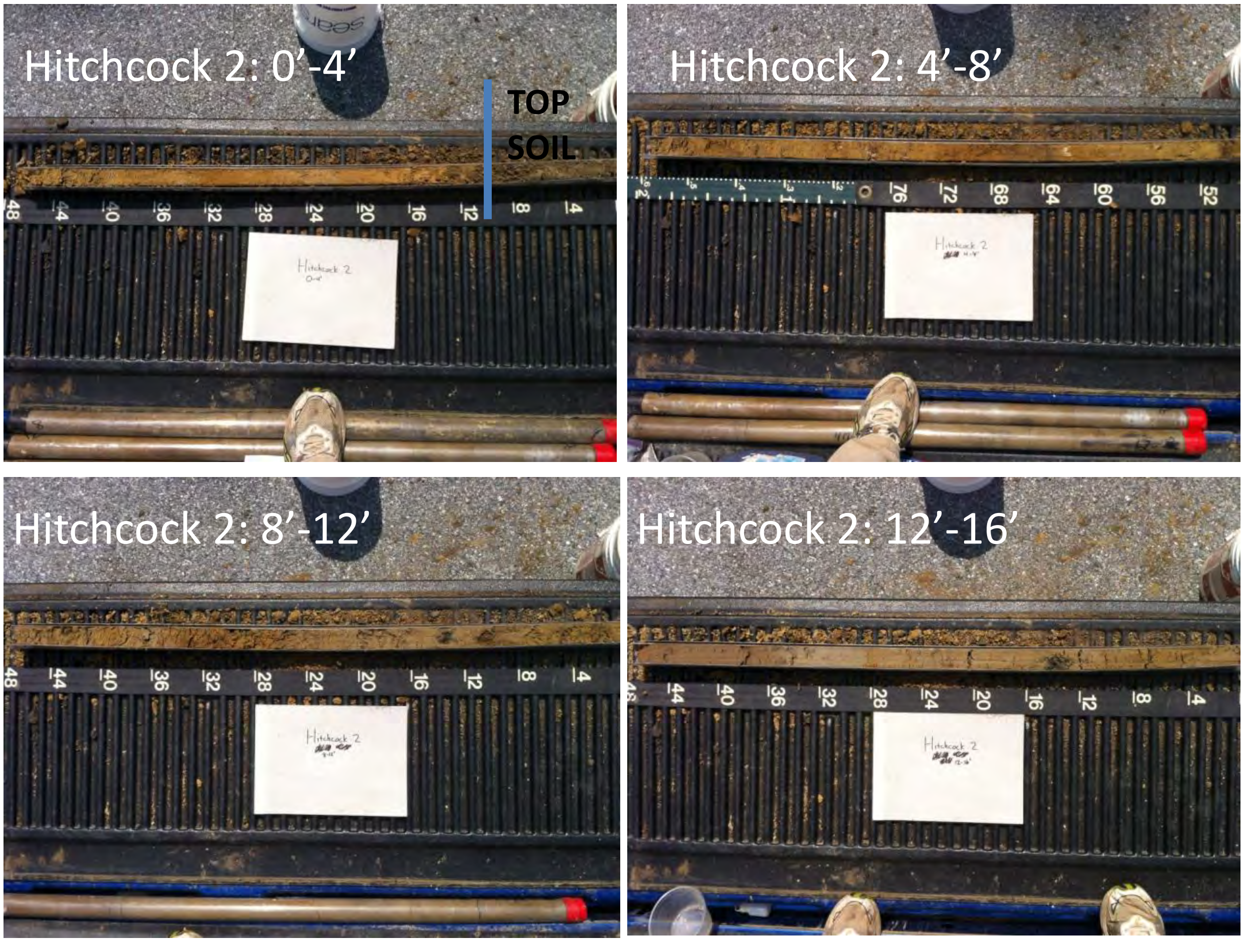

Figure 3. Representative series of soil cores from a single sampling location. In this case, the core was taken from Hitchcock Park, Omaha NE, July 2012. Note topsoil delineation in 0-4' section, top left image.

At each site where the soil cores for soil taxonomy were taken, a second adjacent hole was bored to the depth of transition, which we deemed the most hydraulically-restrictive layer. This layer was determined by soil taxonomy using the cues of soil texture and color. The hydraulic conductivity in this sub-soil transition zone was measured with a compact constant head permeameter (CCHP) (Ksat, Inc., Raleigh, NC). Per Amoozegar (1989), the data collected from the CCHP was used to calculate K_{sat} with Eq. 1:

$$K_{sat} = AQ \qquad [1]$$

where K_{sat} is the calculated hydraulic conductivity (cm hr^{-1} or in hr^{-1}), A is a constant based on the radius and head of water in the borehole (cm^{-2}), and Q is the steady-state rate of water flow into the borehole (cm^3 hr^{-1}). The CCHP method is employed to measure the saturated hydraulic conductivity (K_{sat}) in the sub-soil and is a measurement made in three dimensions. As a hydrologic process, infiltration-type GI practices move runoff volume into the soil matrix via infiltration, potentially leading to saturated conditions in the subsoil. Subsoil hydraulic conductivity (as an approximate rate of redistribution or drainage) is the major limiting factor for reliable design and management of stormwater by infiltration. The measurement integrates across the water exfiltrating radially outwards from the borehole. This quantitative measurement (borehole or subsurface K_{sat}) is used in conjunction with qualitative soil taxonomic data to better understand the tendency for water (as soil moisture) to redistribute.

The near-saturation hydraulic conductivity (K) at the soil surface was estimated with tension infiltrometers run at a suction head of 2 cm (mini-disk infiltrometers, Decagon Devices, Pullman, WA). At least four measurements were made at each sampling point. The manufacturer's general recommendations for data treatment were followed to estimate hydraulic conductivity from the disk infiltrometer. A unique design feature of the tension infiltrometer is that it can be set to eliminate or separate out the often significant influence of large macropore flow on the surface K measurement. We would consider this measurement a more conservative estimate of infiltration rate, as it measures the flow into the typically predominant smaller macropores that form the soil matrix. The sealing of the soil surface was particularly prominent in this study, due to the tendency of local Omaha soils to crust under the influence of protracted drought conditions. We used measured values of K in the rain garden simulation model RECARGA (Atchinson et al., 2006).

The soil cores were retained in sample sleeves for subsequent morphological description and sub-sampling horizons for basic physicochemical characterization. Particle size analysis was conducted using the pipette method (Gee and Bauder, 1986), soil pH was measured using a Ross combination glass electrode (Thermo Fisher Scientific; Beverly, MA) with a 1:1 suspension (Eckert and Sims, 1995); available Ca, Cu, Mg, P, K, S, and Zn were measured using the Mehlich 3 extraction with inductively coupled plasma atomic emission spectroscopy (Varian 730-EOS; Agilent Corp., Santa Barbara, CA) quantification (Wolfe and Beegle, 1995); with cation exchange capacity (CEC) subsequently calculated by summation (Ross, 1995). Ignition methods were used to determine total C (Nelson and Sommers, 1996) and total N (Bremner, 1996) with a CE instruments (Wigan, UK) EA1110 CHNS-O analyzer. Particle size data was also utilized to select the texture-dependent constant in the surface tension infiltrometer data which was determined for each diagnostic horizon.

Results and Discussion

In addressing the stormwater management options within an urban area, it is critical to consider both the original landscape and human actions that created these unique landscapes. One striking characteristic of the city of Omaha is that there are no low-order streams found within the city. Logic would dictate that some of these streams would feed the Missouri River, which is a major navigational waterway in the Midwest US. In reviewing historical maps of and documents about Omaha, we found that there were originally many streams present within the city. Based on the general climate in Omaha and eastern Nebraska, it is likely that some of the streams were intermittent in nature, flowing only during wet weather events. Early in Omaha history, city planners, engineers, and landscape architects identified these areas as being unsuitable for development. The riparian areas and floodplains were subsequently filled in, and many of these reclaimed areas were converted into parks. As a part of this process, the streams themselves were either filled in entirely, but were often run in pipes and became part of the CSS in Omaha. As pointed out for the Paxton Blvd. area, it is worth considering that the baseflow (now subsurface flow) in these buried stream corridors may be quite high. Therefore, it is recommended to quantify or estimate how much of the combined sewer flow in these areas is actually baseflow (i.e., groundwater contribution) from a stream network. These areas may profit from further modification of stormwater drainage, potentially benefitting from residential stormwater volume management retrofit programs, such as the Shepherd Creek stormwater management project (Thurston et al. 2008, Mayer et al. 2012).

Many of the parks investigated are at least 100 years old (the most recently established park investigated was 56 years old). At this time of construction of the oldest parks, fill activities were likely conducted with hand tools, which may suggest less compaction and more variety in layering. Our assessments of soil characteristics for sites in the vicinity of Omaha, NE, indicate the predominance of silt loam and finer soil textural classes (Figure 4). The texture of these soils is patterned after their formation in large deposits of wind-blown loess, which is predominantly composed of finer silt and clay materials. Over time, these landscapes eroded and stream channels formed, creating landscapes with both colluvial (rock and soil moved under the influence of gravity and deposited at the bottom of the slope) and alluvial (soil moved by streamflow and left behind during recession in stream and river flows) deposits. However, these deposited materials are originally the finer-textured loess material that was deposited from upland sources. Even though there may be differing parent materials, the soil textures are remarkably consistent as they all were identified to originate from an aeolian parent material. The uniformity of these soils is such that deep sampling (below 4’) may not be necessary without sacrificing predictability of deeper soils. One important attribute of these fine textured soils is that they have a tendency to hold water rather than redistribute or drain this soil moisture.

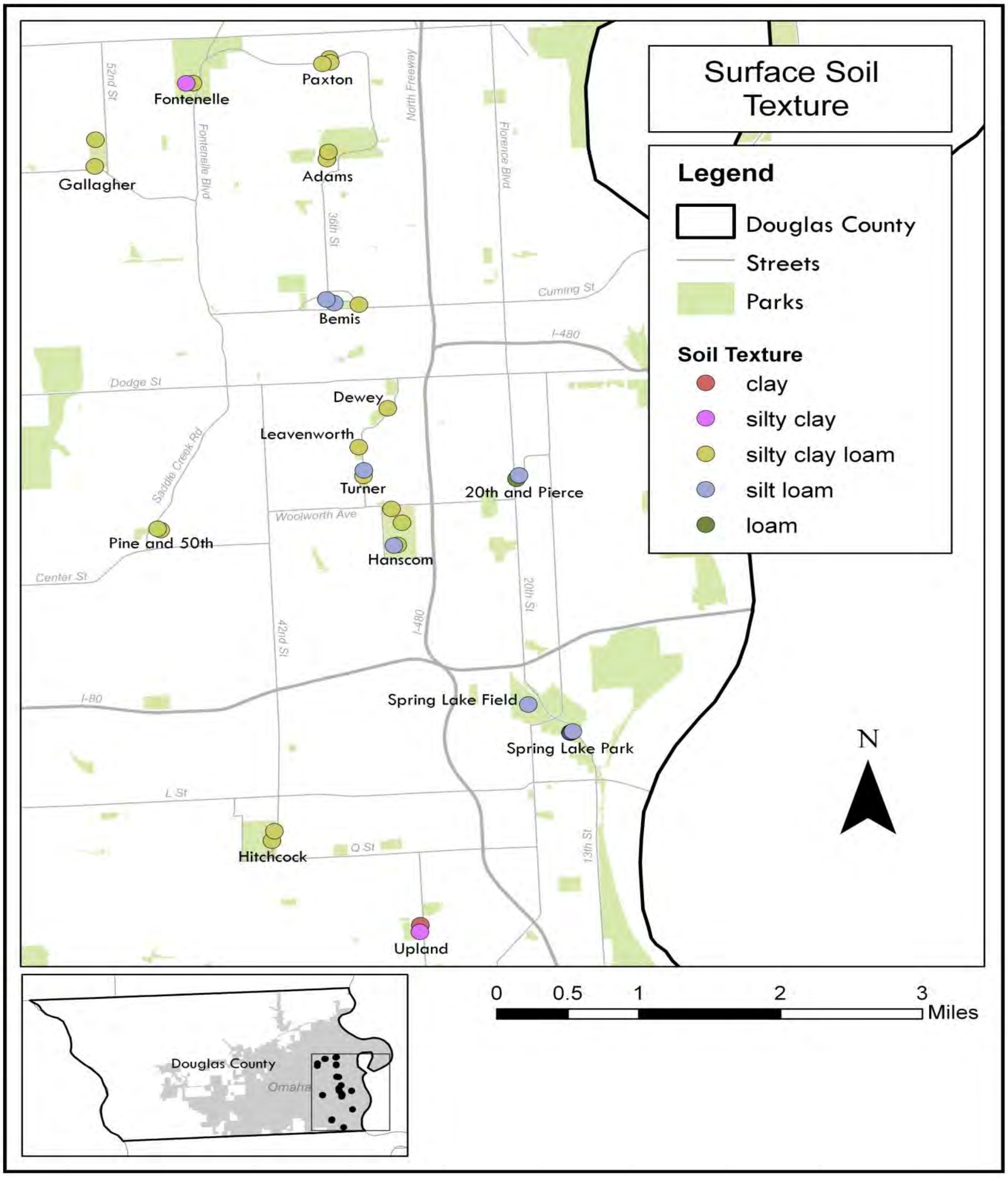

Figure 4. Surface soil texture for sites in Omaha, NE. Soil texture at the surface is one factor in the regulation of infiltration, which is the process whereby water moves from the surface into the soil profile.

In several sites (Figure 5), these native horizons were affected by urbanization; materials like brick, glass, gravel, and concrete were found in more urbanized right-of-way sites, while yard waste and household refuse were found in the Spring Lake Park southern site. The fill material was likely drawn from local sources and may have been the inverted horizons from adjacent residential development projects. The fill soils are fine-textured and consistent with the undisturbed native soils that formed in aeolian parent materials. Compaction is an additional human activity that has degraded the permeability and drainage characteristics of these soils. Foot traffic from city residents utilizing these recreation areas has compacted the soil surface over time, especially at heavily-traversed parks like Fontenelle Park which was maintained as a golf course. At the time that these parks were originally graded and landscaped, soil disturbance and compaction likely depressed soil permeability to a greater depth than foot traffic. This cumulative impact of apparent compact soil layers in both the surface and subsurface has further reduced the permeability of soils that have low infiltration rates to start with.

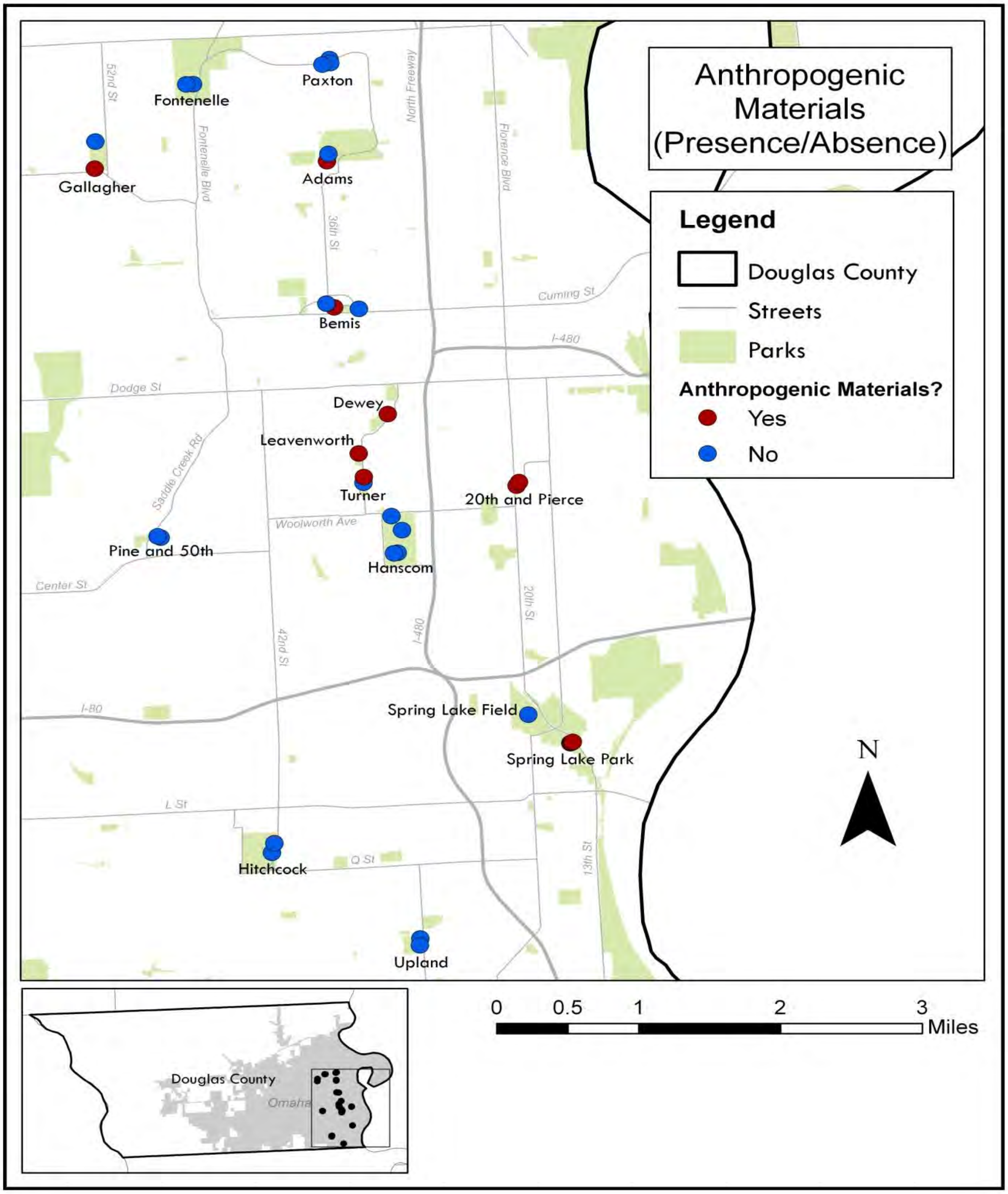

Figure 5. Soil anthropogenic material contents for sites in Omaha, NE. Assessment of soil cores allowed the team to discern non-native, anthropogenic fill material from the native silt-loam and finer soils. Locations where urban fill was found are indicated in this plot.

Soil texture, which is the proportion of sand, silt, and clay particles, exerts strong control over the infiltration process. Infiltration rates were classified according to Natural Resources Conservation Service Hydrologic Soil Group (HSG) categories (Figure 6), which are often used in the hydrologic calculations made in the design of water resources management infrastructure. In addition, the HSG designation is used as convenient shorthand to communicate the relative permeability or infiltration rate of a soil, with HSG A being the fastest class, and HSG D the slowest. The finer soil textures found in the metro Omaha, NE, area constrain soils to relatively low infiltration rates. In addition, the weathering of the soil surface (sealing, crusting, etc.), low proportional vegetative cover, and long-term drought conditions that persisted into 2012 all combined to further limit infiltration rates (Figure 6).

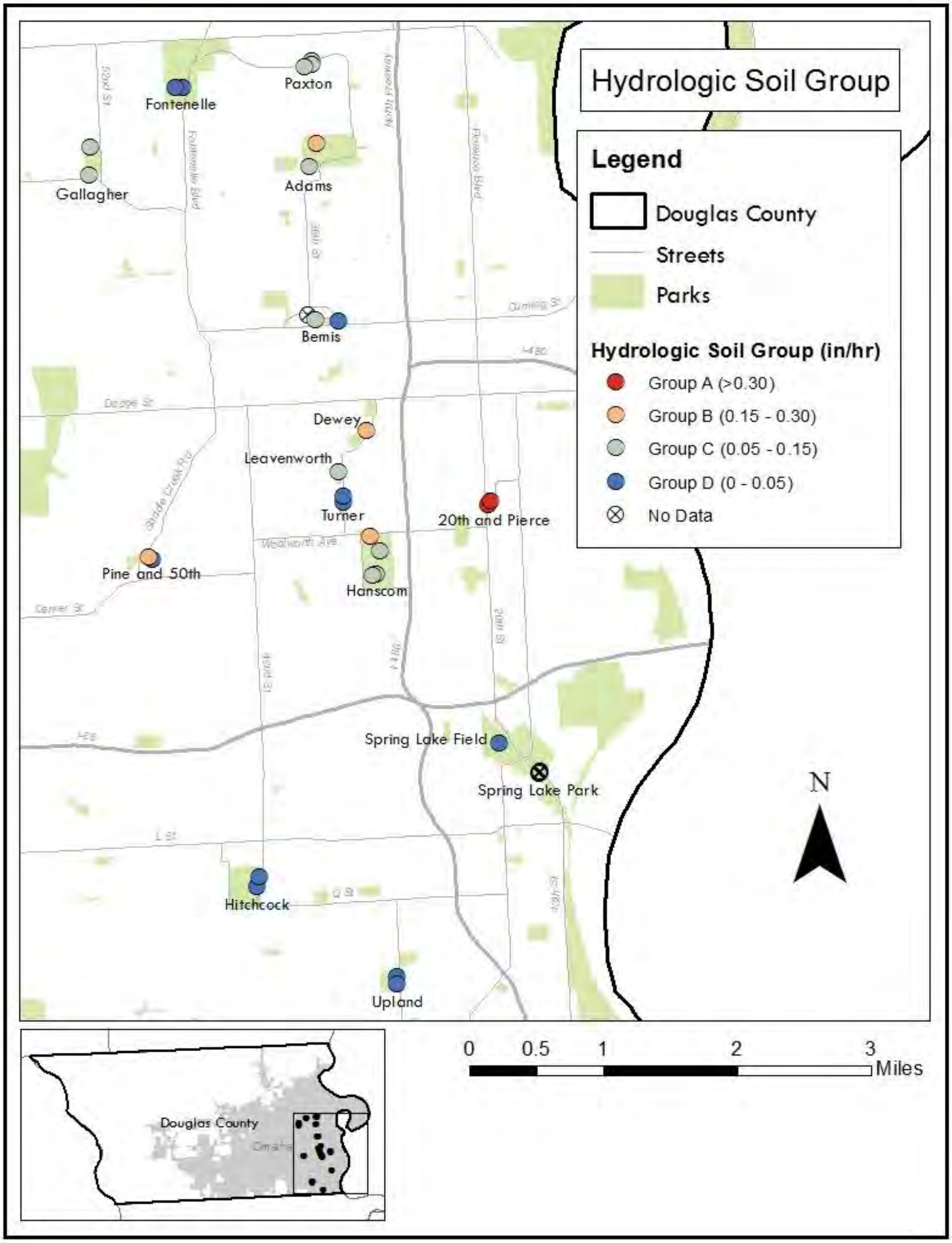

Figure 6. Soil hydraulic conductivity for sites in Omaha, NE. The hydraulic conductivity at the soil surface was grouped by hydrologic soil group (HSG) for Omaha NE sites.

The technique that was used to estimate the surface hydraulic conductivity, which is a measure of infiltration rate, eliminated flow into the larger surface-connected pores (> 0.09" or 2 mm). Flow into any larger pores is highly variable from location-to-location and can yield poor estimates of a representative infiltration rate. Therefore, these measures should be interpreted as conservative. The distribution of HSG across assessment locations was generally in the low permeability C and D categories, with some notable exceptions. The recently-worked stormwater management site at 20th and Pierce exhibited high infiltration rates as HSG A soils. Poor establishment of a turf cover (which had been attempted), however, leaves this unprotected soil vulnerable and subject to raindrop impact or other processes that serve to seal the soil surface and reduce infiltration. Measurements made along transects in parks (Dewey, certain locations in Adams, and Hanscom Parks) and at the 50th and Pine fire station had higher infiltration rate as HSG B soils. The 50th and Pine site had good turf cover and a friable surface soil structure, indicating conditions for higher infiltration; these observations suggest that the site is a good candidate for its planned use as a demonstration site for a combination of capture and infiltration-type GI.

We used the hydraulically-restrictive (HR) depth as a proxy for a worst-case/slowest-drainage scenario in our sub-soil assessments, and made a measurement in the midst of this layer to quantify sub-soil hydraulic conductivity (borehole K_{sat}, Figure 7). Note that the HR depth does not go much below a depth of 4 feet (~1.3 m) for the Omaha soils that were assessed. This measurement of sub-soil K_{sat} is important in the design process for infiltration-type GI as it indicates the ability of the subsoil to draw down the water that has infiltrated; this drawdown period should be limited to a reasonable amount of time (24-36 hours). These matters will be discussed in the forthcoming section on modeling.

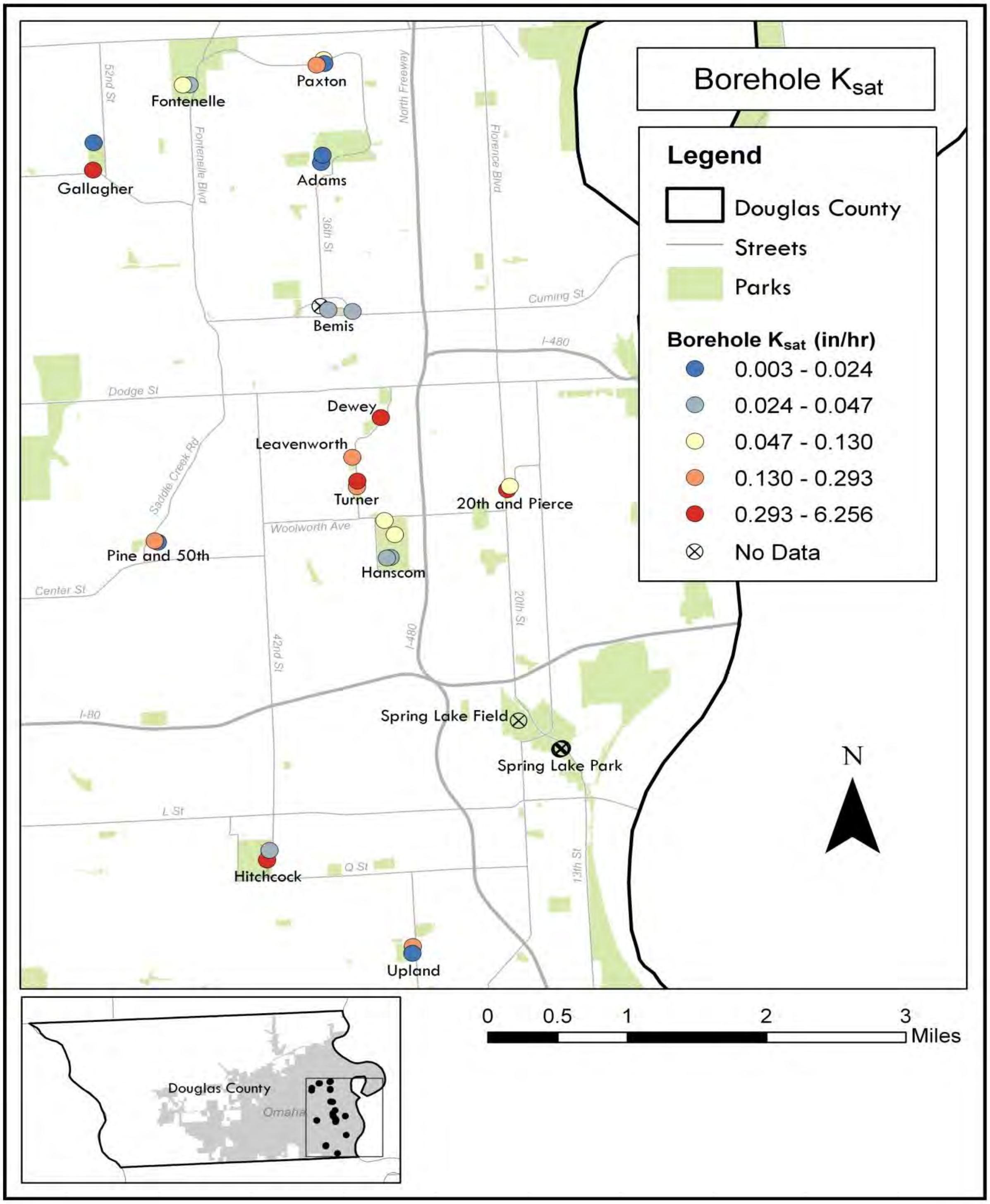

Figure 7. Borehole saturated hydraulic conductivity for sites in Omaha, NE. Rates can be interpreted as the drainage rate for sub-soils. This quantity is one factor that regulates how, for example, an infiltration GI practice would drain.

There was also evidence that many sites had rock fragments (Figure 8), whose origin was possibly demolition debris used as fill, as well as documentation of buried anthropogenic materials. If rock fragments are present in the sub-soil, then their proportion of the sub-soil volume affects borehole K_{sat} (Figure 7). If there is higher proportion of rock fragments in a sub-soil layer, then there is typically also more void space among the rock fragments. This void space provides avenues for water flow in the subsurface, and the flow rate is usually higher than surrounding silt-loam soils, which have comparatively small pores separating soil particles. Assessments in areas like the Leavenworth-Turner-Dewey Park network show higher sub-soil permeability with low percentage rock fragment. The higher observed borehole K_{sat} may have been due to a highly-aggregated soil structure under long-term turf cover and a coarser soil texture favorable to moving water. The coincidence of high borehole K_{sat} and rock fragments is apparent at Gallagher, Dewey, and 20th and Pierce. As for the latter site, a shallow gravel-fill layer was used to bed the stormwater storage tank gallery, allowing high sub-surface flow rates at this location. This type of stormwater control measure (SCM) consists of engineer-designed stone and pipe recharge systems installed in the subsoil that provide both storage and recharge of stormwater. These SCMs require a greater cost in construction materials (pipe and stone), but can also store more stormwater than other SCMs and, therefore, keep a greater volume out of the combined system. Because these are structural SCMs, it would be possible to install these SCMs below paved surfaces (porous paved parking lots, sidewalks, etc.) Since these SCMs use subsoils for recharge, they may be best installed where there is some measurable amount of subsoil permeability. It is advisable to maintain a minimum 2-foot separation between the bottom of the structure and the depth of a seasonally high water table.

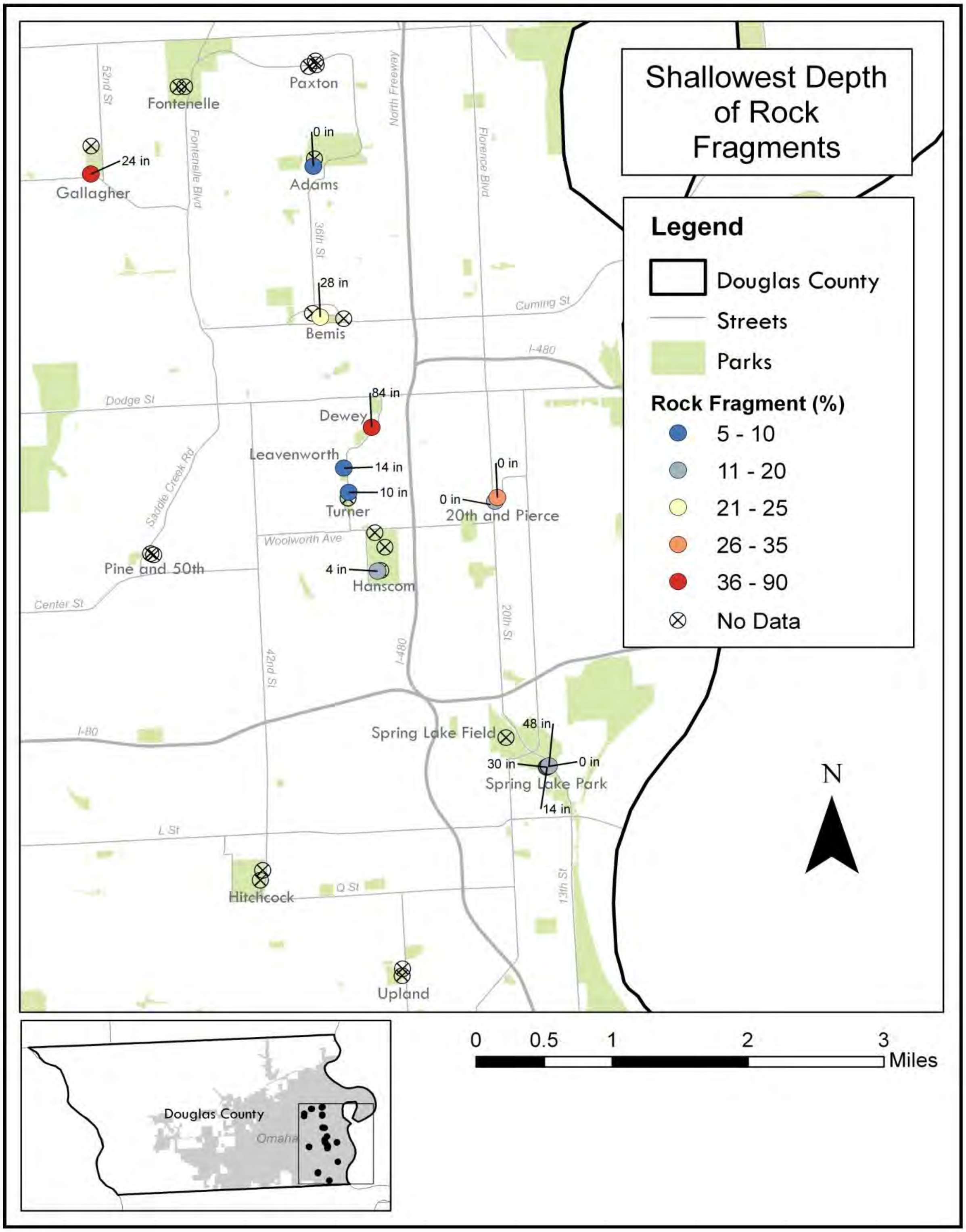

Figure 8. Top soil horizon(s) rock fragment percentage for sites in Omaha, NE. If there is large percentage of rock fragment in a soil layer, there is usually greater void space, and so water flow in rockier sub-soil (borehole K_{sat}) is usually also high.

As a complement to hydraulic measurements (i.e., surface and subsurface K_{sat}), the taxonomic investigation of soils offers many clues to determine the present and historical soil water status, or soil wetness. The term "soil wetness" refers to the presence of either seepage, redoximorphic features (which is often called mottling due to the variation in coloration of the soil due to the effect that water has on the chemical status of the soil, Figure 9), a groundwater table, or some combination of these soil water conditions. Seepage was noted as water that wet the inside or outside of the plastic boring sleeve, or observed as free water (i.e., a shallow groundwater table or local mounding) in the borehole as in the Spring Lake Field location. In this context, the presence of seepage indicates a proximate, seasonal water table. Redoximorphic features describe the presence of reduced iron, which only occurs during saturated conditions. For example, in an undisturbed forested soil, clues to understand the persistence of soil water in soils would be quite different than that for highly disturbed urban soils. In an urban setting, redoximorphic features can indicate the presence or impact of:

- Shallow water table: an aquitard or otherwise perched water table can cause persistently wet soil conditions.
- Compaction: Urban soils are typically compacted by human activities, which collapse soil pore space that would otherwise hold and transmit water, leading to poor drainage.
- Presence of imported fill: If imported fill soils were transported from a wet condition to more of an upland condition (where better drainage is expected), the intrinsic redoximorphic features remain in the fill soil, even when placed in a landscape that is not wet.

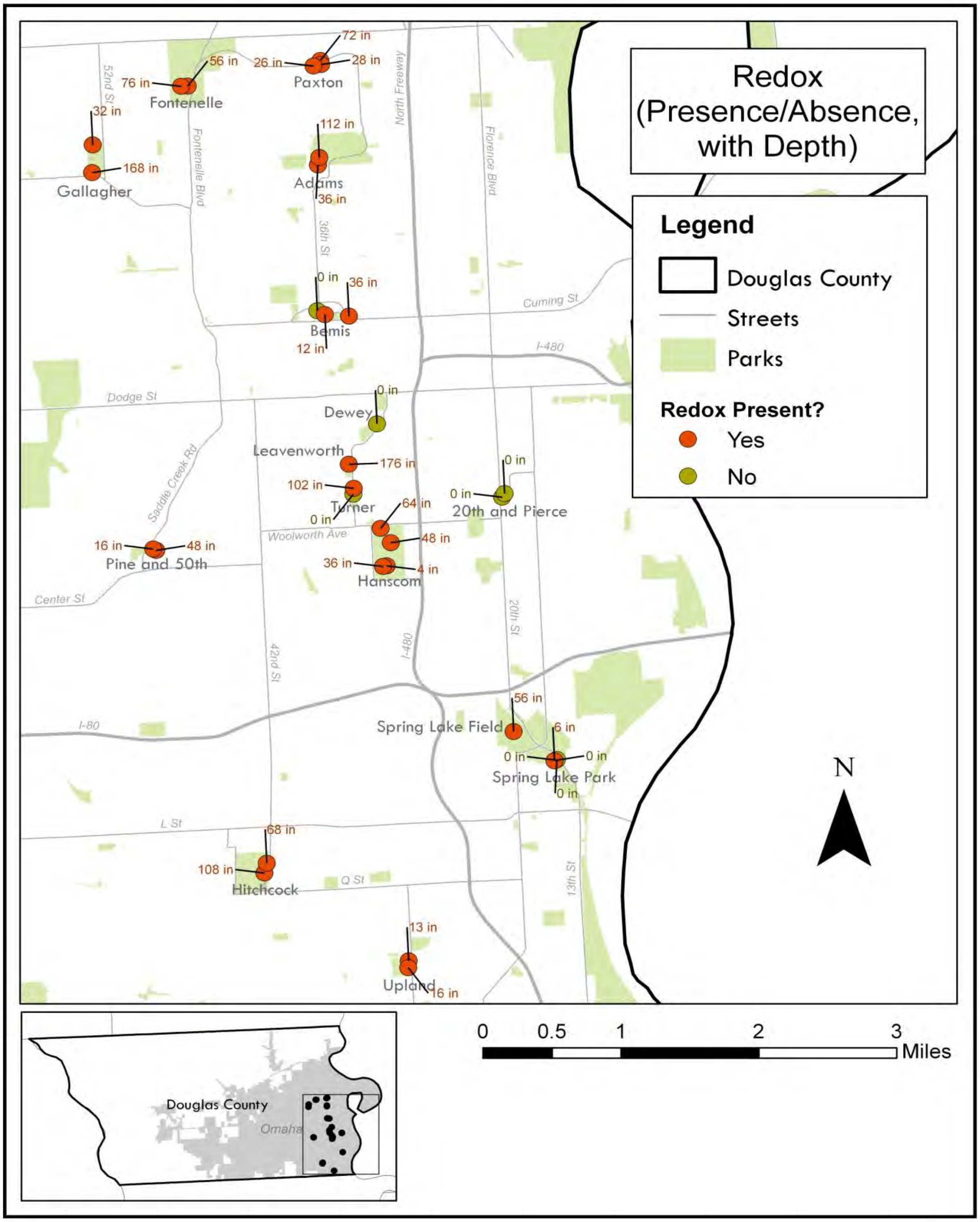

Figure 9. Redoximorphic conditions for sites in Omaha, NE. Redoximorphic conditions are a clear indication of historical soil water status. We expect more reduced conditions in the more poorly-drained soils, which is qualified by taxonomic assessment and quantified by borehole K_{sat} measures.

- Relict conditions: These soils may be located in a low part of the landscape and were historically wet, but there could have been drainage improvements that have removed a water table condition from a specific area.

As a general rule, any soil that has evidence of redoximorphic features should be avoided for any type of infiltration- or recharge-type GI. This is because there is little capacity to absorb stormwater routed to the soil for infiltration and subsequent redistribution and because the typical soil water status may indicate a typically high (or shallow) groundwater table. It is advisable to plan for a separation distance (the distance between the bottom of the infiltration practice to the depth of seasonally-saturated soils) of no less than 2' (~ 0.7m). On the other hand, the presence of redoximorphic features may not indicate a true water table condition, and other site factors should be investigated (e.g., leaking underground pipes, nearby swimming pool drainage, septic fields, streams, hillslope seeps, etc.) before a final judgment is made on site suitability for infiltration-type GI. There is the possibility that if sufficient land area is available, the GI facility can be designed to work within the boundaries of the limited hydraulic capacities of its host soil. Additionally, the presence of redoximorphic features may represent a perched condition; the soils below this perched condition may be suitable for infiltration. Overall, if a parcel has soils with extremely low potential for infiltration, drainage, and redistribution, and there is also not enough land surface area to provide sufficient infiltration (and redistribution) opportunities for anticipated runoff (and infiltrate) volumes, then water management infrastructure based upon infiltration ***is not recommended***. Appropriate alternative runoff control measures include: cisterns, wet retention, and other practices that store, rather than infiltrate, runoff volume. Overall, we find that most sites (with the exceptions of 20th and Pierce, Dewey sites) are not particularly amenable to infiltration-type green infrastructure implementation. Yet, we go on to demonstrate how the quantitative data gained from these assessments may be used to make the most of the limited capacity for infiltration and redistribution in Omaha urban soils.

Modeling Approach

As a note of clarification, the terms bioretention and biodetention have been used interchangeably in the literature, making it difficult to establish which means what. In this case, we will use the term biodetention to represent plant-soil systems that are designed to accept, infiltrate, and redistribute runoff volume, thereby detaining runoff with no avenue for slow release other than possibly an overflow pipe that would drain excess moisture from the root zone. A comprehensive rainfall-runoff model with soil moisture redistribution, RECARGA (Figure 10), is used to illustrate how rain gardens can cycle water. We use this model to illustrate how soil hydrologic assessment data can be used to plan effective GI. These simulations are broad approximations that give us a sense of how a rain garden can respond to a given rainfall pattern, given a certain set of other features. As is customary for many sewer districts around the country, we used the annual rainfall record deemed to be the long-term average record, which for Omaha, NE, is the 1969 hourly-resolution rainfall record. Although RECARGA accepts hourly evapotranspiration (ET) data, we did not explicitly determine this (as there was no correspondent record for 1969) and instead sub-divided a seasonal, average daily ET to develop an hourly ET record.

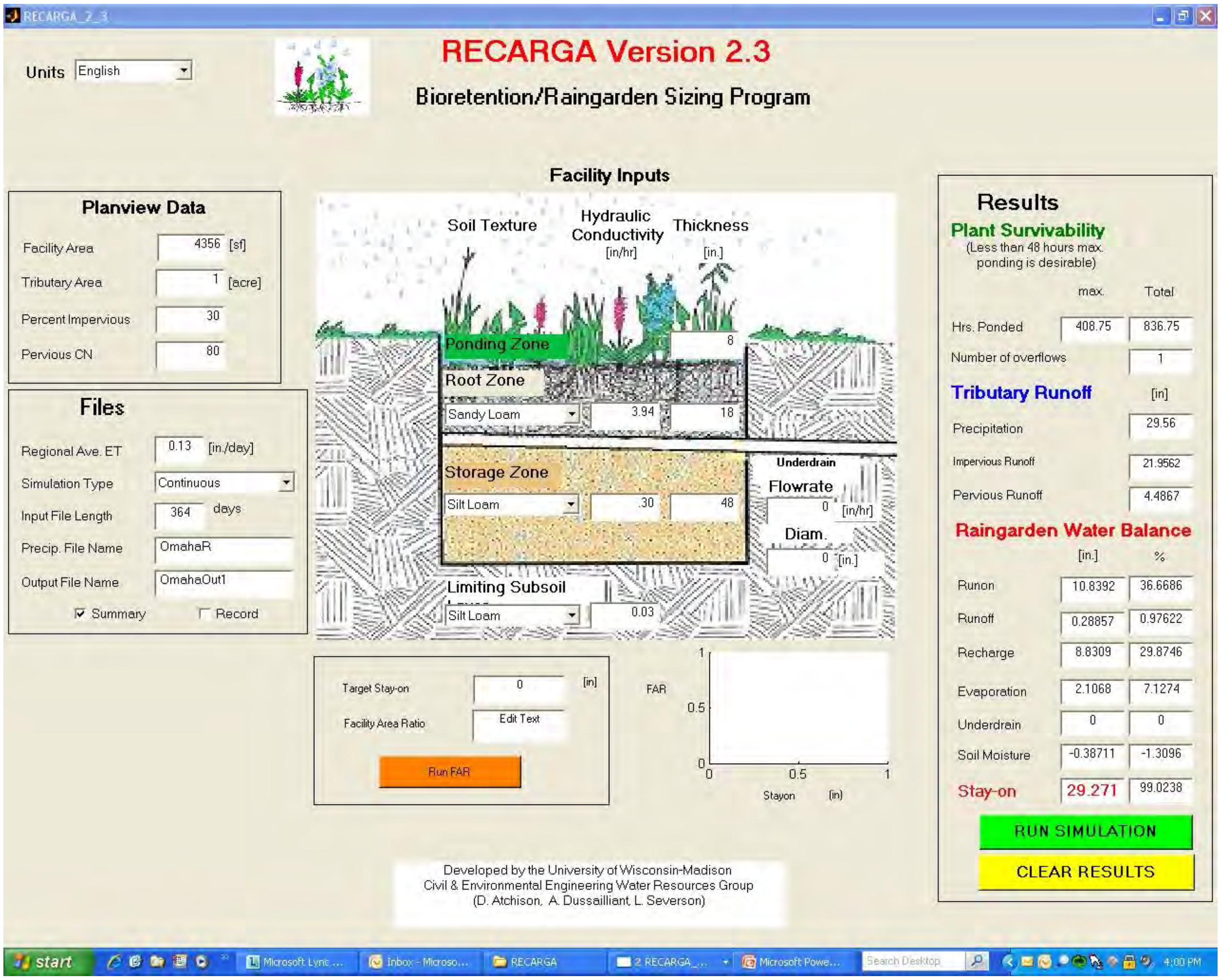

Figure 10. RECARGA rain garden simulation using Omaha (1969) rainfall record. RECARGA uses TR55 methods to route runoff into 1-D infiltration (Green-Ampt) and redistribution with van Genuchten sub-model. The RECARGA user interface is arranged with site details, rainfall inputs on the left, rain garden (facility) design in the middle, and the resulting water balance and what this means for plant survivability on the right.

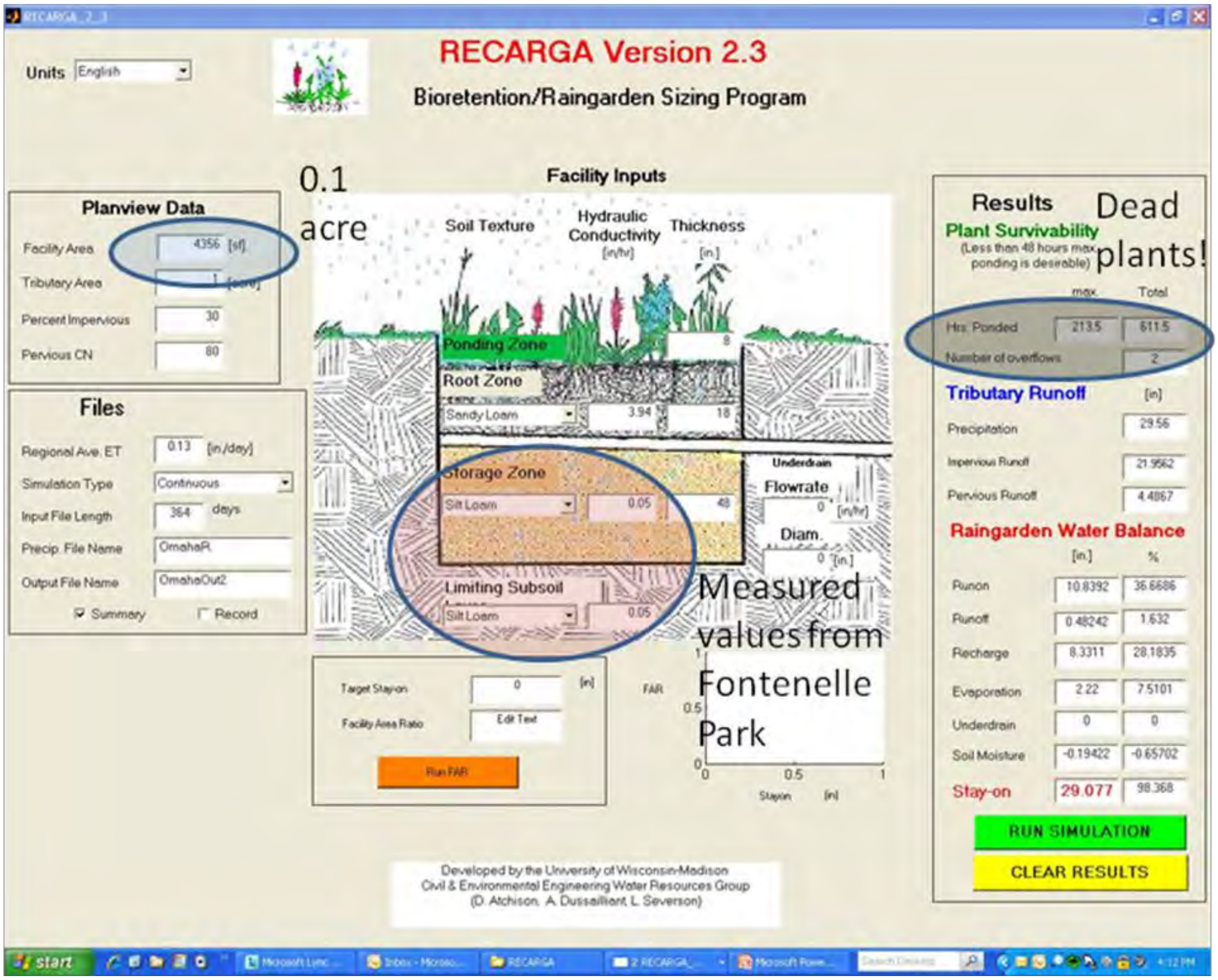

Figure 11. 0.1 acre-sized rain garden simulated in Fontenelle Park (Omaha, NE). This simulation shows that the limited drainage at this size of rain garden leads to poor performance.

The first simulation (Figure 11) was set up to depict a modestly-sized rain garden set in a 1 acre sub-watershed, within the overall large expanse of Fontenelle Park (see Appendix A). The RECARGA program is limited in terms of the choice of rooting zone soil, so a sandy loam soil was used, which might be obtained by amending and managing native surface soils in vegetation to maintain a higher infiltration rate or by using imported engineered soils. The borehole K_{sat} data that was explicitly measured at this park was used so that the subsoil is properly and realistically represented in the model input. The simulation output indicates that the rain garden will overflow at different points in the simulation period, and plants may not survive the length of time that the root zone is saturated (Figure 11), a period that should be limited to less than 48 hours. Overall, there is insufficient drainage into the subsoil, though we might also conclude that the rain garden is not large enough in surface area to handle the runoff volume resulting from the average annual rainfall record.

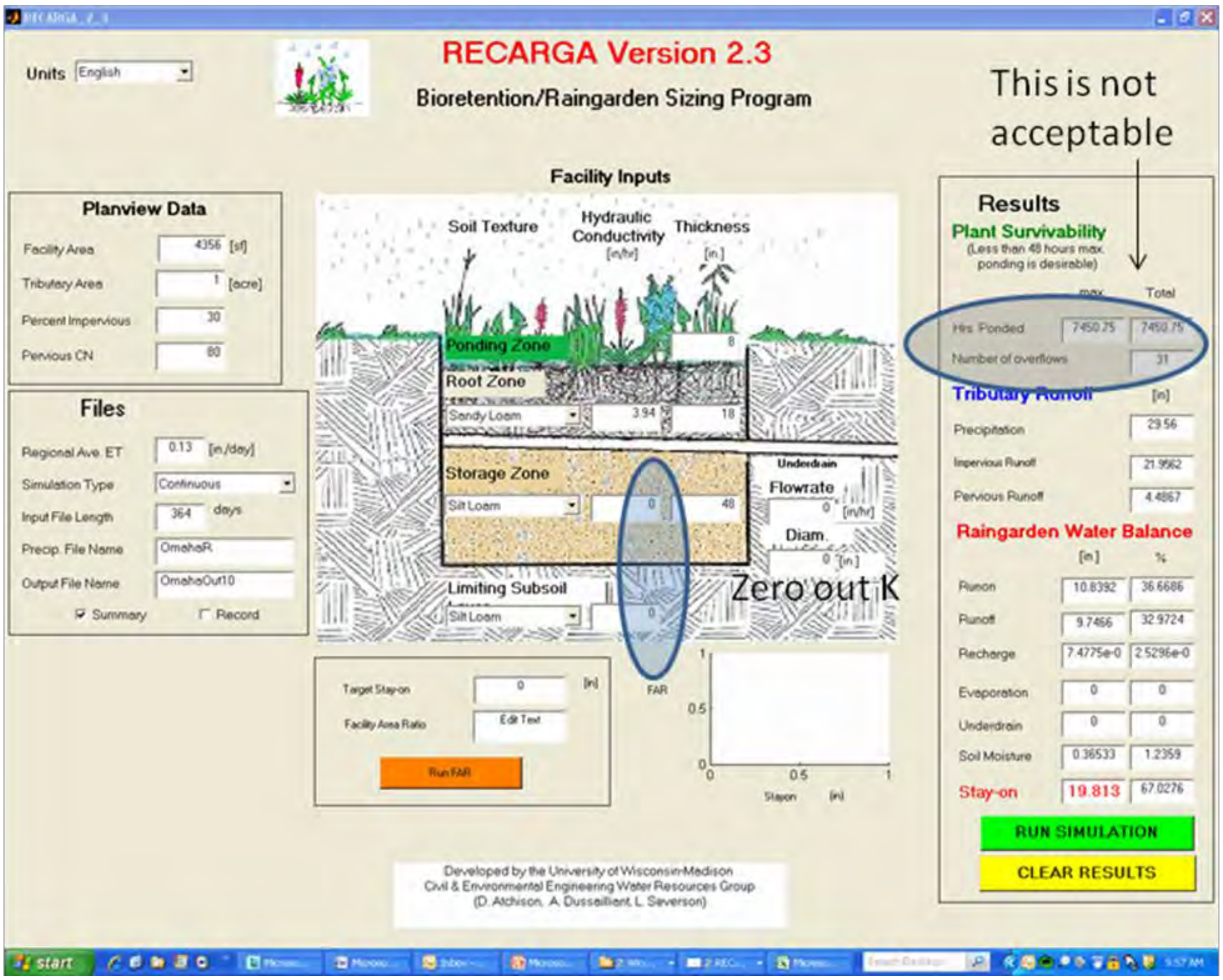

Figure 12. Rain garden simulation with subsoil hydraulic conductivity zeroed-out. The unacceptable performance of the simulated garden emphasizes the importance of considering sub-soil drainage.

As a check, the next simulation illustrates what happens if we do not consider the potential subsoil rate of drainage (Figure 12), even if this drainage rate is very small. This simulation indicates that, within the approximation of the model and its formulation, that the subsoil drainage rate indeed has some beneficial impact on the performance of this 0.1-acre rain garden. This is a hypothetical situation where a one-acre subsection of this ~40-acre former golf course is split out and drained into a 0.1-acre rain garden.

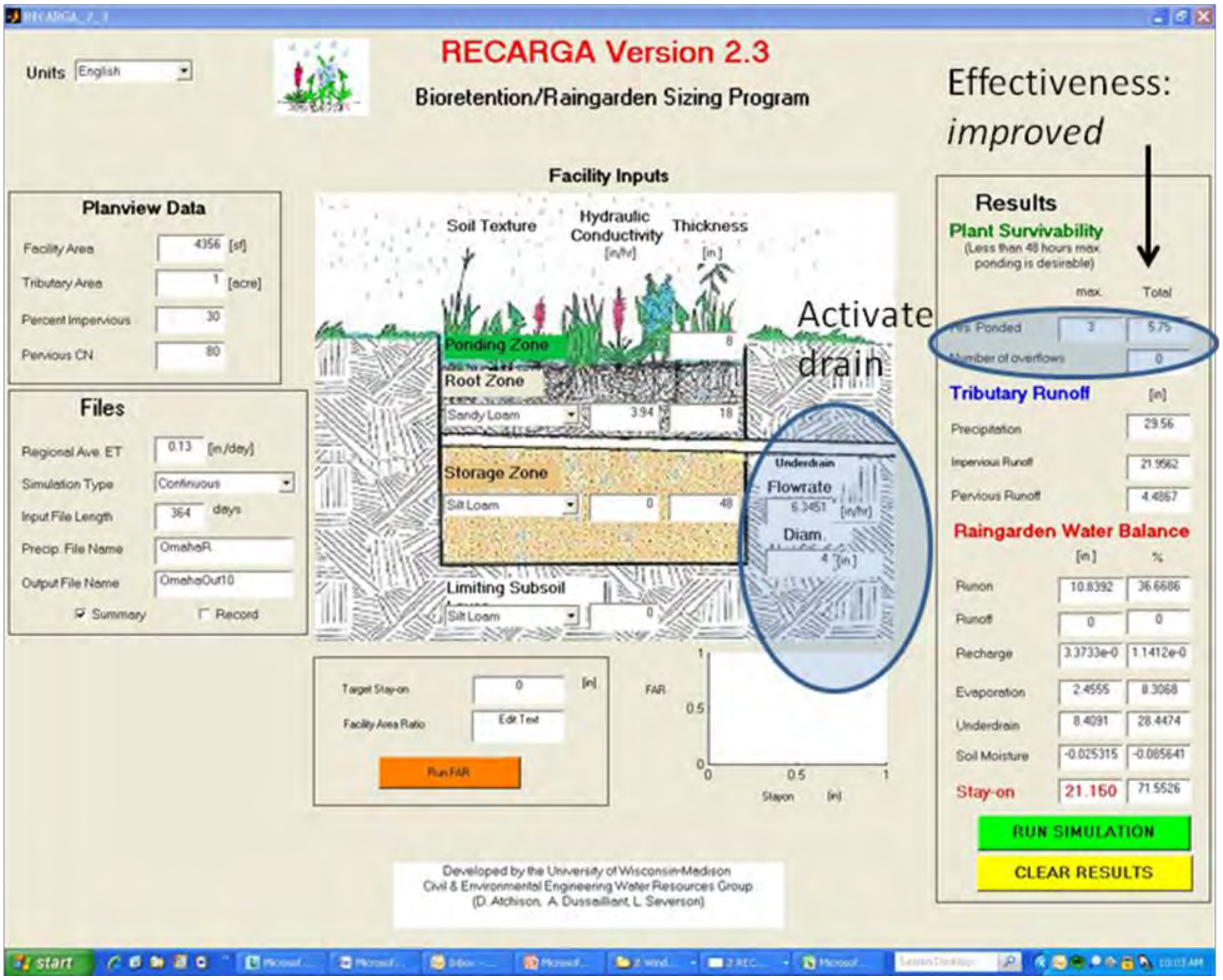

Figure 13. Rain garden simulated with an underdrain. The underdrain keeps the rooting zone from saturating for too long. Note that the model output predicts improved plant survivability.

As a first pass at an engineered "fix" for rain gardens with wet rooting zones, an underdrain is added to drain excess soil water from the garden (Figure 13). This excess water volume is then daylighted or conveyed out of the rain garden and into a flow spreader, a turf area, or other receiving area. The installation of an underdrain requires some slope difference between the rain garden and its surrounding landscape. We can see that the underdrain imparts a great improvement in rain garden performance, as the raingarden does not overflow, and plant mortality is no longer an issue. The underdrain is an effective approach to allow the placement of rain gardens in marginal areas. Yet, there is still the matter of what is to be done with the volume of water that comes out of this pipe, and where would it go? Again, this outflow can be spread onto turf lawns or even put back into the combined or separate sewer system. In the latter case, putting underdrain flow into the sewer system cuts down on the frequency and likely the volume of flow from larger storm events. It still improves on not having any detention of stormwater runoff. In addition, the underdrain can be "throttled down" or partially closed off so as to tune the trade-off between the amount of underdrain flow and the extended length of time needed allowing the water to percolate into and through the rain garden. In other words, the diameter of the underdrain pipe can be regulated with a valve to control the balance between: a) detention of excess urban runoff volume (open underdrain) for a slightly longer time period than if it had not infiltrated into the root zone of the garden, versus b) forcing an increased interaction with subsoil and subsequent drainage through the surrounding soils.

On the other hand, if the desired setting for the rain garden has sub-optimal drainage and there is no acceptable way to drain underdrain flow, then a "space for drainage" substitution may be workable. This is especially true for urban park areas where there is usually acreage that can be assigned to not only recreation but also as a stormwater management tool. As shown in Figure 14, the size of the rain garden area is increased, and the drainage rate is held constant. More of the permeable rain garden surface area is available to ensure that there is sufficient

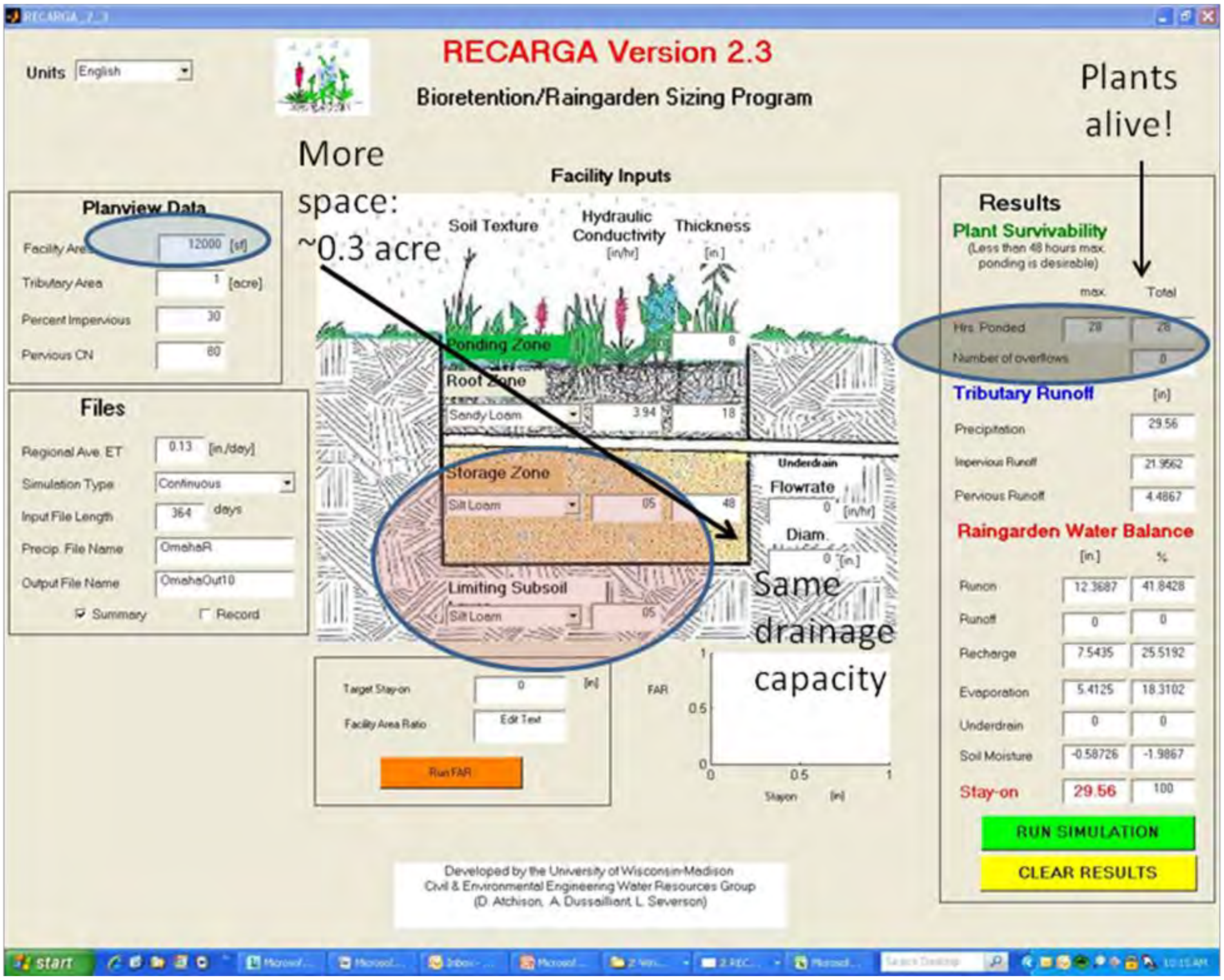

Figure 14. Simulation of an enlarged rain garden. For this simulation, the underdrain is removed and the area of the rain garden is increased. This is a *"space for drainage"* substitution of more space as a way to make up for limited drainage rate. The large land area of Fontenelle Park offers sufficient space to accommodate this approach, though surface soils would have to sustain high infiltration rate and have a sandier texture to produce similar results to this simulation. Long-term soil building (better soil structure) may be one strategy.

capacity for the anticipated runoff volume. The full use of a decommissioned park like Fontenelle is also in keeping with the spirit of GI concepts, which emphasize connecting parcels together into cohesive corridors and land management units that provide contiguous habitat, not to mention a wide variety of opportunities to absorb and percolate stormwater runoff. Although a considerable amount of land is put under management, the operation and maintenance of these landscapes can borrow from agricultural techniques and also may be used in the pursuit of urban agriculture.

Soil Chemistry

Overall, the soils assessed in Omaha tested fertile with high amounts of organic matter (see Appendix B, Figure B1), moderate to high cation exchange capacity (see Appendix B, Figure B2), and approximately neutral pH (Figure B3) (except for Fontenelle Park, where the slightly acidic soils were highly-leached from years of irrigation). The soil chemistry measured at both the surface and subsurface soil horizons was consistent with native soils in and around Omaha. Based on these analyses (with map plots included in Appendix B), there are no chemical factors which would adversely impact any potential infiltration or redistribution altered by the addition of stormwater management features to this site.

Soil Management

GI is based on the soil ecosystem providing physical support (i.e., a rooting zone) and sustaining the supply of water and nutrient resources to plants. There is an opportunity to manage soils in GI to support vigorous plant growth and to promote or maintain high infiltration rates. If native soils are to be managed in-place (an economical option) for infiltration-type GI, careful tillage and organic matter are inputs that can help to retain and build soil structure. Soil structure is the relative proportion of soil particles and the voids between them; a balance between the two provides good stable support for the root zone, with sufficient void spaces to conduct water into the soil profile. Improvement in soil structure is directly tied to a correspondent improvement of infiltration characteristics. Soil structure can be affected by tillage, which can break up hard soils and create voids but can also compact and destroy soil structure. Periodic tillage should be done in a way that minimizes compaction to any layer of the soil. Tillage will at least temporarily create larger void spaces among soil aggregates through which water can more easily infiltrate and redistribute. Tillage must be executed carefully and at proper soil water content so as not to smear or slake soils. Soil structure can also be passively promoted through seasonal freeze-thaw cycles, which push aggregates together and alternately force them apart, and plant roots moving into the soil, which leave void spaces at senescence. Amendments rich in organic matter can be added to native or fill soils and carefully incorporated with tillage as one way to spur development of structure. A locally-produced nutritive organic waste residual (e.g., Omagro – local Omaha-composted yard waste) is another option. Soil structure can promote infiltration, and with the help of deep-penetrating plant roots, drainage might be improved, but none of this can happen overnight. Therefore, take the long view to build and maintain structure in native soils and work toward improved hydrologic function. In review, soil structure develops over time with: freeze/thaw cycles, organic matter amendments, sensible tillage at the right moisture content, and establishing a plant community with diverse foliage and root structures.

On the other hand, engineered soils provide a more consistent soil material that can be customized to the needs of the particular circumstances. Yet, depending upon the details of sourcing soil materials and blending, and transportation and placement, this soil fill option often is a more expensive proposition compared to managing native soils in place. These soil blends are often sandier in texture and have faster infiltration rates (at least initially); once water moves into the engineered soil profile, the soil water will tend to move relatively quickly, vertically and laterally through the engineered soil material. However, the potential for these soils to build soil structure may be lower than with soils that have slightly higher proportions of silt and clay. This is where engineered soils can be deficient in terms of performance, as the soil and organic materials tend to separate before building any structure. In addition, the coarse texture of sandier soils may be more susceptible to clogging, and short retention times may inhibit desirable processes that contribute to improved water quality. There are attributes to each of these approaches to soil management, with correspondent tradeoffs in their costs, operational details, and maintenance needs.

Stormwater and CSO Management with Green Infrastructure

In looking at a particular sewershed for GI, it is tempting to try and attenuate the flows from an entire sewershed into one or two particular locations regardless of the soil conditions encountered. This is "outside-in" thinking about mitigating CSO events. While this optimistic thinking may be *conceptually* cost effective, the soil conditions may not be suitable for the types of GI being proposed for a particular location. If unsuitable soils are encountered, it may be possible to import a sand-based infiltration medium for the proposed GI; however, the costs of importing resources into SCMs are substantial. This study utilizes data on intrinsic features of the soil to promote "inside-out" thinking. Based on the now-known, quantified soil hydrologic properties, the limitations of the soils at each location are also known. In this way, planners can determine how much water volume each site can reasonably accommodate.

As with any practice that serves to put additional stormwater volume into the subsurface, a holistic view of the entire landscape and wastewater infrastructure setting must be made as a part of the planning process. The runoff volume that is infiltrated can create substantial moisture in the subsurface; if wetness is in the vicinity of buried wastewater/water supply pipes, then exchange with these leaky conveyances may aggravate existing inflow/infiltration issues. Or, the GI practice may itself be affected by leaking pipes that exfiltrate wastewater, stormwater, or combined flow volumes and thereby contribute to changing local water balance. Overall, it is key to make use of these best know measures (i.e., the borehole permeability measurements) of soil moisture redistribution in the planning process to understand the risks of GI creating return flow to the combined system via subsurface flow. It is our understanding that the data provided in this report will help manage the possibility of unwanted outcomes and reduce the risk to acceptable levels.

Conclusions

A standardized protocol was applied to assess soil hydrologic conditions in Omaha, NE. The protocols used in this study will provide a template for future site-specific investigations in other US cities. This data attempts to provide the type and detail of soil hydrologic information that is needed to support the overall goal of contemporary hybrid grey-green CSO management, which is to maximize the amount of runoff volume that is detained in GI and keep these flows out of the combined system. This is one strategy to control the frequency and volume of combined system overflow events. The information in this study can illuminate problematic soil formations or drainage areas, minimizing risks of unintended outcomes (e.g., water in basement issues, septic sewer overflows) and preventing the needless expense of further design work, study, or implementation at an impossible site. Although more specific commentary on the suitability for each site follows in Appendix A, the following are some general ideas to keep in mind:

1) ***Site-specific data on soils and their hydrology is essential.*** All too often, projects are designed and undertaken based upon general, regional soils data. It usually turns out that actual site conditions are quite different from generalized tables and interpolated datasets. This is especially true in highly disturbed urban areas where soils were either not mapped or only minimally so.

2) ***If a parcel has soils with extremely low potential for infiltration, drainage, and redistribution, then capture it in storage.*** If there is not enough land surface area to provide sufficient infiltration (and redistribution) opportunities for anticipated runoff (and infiltrate) volumes, then water management infrastructure should be based upon GI methods that capitalize on capture and retention.

3) ***Ensure that the soils are appropriate for use in seasonally wet or dry conditions.*** In a typical geotechnical investigation, the focus is on the physical characteristics of the soils as they relate to supporting structures, roads, sidewalks, and providing a stable bed for underground utilities. The emphasis in the present study is instead on evaluating the tendency of the soil to either transmit or store water, and to support plant life, which can create desirable losses of soil moisture as transpiration during the growing season.

4) ***For future projects, care must be taken in the inspection of each phase of these projects.*** While municipal budgets are often stretched and there is little time for inspection, post-construction monitoring (i.e., does the practice work as designed?) and appropriate operation and maintenance should be conducted to insure design effectiveness and otherwise guide corrections.

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Appendix A. Site Details

Adams Park

Adams Park is a 60-acre (24.2 ha.) park in the northern section of Omaha. It is located along the John A Creighton Boulevard, between Maple and Bedford Avenues. The park is located within the Minne Lusa Sewershed portion of the Omaha combined sewer system.

History

Adams Park was established in 1948. In the year 2000, a pond was constructed in the southwestern corner of the park, near Maple Avenue. It is our understanding that there have been periodic issues with this pond holding water.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Ida, Judson, Marshall, and Monona. All soils are considered well drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in the southwestern portion of the park: one closer to Maple Avenue and another between the pond and the combined sewer conveyance system.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There was a stark contrast in amount and variety of fill materials at the two test locations. At test location #1, near Maple Avenue, there was 56 inches of fill material present. This fill material consisted of gravels, brick, slag, and glass. At test location #2, nearest the pond, there were 12 inches of clean fill material present.

Soil Wetness

At test location #1, there were two perched conditions at 36-48 and at 56-96 inches. These perched zones were likely caused by composition and compaction activities involved in the filling processes that took place at this location. At 36-48 inches, the perched zone was located within the area of filled soils. At 56-96 inches, the perched condition was directly beneath the filled soils, and the saturated soils were likely more strongly influenced by the compaction that occurred during the filling of these soils. At 156-192 inches, there were both saturated conditions within the boring (free water) as well as redoximorphic features; these represent the depth to an apparent or regional water table at the time of sampling in July 2012. At test location #2, there were no perched conditions throughout the profile. At 112-192 inches, there were both saturated conditions within the boring (free water) as well as redoximorphic features; these together confirm and represent the depth to an apparent or regional water table.

Table A1. Soil wetness conditions in Adams Park

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	36-48; 56-96	156-192
2	----	112-192

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is extremely low, and therefore the potential for redistribution of soil moisture is likewise low.

Table A2. Soil Hydrology conditions in Adams Park

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.14
	49	0.003
2	Surface	0.26
	47	0.014

Soil Chemistry

Surface pH values measured 7.7 and 7.8 at test locations #1 and #2, respectively.

The soils around Adams Park are primarily limited by their slow permeability in the subsoil. Since there were non-zero infiltration rates, the areas at Adams Park may accommodate excess stormwater runoff volumes. However, these landscapes could be bermed to concentrate and capture overland flow that is generated by infiltration excess. Infiltration rates would be appropriate to handle only the more-frequent rain events that have smaller total depth.

The deep depth to clay and the saturated conditions encountered during a protracted and severe drought would indicate that a pond-type or constructed wetland retention system may be most beneficial at this location. The operation of biodetention (raingarden) systems would likely be problematic for this location. This is due to the extremely low permeability measured in the subsoils. If stormwater control measures that rely on infiltration are used in this area, careful consideration of sizing and design is critical. If a biodetention system is constructed to a depth of 3-4 feet, this stormwater facility could very easily be inundated with water, as there is little opportunity for the redistribution of soil moisture nor deep percolation into these soils. In this instance of the Adams Park area, an additional bioretention (e.g., wetland) facility may be established. If this area were planted with a mixture of vegetation adapted to drier and wetter conditions, this area could evolve over time into a wetland.

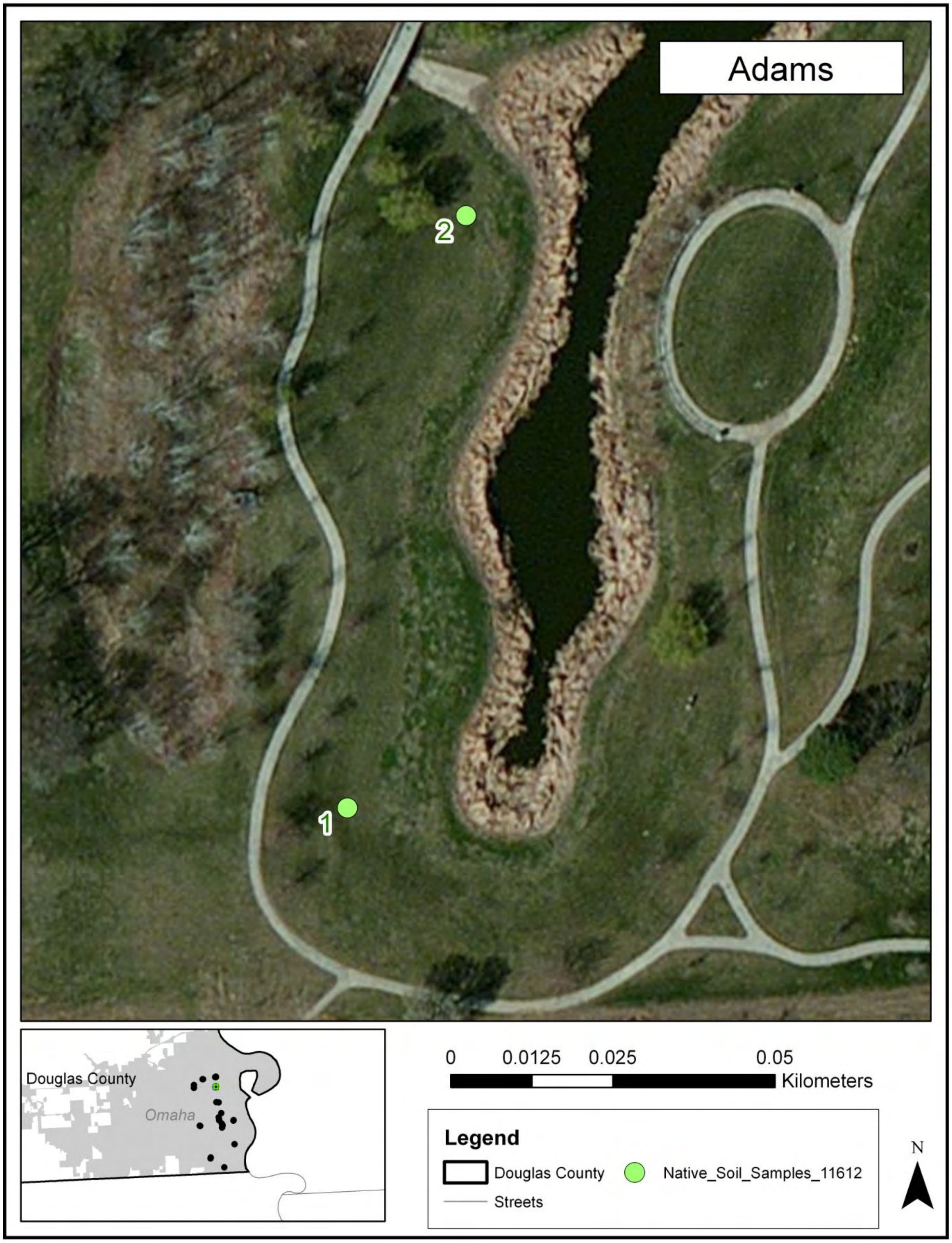

Figure A1. Satellite photograph of Adams Park.

Bemis Park

Bemis Park is a 10-acre (4 ha) park located just northwest of downtown Omaha, between both Lincoln Boulevard and Cuming Street, between 33rd Street and Glenwood Avenue. The park is located within the Burt-Izard Sewershed portion of the Omaha combined sewer system.

History

Bemis Park was first established in 1891. This was one of the first purchases by Omaha's Board of Park Commissioners, which was created in 1889. The land for Bemis Park was donated by the local builder because the original landscape was considered too steep (a "ravine") with a stream running through it, and, therefore, considered unsuitable for house construction.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Urban Land-Pohocco map unit. The Pohocco series is considered a well-drained soil with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Three test locations were advanced along the low spots of the park: soil permeability and chemical analyses were conducted in the two easternmost test locations only, as shallow seepage was encountered at the westernmost test location.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There was a stark contrast in amount and variety of fill materials at the three test locations. At test location #1, no fill material was observed. At test location #2, there were 56 inches of fill material present. This fill material consisted of concrete. At test location #3, no fill material was observed.

Soil Wetness

There was evidence of both perched conditions and saturation at the three test locations. These test locations likely reflect the location of the original stream in this area.

Table A3. Soil wetness conditions in Bemis Park

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	68-192	----
2	12-144	90-144
3	----	----

Soil Hydrology

These soils have extremely slow permeability, and would be expected to have equally slow potential for redistribution of soil moisture.

Table A4. Soil hydrology in Bemis Park

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.02
	24	0.05
2	Surface	0.11
	48	0.05

Soil Chemistry

Surface pH values measured 8.1 and 7.5 at test locations #1 and #2, respectively.

The soils around Bemis Park are primarily limited by their extremely slow permeability in the subsoil. Steep slopes will generate and convey runoff as sheet flow into bottomland areas where non-zero approximate infiltration rates can absorb some proportion of runoff volume. The slow infiltration rates as measured would be appropriate to handle only the more-frequent rain events that have smaller total depth. In addition to low subsoil permeability, the lack of space in the flatter, lowlands of the park, would make design and operation of biodetention (raingarden) systems problematic. If stormwater control measures that rely on infiltration are used in this area, careful consideration of sizing and design is critical. If a biodetention system is constructed to a depth of 3-4 feet, this stormwater facility could very easily be inundated with water, as there is little opportunity for the redistribution of soil moisture nor deep percolation into these soils. A managed reforestation project could help in some respects, though soil moisture would have be carefully managed with regard to tree species selection and their relative impact on benefits (breaking up the local soils and improving structure) and costs (actual cost of trees and their installation), and their impact on scavenging local soil moisture, and increasing local evapotranspiration losses.

Figure A2. Satellite photograph of Bemis Park.

Dewey Park

Dewey Park is a 7-acre (2.8 ha) park located just west of Downtown Omaha, between both Turner Boulevard and Dewey Avenue, between 33rd Street and Harney Street. The park is located within the Burt-Izard Sewershed portion of the Omaha combined sewer system. A "piano-inlet" is located on the street near the parking lot right-of-way (see image below) and is evidence of legacy-historical storm drainage issues in this low-lying area.

History

Dewey Park was first established in the early 1900s. This park was the location of one of the original baseball fields set out by the Omaha Parks Commission in 1913.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Urban Land-Udorthents map unit. This map unit describes soils that have been disturbed by humans with a seasonal high water table at greater than 80 inches.

Investigation

One test location was advanced in the northern portion of the park, near the parking lot and handball courts closest to Harney Street.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There were 42 inches of fill material present at this test location. The fill material consisted of asphalt, coal, and cinders.

Soil Wetness

No evidence of saturated conditions were observed at this test location.

Soil Hydrology

These soils would be considered to have moderate permeability and likewise moderate potential for redistribution of soil moisture. This increased permeability is likely caused by the presence of the fill material, which was composed with materials that created voids through which water can percolate.

Table A5. Soil hydrology in Dewey Park

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.22
	24	0.42
	48	0.49

Soil Chemistry

Surface pH values measured 7.9.

The asphaltic materials that are mixed in with the existing fill soil material may be leached by infiltrating water, thereby creating a possible contamination issue for water that may eventually percolate to recharge groundwater. Depending upon how the fill materials are treated in a design concept (replaced or managed in place with additional soil), the Dewey site may present favorable conditions for infiltration-type green infrastructure, though only if potentially toxic aspects of the extant soils are remediated (e.g., capped or replaced). However, the measured parameters could be taken as best estimates for infiltration and potential for drainage-redistribution rate and to trial designs within hydrologic models as “what-if” scenario analyses.

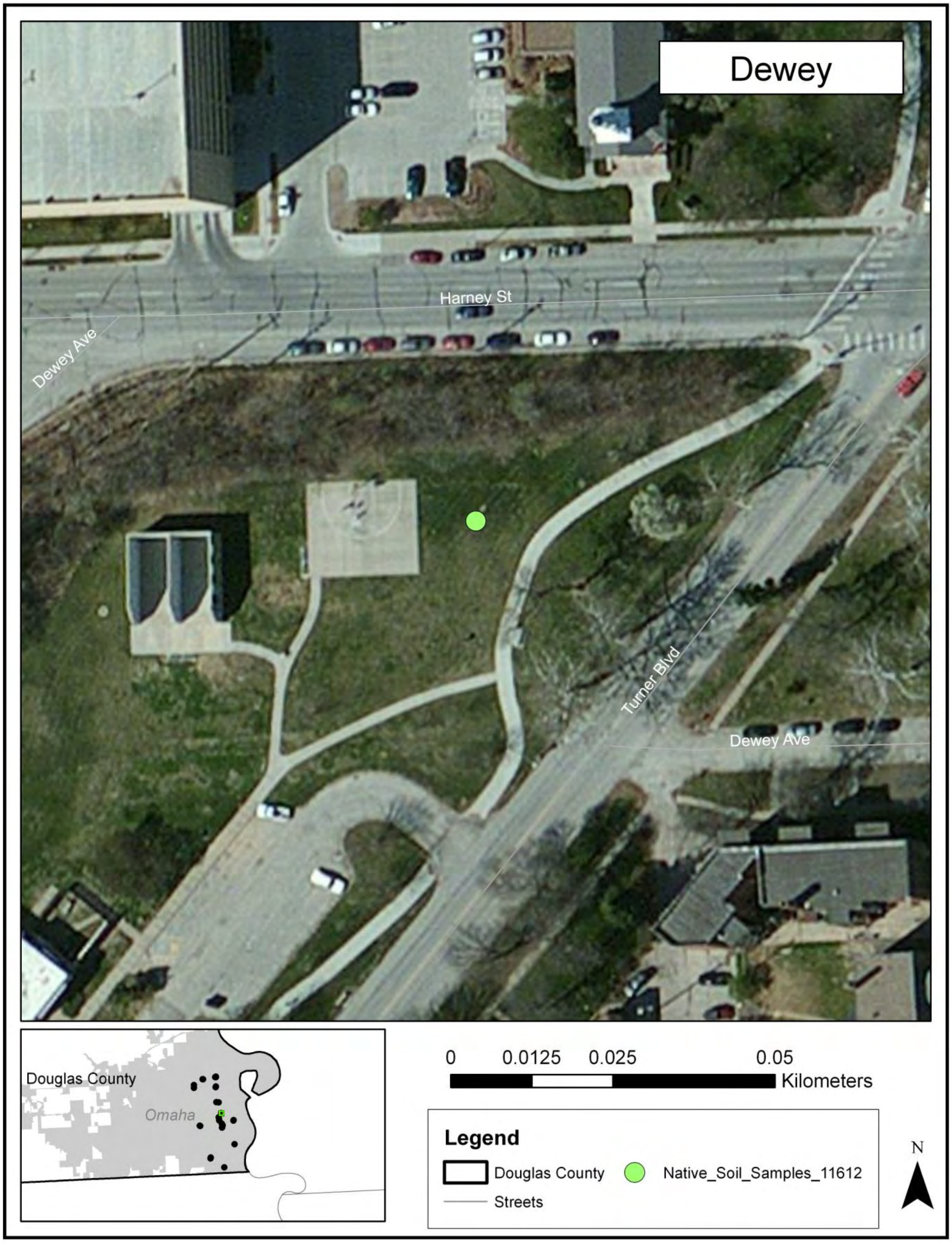

Figure A3. Satellite photograph of Dewey Park.

Fontenelle Park

Fontonelle Park is a 108-acre (43.7 ha) park in northern Omaha. It is located between Ames Avenue and Pratt Street, between 42nd and 48th Streets. It is bisected by Fontenelle Boulevard running north-south and Paxton Boulevard running east-west. The park is located within the Minne Lusa Sewershed portion of the Omaha combined sewer system.

History

Fontonelle Park was first purchased by the Parks Commission in 1893. In 1911, a large section of this park was graded, and out of this area, a 9-hole golf course was created; this is the oldest municipal golf course in Omaha. This park was also the location of one of the original baseball fields, established by the Omaha Parks Commission in 1913. There is a large pond (the "lagoon" in the local parlance) in the central portion of the park. The golf course was closed in 2012 and maintained with mowing. The site currently has a 5-acre lake that is utilized for stormwater detention. The closing of the golf course allows for the potential of additional detention storage if the lake were to be expanded.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Ida, Judson, Marshall, Monona, and Pohocco. All soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in fairways in the southern portion of the park, approximately in line with Ruggles Street.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

No evidence of fill material was observed at either test location.

Soil Wetness

There was evidence of saturated conditions deep in the soil profile (160 to 192 inches). However, the soils also exhibited carbonates, which only occur under long-term unsaturated conditions. For that reason, these redoximorphic features are considered relict and do not represent a persistent, regional water table condition.

Table A6. Soil wetness conditions in Fontenelle Park

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	56-192	----
2	76-144	----

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is extremely low as is the potential for redistribution of soil moisture.

Table A7. Soil hydrology in Fontenelle park

Test Location	Test Depth (in)	K (in/hr)

1	Surface	0.02
	47	0.03
2	Surface	0.05
	46	0.07

Soil Chemistry

The pH values are significantly lower than what is found elsewhere in Omaha and probably due to long-term irrigation (i.e., leaching of cations) and fertilization (i.e., sulfur, urea, or other acid-forming amendments) management. Based on these analyses (included in the Appendix), there are no chemical factors which would adversely impact any potential infiltration or redistribution altered by the addition of stormwater management features to this site. However, because this is a former golf course, it would be advisable to test for residual chemical pesticides in the soil.

The soils that underlay Fontenelle Park are limited by their extremely slow permeability at the surface and in the subsoil, but carefully-planned soil and vegetation management may help to correct this condition. The park's gently undulating landscape offers a great deal of flexibility in terms of creating infiltration opportunities through swales and other landscape routing features. Some degree of soil management (careful tillage, organic matter additions, cover cropping with deep-rooted plants, etc.) may improve on the compacted conditions that are likely driving the low observed permeability.

Figure A4. Satellite photograph of Fontenelle Park.

Gallagher Park

Gallagher Park is an 18-acre (7.3 ha) park in northwestern Omaha. It is located between Radial and Bedford Avenues, between 52nd and 54th Streets. The park is located in the southeast corner of the Cole Creek Sewershed portion of the Omaha combined sewer system.

History

Gallagher Park has one of the more unique histories within the Omaha parks system. It is located in the northwestern section of Omaha, which was originally the City of Benson (annexed by the City of Omaha in 1917). A park on the current Gallagher Park site was founded in 1895. In 1902, the site was purchased by the Krug Brewery and transformed into an amusement park until 1940. In 1955, the Omaha Parks Commission acquired the property and converted it into a municipal park.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Marshall, and Pohocco. All soils are considered well drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in this park, one in the northern portion of the park, near Bedford Avenue. The other test location was in the southern portion of the park, near Radial Avenue.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There was a stark contrast in amount and variety of fill materials at the two test locations. At test location #1, near Bedford Avenue, there was no fill material present. At test location #2, near Radial Avenue, there were 66 inches of fill material present. This fill material consisted of large amounts of crushed asphalt and concrete.

Soil Wetness

There was evidence of saturated conditions deep in the soil profile (160 to 192 inches). However, the soils also exhibited carbonates, which only occur during unsaturated conditions. For that reason, these redoximorphic features are considered relict and does not represent a pervasive water table condition.

Table A8. Soil wetness conditions in Gallagher Park

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	32-192	----
2	168-192	----

Soil Hydrology

The higher permeability value at test location #2 is due to the presence of construction debris at this location, and redistribution potential is likely enhanced in the area around location 2.

Table A9. Soil hydrology in Gallagher Park

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.15
	65	0.02
2	Surface	0.10
	47	2.12

Soil Chemistry

The soil chemistry measured at both the surface and subsurface soil horizons was consistent with native soils in and around Omaha.

The contrast between the two test locations is striking, and suggests that site 2 offers some degree of opportunity to infiltrate and redistribute runoff produced from nearby impervious surfaces in the park area. However, the fill material may present leaching risks for groundwater quality. Any planned infiltration-type GI should be considered in light of these risks prior to proceeding with design.

Figure A5. Satellite photograph of Gallagher Park.

Hanscom Park

Hanscom Park is a 64-acre (25.9 ha) park just west of downtown Omaha. It is located between Woolworth and Ed Creighton Avenues, between 32^{nd} Street and Park Avenue .
The park is located within the Leavenworth Sewershed portion of the Omaha combined sewer system.

History

Hanscom Park was one of the original parks designed by H.S.W. Cleveland, a national figure in the development of city parks. The land for the park was first donated to the City of Omaha in 1872; the park was fully designed by Cleveland in 1898.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Ida, Judson, Marshall, Monona, and Pohocco. All soils are considered well drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Four test locations were advanced in this park. Two of the test locations were in upslope areas near combined sewer inlets, just east of the existing pond. The other two test locations were along the low areas in the northern portion of the property, near the fenced dog park.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

At test location #2, there were 78 inches of fill material present. This fill material consisted of brick, gravel, and concrete. At test location #4, there were 16 inches of clean fill material present. No evidence of fill material was observed in the other two borings. Dynamic cone penetrometry to 15cm depth indicated that surface soil strength was highly variable across the landscape, requiring from 27 to 102 drops. Dry soil was the main factor affecting these measurements.

Soil Wetness

At test location #1, there were two perched conditions, at 4-14 and at 23-36 inches. These perched zones were likely caused by the composition of fill material and compaction activities involved in the filling processes that took place at this location. At test location #2, there was a perched condition at 36-78 inches. This perched zone was also likely caused by the composition of fill material, and the compaction activities involved in the filling processes that took place at this location. At test location #3, there was evidence of a seasonal high water table, starting at 48 and continuing to 192 inches. This boring is likely located in the area of the original stream channel. At test location #4, a perched condition was encountered at 64-112 inches.

Table A10. Soil wetness conditions in Hascom Park

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	4-14; 23-36	----
2	36-78	----
3	48-192	----

4	64-112	----

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is moderately to extremely slow, and redistribution is likewise highly restricted except for test location #3.

Table A11. Soil hydrology in Hascom Park

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.07
	48	0.05
2	Surface	0.10
	45	0.03
3	Surface	0.07
	65	0.13
4	Surface	0.16
	50	0.05

Soil Chemistry

The soil chemistry measured at both the surface and subsurface soil horizons was consistent with native soils in and around Omaha.

Marginal potential for both infiltration and subsoil drainage in combination with a variety of perched water table conditions lead to a hydrologic setting that is likely too complicated for efficient and effective infiltration-type green infrastructure. Yet, using these measurements in infiltration models may suggest tractable and attractive landscape features to at least decrease the extent and total volume of runoff produced from the smaller, more frequent storms. Proper management of surface soils may enhance infiltration capacity, though the effectiveness of this, too, may be limited by the pronounced slopes in this park area. The collection area near test boring #1 could be sealed with hillslope runoff alternately directed instead to the pond.

Figure A6. Satellite photograph of Hanscom Park.

Hitchcock Park

Hitchcock Park is a 38-acre (15.4 ha) park in southwestern Omaha. It is located north of Q Street, between 42nd and 45th Streets. The park is located within the Papillion Creek Sewershed portion of the Omaha combined sewer system.

History

The land for the park was first acquired in 1946, and the park was completed in 1956.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Marshall, and Pohocco. All soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in this park. These test locations are along 42nd Street, in line with O and P Streets.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

At test location #1, there were 24 inches of clean fill present. At test location #2, no fill material was observed.

Soil Wetness

At test location #2, there was a perched condition present from 68 to 96 inches. Between 106 and 108 inches at test locations #1 and #2, respectively, there were gleyed conditions. These gleyed conditions indicate long-term soil saturation and reflect an apparent or regional water table.

Table A12. Soil wetness conditions in Hitchcock Park.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	68-96; 106-192	----
2	108-192	----

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is moderately to extremely slow, and redistribution of soil moisture is likely extremely slow. The difference in subsoil permeability may be due to subsurface tillage and local loosening (or compaction) of soils from prairie dog (genus: *Cynomys*) activity, whose burrows were observed near our measurement sites.

Table 13. Soil hydrology in Hitchcock Park.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.04
	47	0.30
2	Surface	0.01
	48	0.03

Soil Chemistry

The soil chemistry measured at both the surface and subsurface soil horizons was consistent with native soils in and around Omaha.

The hydrologic conditions in this park are not favorable for infiltration-type green infrastructure. The subsoil hydraulic conductivity can be used as the constraint on a prospective modeling effort. For conceiving a design for infiltration-type green infrastructure, a model such as RECARGA (Wisconsin DNR) or SWMM 5 can be used to determine the proper land area needed to absorb a given amount of runoff.

Figure A7. Satellite photograph of Hitchcock Park.

Leavenworth Park

Leavenworth Park is a 4.5-acre (1.8 ha) park just west of downtown Omaha. It is located between both Turner Boulevard and 35 Street, between Leavenworth and Mason Streets. The park is located within the Burt-Izard Sewershed portion of the Omaha combined sewer system.

History

Leavenworth Park was established in 1935.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Urban Land-Pohocco map unit. These soils are considered well drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

One test location was advanced in the northern portion of the park near the combined sewer inlet near Leavenworth Street.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There were 42 inches of fill material at this test location. The fill material was mostly clean but also contained 10% fragments of concrete.

Soil Wetness

No evidence of soil wetness was encountered at this location.

Soil Hydrology

These soils would be considered to have moderately slow permeability and a similar tendency for redistribution of soil moisture.

Table A14. Soil hydrology in Leavenworth Park.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.19
	30	0.17
	48	0.21

Soil Chemistry

No apparent limitation.

This park is set on slopes which lead to sharper slopes forming a wide, flattened bowl area. The site could then serve multiple purposes, for example, a stormwater infiltration area during storm flow and for 36 hours thereafter; then also as a sport field when drawdown is complete. As in other cases, the use of the subsoil hydraulic conductivity as a model constraint should be used to run a series of prognostic simulation for different-sized storms and antecedent conditions. These models would serve to illustrate the size of the area required to fully infiltrate the estimated runoff volume that would enter into this park area.

Figure A8. Satellite photograph of Leavenworth Park.

Paxton Boulevard

A 3-acre (1.2 ha) site along Paxton Boulevard was investigated in northern Omaha. It is located between Sahler and Sprague Streets, between 32nd and 34th Streets. The property is bisected by Paxton Boulevard and located within the Minne Lusa Sewershed portion of the Omaha combined sewer system.

History

There are several city-owned properties along Paxton Boulevard. It is known that this area was once a broad stream valley, which at the time of suburban developed was eventually conveyed into a culvert, filled, and the road constructed.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Judson and Pohocco. All soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Three test locations were advanced in this park. Two test locations are south of Paxton Boulevard; the third test location is near the intersection of Paxton Boulevard and 34th Street.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

At test location #3, 18 inches of mostly clean fill material were observed. No other fill materials were observed at the other test locations. Cone penetrometry to 15cm depth indicated that 47-86 drops were required to penetrate the surface soil layer.

Soil Wetness

There were numerous perched conditions at all three test locations. This was due to the heavy textured clay soils that were present. There were gleyed conditions, starting at 52 to 78 inches at all three test locations. These gleyed conditions indicate long-term soil saturation and reflect an apparent or regional water table.

Table A15. Soil wetness conditions in Paxton Boulevard.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	72-192	----
2	28-52; 58-176	----
3	26-52; 78-96; 128-192	

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is extremely slow, and likewise the potential for redistribution is also low.

Table A16. Soil hydrology in Paxton Boulevard.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.11
	48	0.13
2	Surface	0.09
	68	0.02
3	Surface	0.07

	46	0.13

Soil Chemistry

No apparent limitation. Surface pH values ranged from 7.7 to 7.8 at all three test locations.

Given the evidence of soil profile saturation and overall low K at the surface and at depth, if infiltration-type green infrastructure were to be attempted, it would have be done with great care and consideration of the hydrologic limitations presented by the extant soils. In this setting, residential and institutional stormwater control measure retrofits may be more effective (as per Shepherd Creek, Thurston et al. 2008) to keep runoff out of the combined systems at the neighborhood level. However, intensive management of soils and using these measurements to set fair expectations for the effectiveness of rain gardens and swales would be important in any type of management approach. A small wetland may also be an effective way to employ the hydrologic implications of gleyed subsoils to better effect.

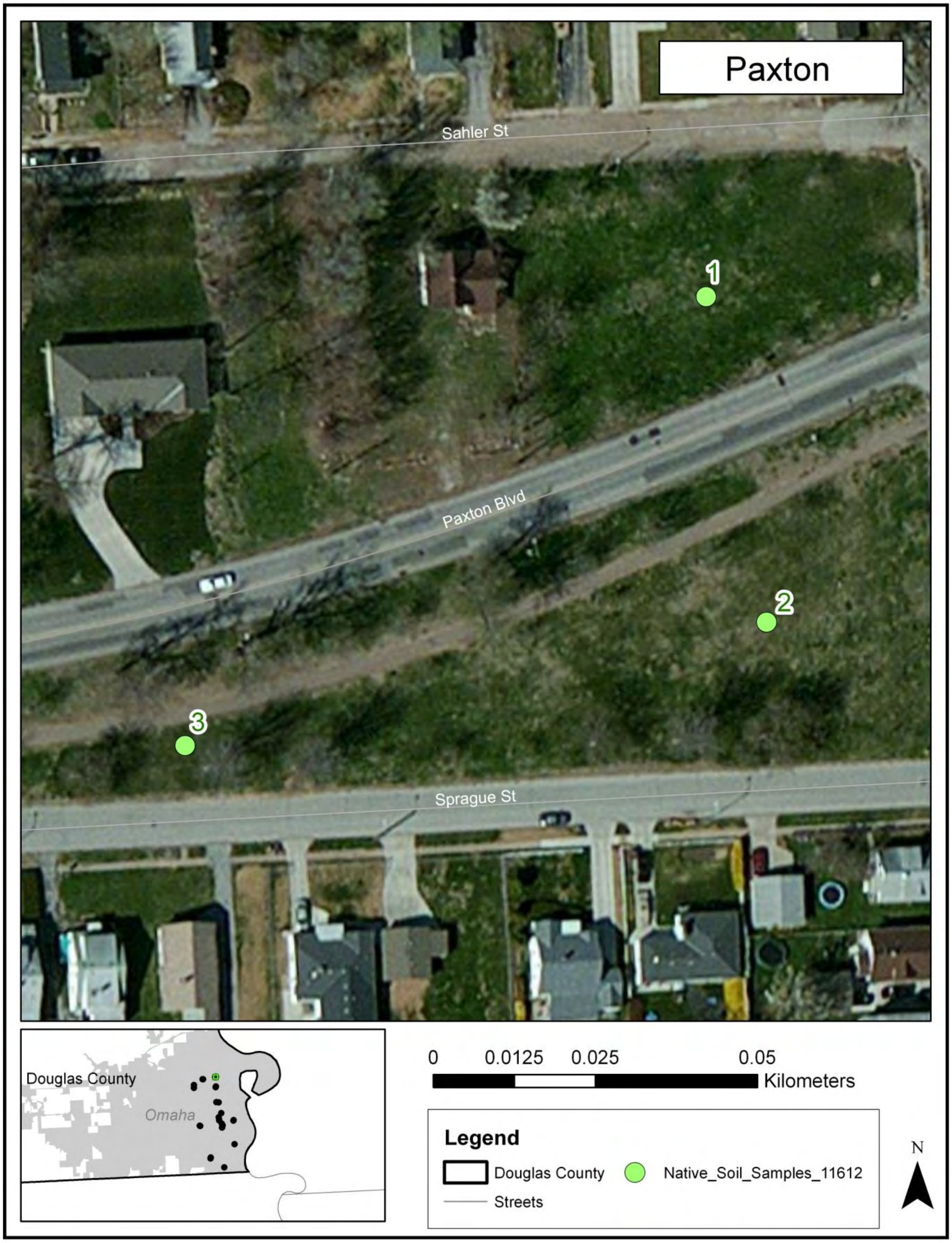

Figure A9. Satellite photograph of Paxton Park.

20th and Pierce Retention Basin

This parcel was recently reclaimed after demolition of an older commercial building and now has recently constructed underground soil storage basin. It is located at the southeastern corner of 20th and Pierce Streets. This site is located within the Leavenworth portion of the Omaha combined sewer system.

History

This is an engineered stormwater detention facility that was constructed in 2012 and consists of a buried corrugated pipe gallery to store water, bedded in gravel and rock.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Urban Land-Pohocco. These soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in this park. One test location is along Pierce Street near the train tracks, and the other test location is along 20th Street.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

This is a filled area for an engineered stone and pipe basin, and the fill materials encountered during this investigation included a significant amount of artifacts and debris, including: gravel, brick, concrete, and bituminous materials. This fill material is construction debris and is not considered a suitable backfill for an engineered detention basin (or for any other public land use).

Soil Wetness

No evidence of soil wetness was encountered at either test location.

Soil Hydrology

These permeability rates are highly contrasted between the two sites, which is attributed to the relative amount of coarse construction debris present in each of the soils. The debris effectively creates large void spaces, and therefore permits high permeability and potential for redistribution. The City will utilize the data that has been gathered to potentially adjust the rate of infiltration from the existing open-bottom storage basin.

Table A17. Soil hydrology in the 20th and Pierce Retention Basin.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.39
	28	0.19
	45	12.52
2	Surface	0.31
	22	0.13
	35	0.86

Soil Chemistry

Surface pH values measured 8.1 and 8.2 at test locations #1 and #2, respectively. Additionally, there are elevated levels of copper and sulfur in these soils, which is consistent with the fill materials observed. It would be advised that further environmental soil testing be conducted at this test location.

This location is the site of a recently constructed underground stormwater retention and recharge facility. The facility consisted of large-diameter, perforated pipe surrounded by quarried stone and covered with geotextile fabric. In this study, two borings were advanced on the outside of this underground facility. At this site, there was no established grass (just straw cover), and the soil surface was extremely compacted. In the soil borings, there was construction debris present to a depth of 16 feet at this location. The construction debris was present throughout the soil profile and consisted of brick, gravel, concrete, and bituminous (e.g. asphalt) materials. Infiltration of water into this subsoil presents risk for potential leaching of toxic materials. This risk should be fully understood and scoped prior to further planning for infiltration-type green infrastructure.

In looking at the potential for green infrastructure at this particular site, the entire area should be considered part of the project. The stone and pipe are designed to accommodate specific stormwater runoff volumes that are conveyed directly to this facility. The surface soils overlying this underground facility consist of a mix of construction debris and compacted fill with poor vegetative cover. These soils have limited ability to infiltrate stormwater runoff volume. Without surface soil improvements, these soils would not be expected to infiltrate water, and it is unlikely that there would be water entering the subsurface.

A well-established vegetative cover with appropriate landscaping would foster opportunities to abstract, capture and otherwise provide more infiltration opportunities for excess stormwater volume. By having unsuitable surface soils and, therefore, an unsuitable environment for the establishment of lawn and landscape areas, there is little chance that this location will be productively utilized as GI. This site is already used as an engineered subsurface stormwater detention area; however, an improvement in surface conditions will add to this parcel's value as a community amenity. The topsoil is not suitable for establishing a vegetative cover. Very light, shallow tillage with a mechanical rotary tiller would be needed to incorporate compost, at which point the area should be seeded and maintained with irrigation so as to promote full establishment and cover in this highly visible area. For water that would infiltrate, drainage is not so much of an issue here, though attention should be paid to how much water can be routed to each subarea so as not to overwhelm infiltration and redistribution capacities.

For future projects, care must be taken in the inspection of each phase of these projects. While municipal budgets are often stretched and there is little time for inspection, there must be an emphasis made to the contractor: that all construction debris must be removed from a demolished site, that GI practices be implemented as per plans and available site data, and that appropriate operation and maintenance be conducted on any SCM that is relied upon for sustained SW abatement and CSO management. Additionally, the soils must be properly placed in lifts to minimize over-compaction and give the soil a good start on the development of soil structure, and to provide an overall optimal environment for the establishment of lawn and landscape areas.

Figure A10. Satellite photograph of 20th and Pierce Retention Basin.

50th and Pine Firehouse

This is a location of a former firehouse located on a ½ -acre (0.2 ha) parcel that is located in southwestern Omaha at the southwestern corner of the intersection at 50th and Pine Streets. The firehouse is located within the Saddle Creek Sewershed portion of the Omaha combined sewer system.

History

The brick firehouse was constructed in 1939. Although no longer an active firehouse, this facility is still utilized by the fire department for administrative purposes.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Urban Land-Pohocco. These soils are considered well drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two test locations were advanced in this park. These two test locations are along the southern property line: one location near 50th Street and the other location along the western property line.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

At test location #1, near 50th Street, there were 22 inches of mostly clean fill material present. At test location #2, no fill materials were encountered.

Soil Wetness

At test location #1, there were two perched conditions, at 48-90 and at 96-132 inches. At test location #2, there was one perched condition, from 16-132 inches. These are the result of poor internal drainage and do not represent a water-table condition.

Table A18. Soil wetness conditions at the 50th and Pine Firehouse.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	48-90; 96-132	----
2	16-132	----

Soil Hydrology

The infiltration rate is higher at test location #2, and we speculate that this is because it is located in the back yard, away from both 50th Street and the driveway and was subject to substantially less compaction from vehicle traffic. Based on these measurements, subsoil permeability in these locations is slow to very slow, and, therefore, the potential for redistribution is likewise limited.

Table A19. Soil hydrology at the 50th and Pine Firehouse.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.03
	49	0.02
2	Surface	0.24
	50	0.19

Soil Chemistry

No apparent limitations. Surface pH values measured 6.8 and 7.0 at test locations #1 and #2, respectively.

This site has higher density of development compared to other sites sampled in this July 2012 study. Poor internal drainage and low potential for redistribution may suggest that an engineered approach to detaining stormwater runoff would be more prudent. Some examples are pervious pavement with an engineered subsurface volume filled with sand and gravel layers with an overflow relief, or rain barrels, small cistern to capture roof runoff for possible re-use to flush toilets or other suitable uses for non-potable water. This location is currently under bid for improvements as a porous pavement parking lot. Putting more runoff volume into this area may also create water-in-basement issues for adjacent parcels.

Figure A11. Satellite photograph of 50^{th} and Pine Firehouse.

Spring Lake Park

Spring Lake Park is an approximately 90-acre (36.4 ha) park in southern Omaha. It is located west of Spring Lake Parkway between B and J Streets. The park is located within the South Interceptor Sewershed portion of the Omaha combined sewer system.

History

The park was established in the early 1900's. Historically, there were several springs and man-made lakes in this park; they have since been filled in.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil series: Contrary, Marshall, and Pohocco. All soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Five test locations were advanced in this park. Four test locations were along a topographic transect in line with 16th Street. Another test location was located in an open field area off of a secluded driveway on H Street. These test locations are thought to be in areas of former springs. No soil physical or chemical tests were conducted at this test location.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There were significant amounts of fill material present in the area of test locations #1 through #4. These materials included concrete, brick, upholstery, wood, glass, and bituminous materials. Due to the amount of fill material present, refusal ranged from 42 to 84 inches. This location is likely the site of a former construction/trash dump. In the upslope decommissioned baseball field, 24” of clean fill material were encountered.

Soil Wetness

While there were some redoximorphic features encountered in the fill area of borings #1 through #4, there was no evidence of a seasonal high water table at this location. At the secluded ball field, there was evidence of soil wetness encountered between 56 and 192 inches. While no seepage was observed, gleyed soil conditions were present. These soils are saturated during significant portions of the year and would likely seep.

Table A20. Soil wetness conditions in Spring lake Park.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
Isolated Field off H Street	56-192	----

Soil Hydrology

Soils had a generally low K_{unsat}. A borehole test was attempted at the secluded field site only. The test at the site was not possible due to a relatively high water table. Overall, the potential for redistribution at these sites is likely low at the secluded field site due to a shallow water table that persisted well into a drought. Alternately, the buried, mixed refuse and debris in the park area may allow for higher permeability and redistribution but with unknown implications for leachate water quality.

Overall, the park areas have little potential for improvement in stormwater management. This area was used as a refuse dump for some time, and as indicated above, these conditions present potentially problematic tradeoffs with regard to local water quality. Further evaluation of the site is needed, and is outside of the scope of this study. As for the Spring Lake Field, the influences of poor internal drainage, low potential for redistribution, and a shallow water table suggest that an engineered approach to detaining stormwater runoff would be more prudent.

Figure A12. Satellite photograph of Spring Lake Park.

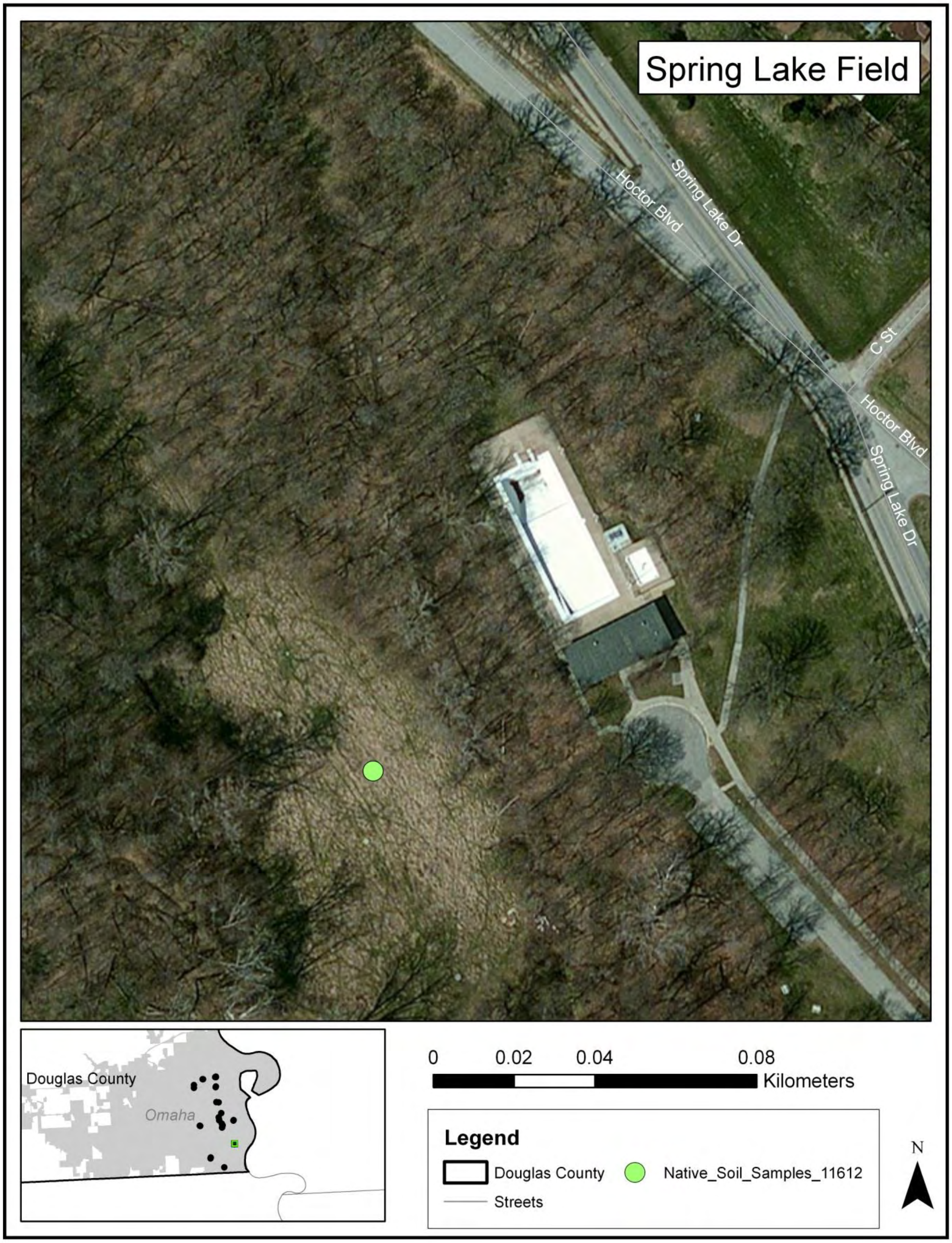

Figure A13. Satellite photograph off Spring Lake Field.

Turner Park

Turner Park is an approximately 6.5-acre (2.6 ha) park just west of downtown Omaha. It is located where Turner Boulevard originates from both Pacific Street and Poppleton Avenue. The park is located within the Burt-Izard Sewershed portion of the Omaha combined sewer system.

History

Turner Park was established in 1900. The land was donated as a memorial for a family that lost its son during the Spanish-American War.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil map unit: Urban Land-Pohocco. These soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two locations were advanced in this park. One test location was in line with Pacific Street; the other test location was in the northern portion of the park, near the combined sewer inlet.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There was a stark contrast in amount and variety of fill materials at the two test locations. At test location #1, no fill materials were encountered. At test location #2, there were 34 inches of fill material present; this fill material consisted primarily of glass and cinders.

Soil Wetness

At test location #1, there was no evidence of any type of water table to a depth of 16 feet below existing grade. At test location #2, there was evidence of both redoximorphic features and seepage between the depths of 102 and 192 inches; these likely represent the depth to an apparent or regional water table at the time of sampling in July 2012.

Table A21. Soil wetness conditions in Turner Park.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	----	----
2	102-192	102-192

Soil Hydrology

Based on these measurements, subsoil permeability in these locations is moderate to moderately slow and exhibits similar potential for redistribution of soil moisture.

Table A22. Soil hydrology in Turner Park.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.04
	31	0.25
	48	0.34
2	Surface	0.02
	18	0.39
	47	0.09

Soil Chemistry

Surface pH values measured 6.7 and 7.2 at test locations #1 and #2, respectively.

The soils at this site exhibit some elevated potential for small installations of infiltration-type GI. Due to the narrow sloped drainage area, these opportunities may be limited to swales along sidewalk areas that would at least collect and infiltrate sheet flow from the upslope residences and the small amounts of runoff volumes expected to be generated by the sidewalk areas.

Figure A14. Satellite photograph of Turner Park.

Upland Park

Upland Park is an approximately 14-acre (5.7 ha) park in southern Omaha. It is located between Upland Parkway and Jefferson Street, between 30^{th} and 32^{nd} Streets. The park is located within the Ohern-Monroe Sewershed portion of the Omaha combined sewer system.

History

Upland Park was first established in 1913.

Native Soils

According to the USDA-NRCS Web Soil Survey, the soils in the park include the following soil map units: Urban Land-Pohocco and Urban Land-Marshall. These soils are considered well-drained with a depth to a seasonal high water table at greater than 80 inches.

Investigation

Two locations were advanced in this park. Both locations are in the soccer field in the northeastern corner of the park, near the combined sewer inlet.

RESULTS

The results of the soil investigation are listed below.

Fill Materials

There was no noticeable evidence of fill materials present at this location. No artifacts were encountered during this investigation. It is logical to assume that some filling/land moving may have occurred to level the property. The soil texture at test location #1 was clay, which is generally a soil texture found in the subsoil, so it is possible that some materials have been transported at this location.

Soil Wetness

At test location #1, there was a perched condition from 13 to 96 inches. At test location #2, there was a perched condition at 16 to 96 inches. These perched zones may have been caused by compaction but more likely are the result of extremely slow permeability in the soils. At both test locations, saturated conditions within the boring (free water) were encountered (96-168 inches at test location #1 and 96-180 inches at test location #2); these represent the depth to an apparent or regional water table at the time of sampling in July 2012.

Table A23. Soil wetness conditions in Upland Park.

Test Location	Depth to Redoximorphic Features (in)	Depth to Seepage (in)
1	13-96	96-168
2	16-96	96-180

Soil Hydrology

Subsoil permeability in these locations is consistently very slow.

Table A24. Soil hydrology in Upland Park.

Test Location	Test Depth (in)	K (in/hr)
1	Surface	0.04
	69	0.13
2	Surface	0.02

	48	0.14

Soil Chemistry

No apparent limitation. Surface pH values measured 6.8 and 7.3 at test locations #1 and #2, respectively.

There is a stormwater inlet toward the center of the west edge of the site. For this area, it is possible that soil and vegetation management may improve drainage characteristics. The site could then serve multiple purposes, for example, as a stormwater infiltration area during storm flow and for 36 hours thereafter and then also as a sport field when drawdown is complete.

Figure A15. Satellite photograph of Upland Park.

Appendix B. Soil Chemical Characteristics.

This appendix provides maps of our study sites and their defining soil characteristics.

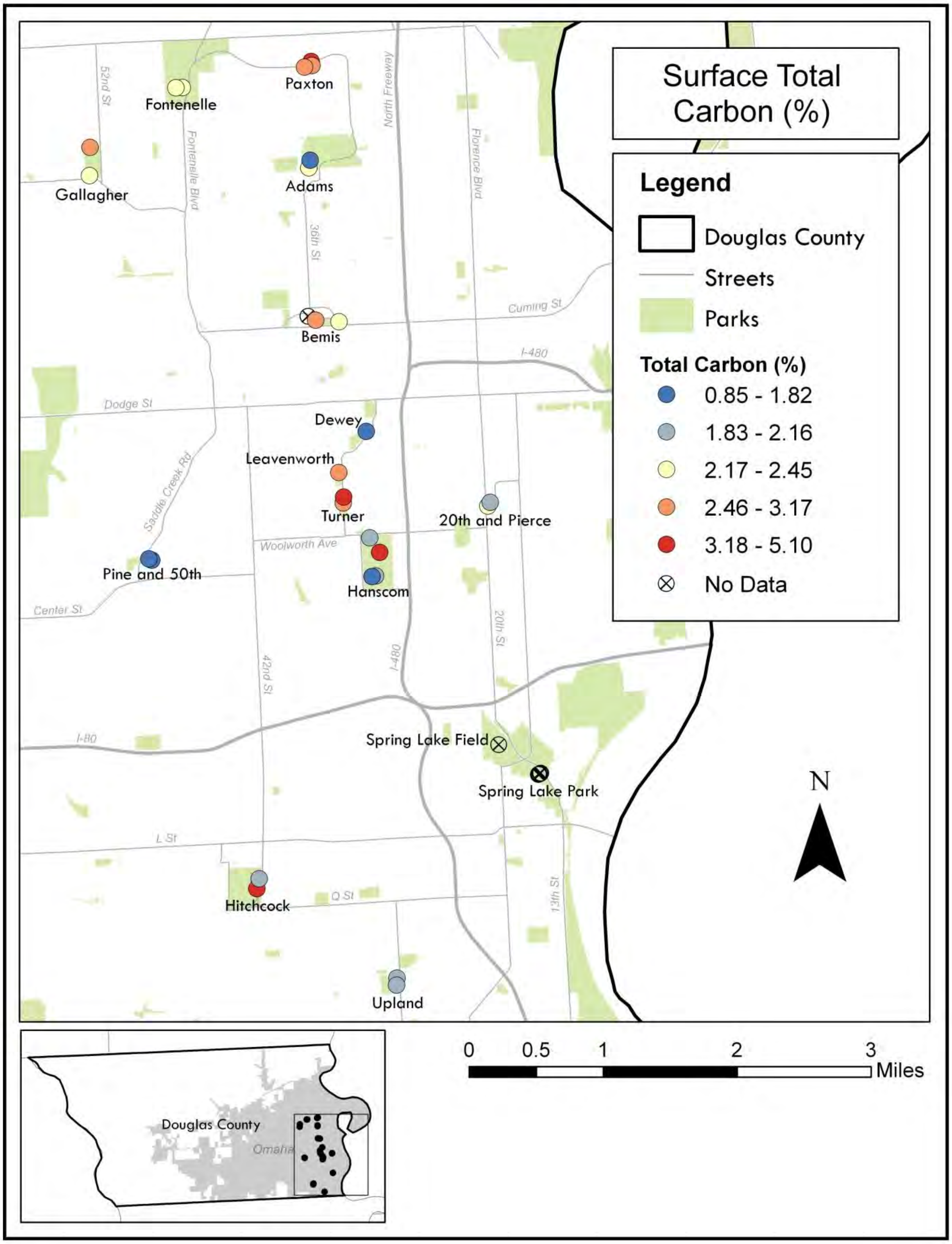

Figure B1. Total soil carbon on a mass percentage basis for surface soils.

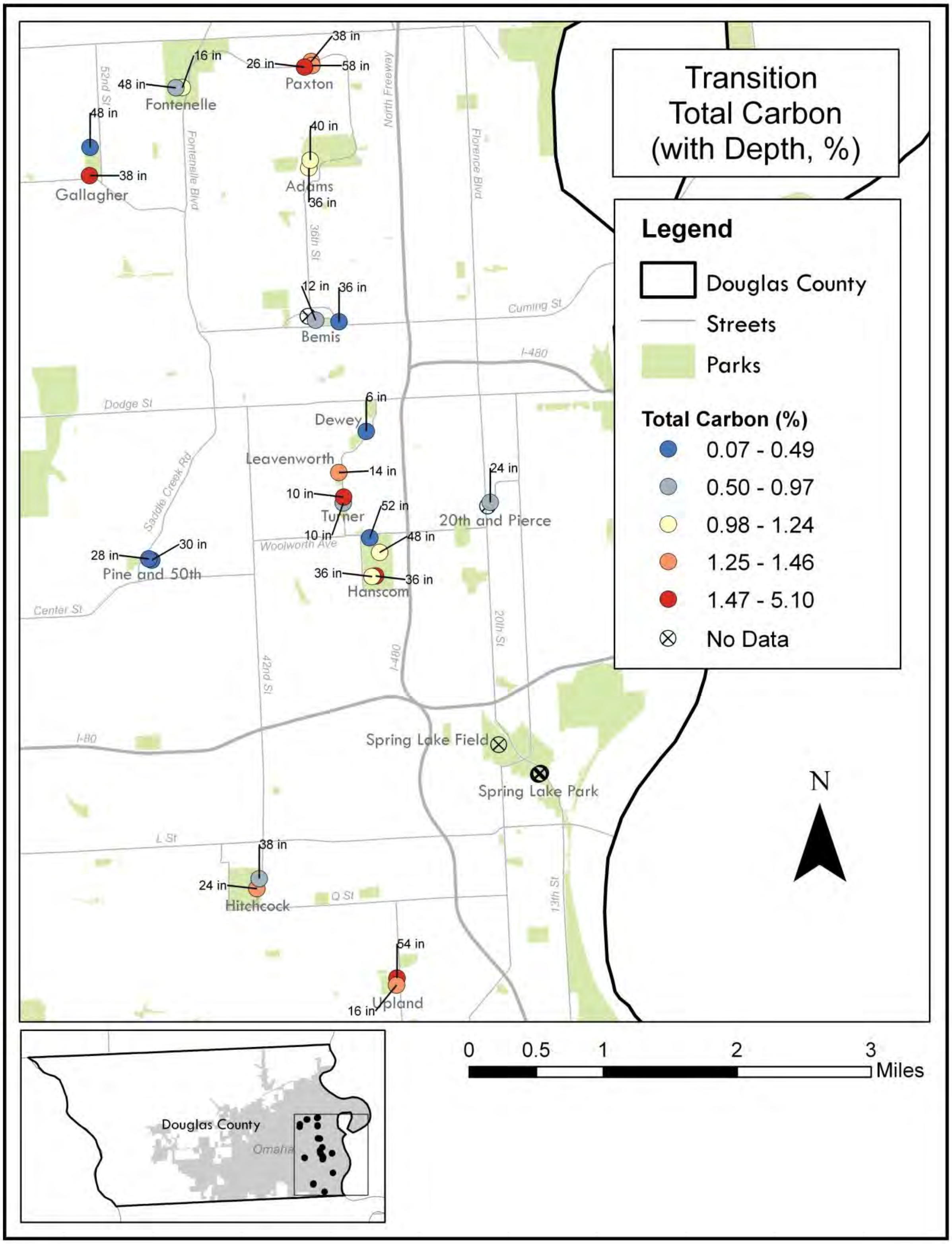

Figure B2. Total soil carbon on a mass percentage basis for subsurface soils.

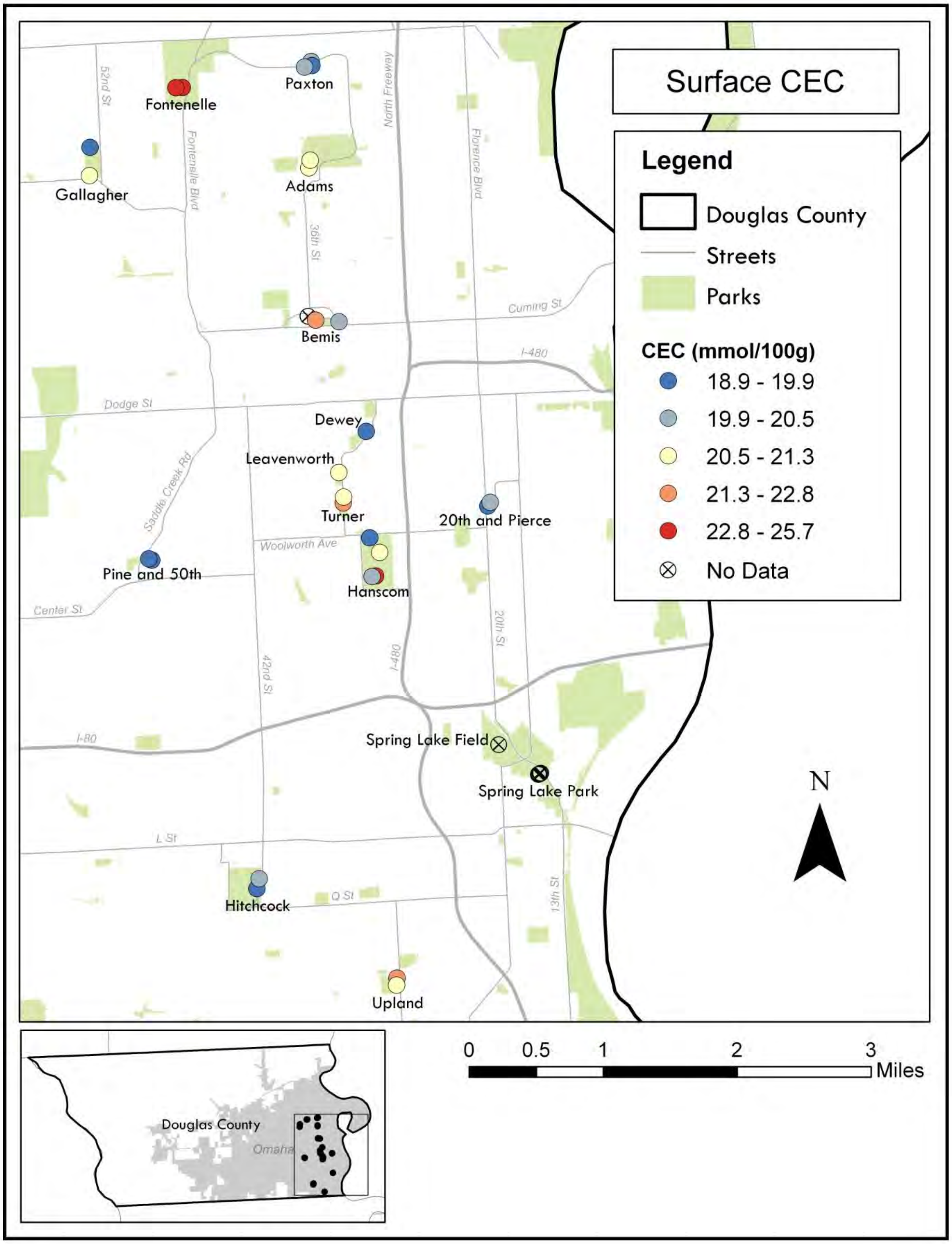

Figure B3. Cation exchange capacity for surface soils.

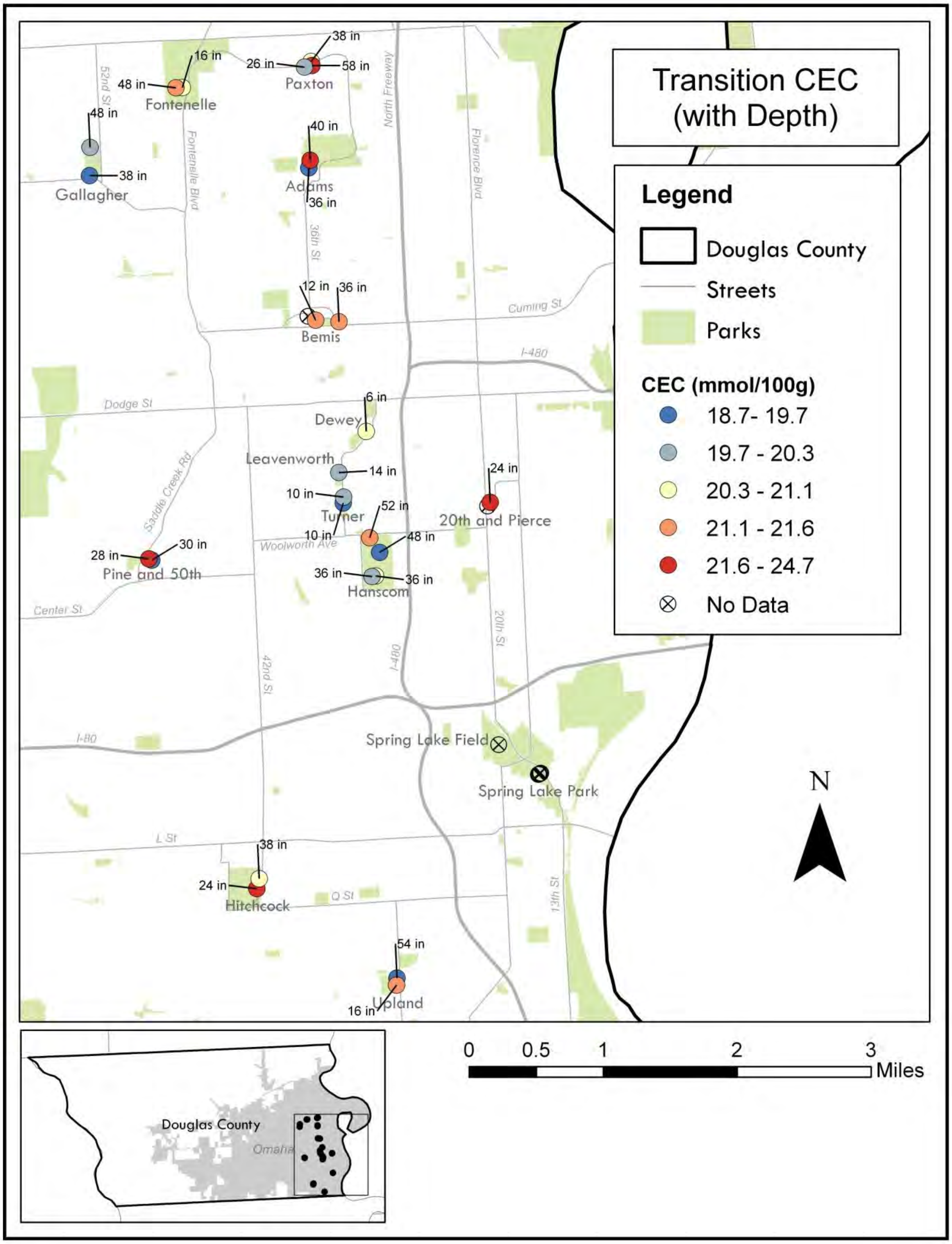

Figure B4. Cation exchange capacity for sub-surface soils.

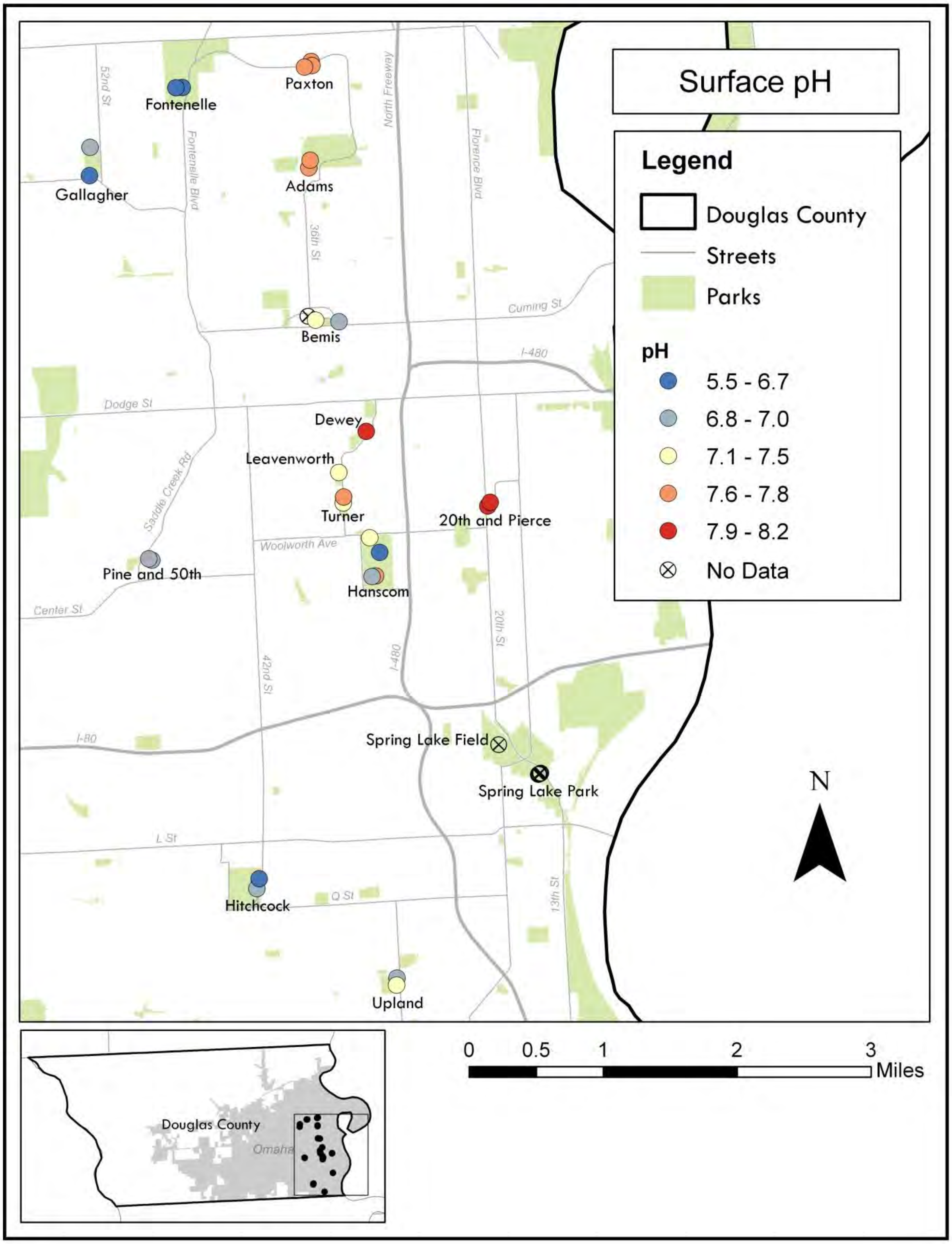

Figure B5. Soil pH for surface soils.

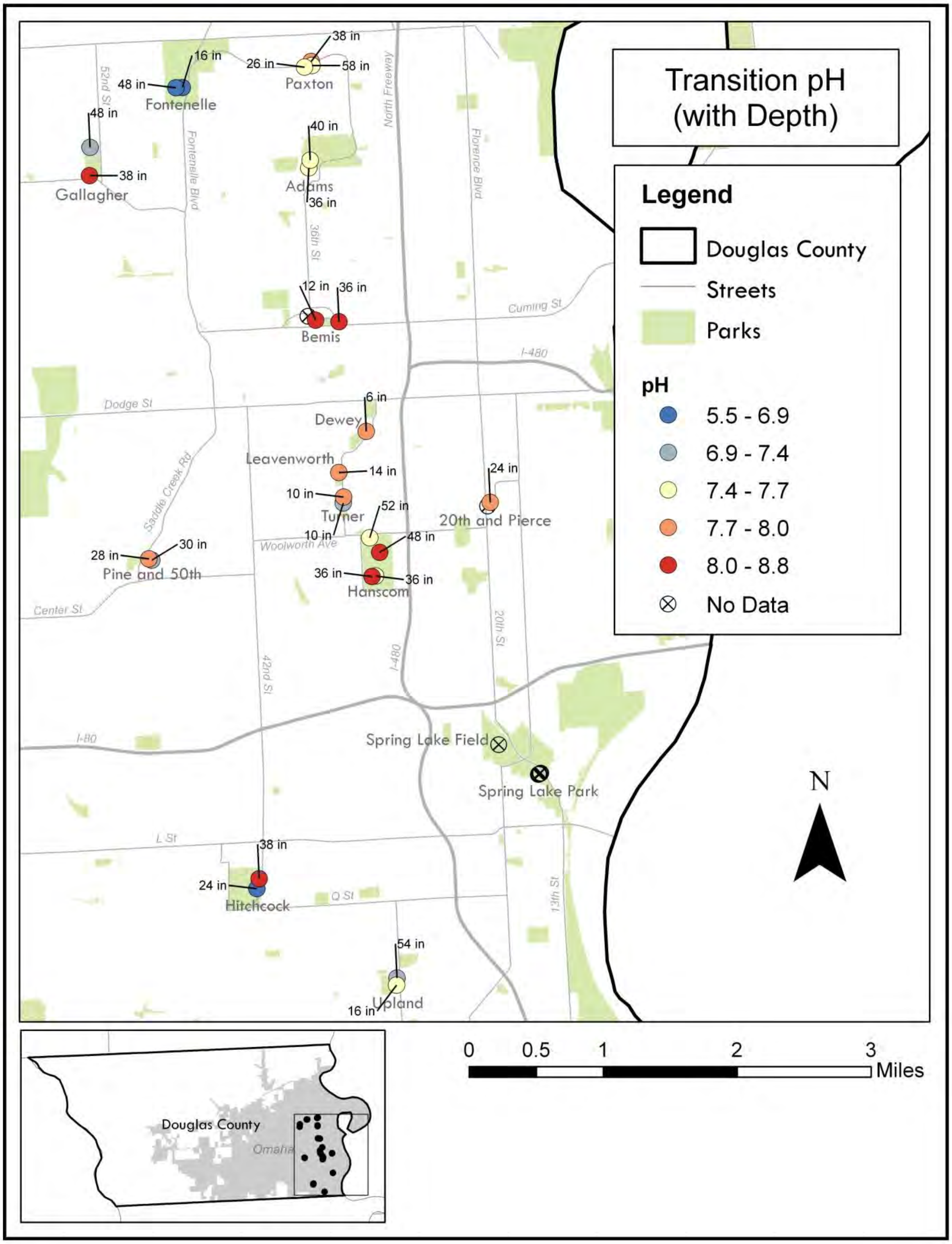

Figure B6. Soil pH for sub-surface soils.