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Volunteered Geographical Information: an Alternative Solution for Overcoming the Chasm Between Stormwater Management and Community Participation

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VOLUNTEERED GEOGRAPHICAL INFORMATION: AN ALTERNATIVE SOLUTION FOR OVERCOMING THE CHASM BETWEEN STORMWATER MANAGEMENT AND COMMUNITY PARTICIPATION

by

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VOLUNTEERED GEOGRAPHICAL INFORMATION: AN ALTERNATIVE SOLUTION FOR OVERCOMING THE CHASM BETWEEN STORMWATER MANAGEMENT AND COMMUNITY PARTICIPATION

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It is a dramatic challenge to promote public engagement in stormwater management and green infrastructure initiatives. When traditional outreach approaches made important influence on public engagement, their limitations are also obvious. With the development of Web 2.0 technology, Volunteered Geographic Information (VGI) has been emerging as one of the most important user-generated geographic contents. The crowdsourcing data that generated by volunteers through geo-web, smartphones, and other geo-devices provides invaluable mass data for decision-making. VGI can provide a better understanding of planning issues and other challenges. The research aims to develop a mobile information platform to allow citizens to report the information of the green infrastructure sites and activities through their mobile devices. This study shares the experiences and lessons of the "U.S. Green Infrastructure Reporter" in national grassroots engagement of stormwater management and green infrastructure initiatives. "U.S. Green Infrastructure reports" in this study has collected over 6,800 reports of 11 types of Green Infrastructure across the U.S. The findings can help investigate both the potential of VGI in urban water management and its challenges regarding to data

reliability and quality. We conclude with recommendations for future development of the advancing technology of VGI in enhancing water resources planning capabilities and future research directions.

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CHAPTER 1 INTRODUCTION

1.1 Volunteered Geographical Information

1.1.1 the origin of VGI

Volunteered Geographic Information (VGI) is a special case of the more general Web phenomenon of user–generated content, and it was first termed by Michael F. Goodchild in 2007 (Goodchild 2007). Volunteered behavior, whether performed by an individual or an anonymous group, has existed in human history for a long time, and played a significant role when human first sought to overpower nature. Although it remains unclear why people volunteer themselves (Denise 2012), the concept of VGI has been applied to many research fields and business areas, and generated countless positive effects in society. For example: In 1854, Dr John Snow, a volunteered doctor, discovered the factor that cholera caused massive deaths in London, when he showed that a central water source was responsible for the outbreak of cholera on his map (Johnson 2006) (Figure 1). However, because there were no modern technologies available at that time, it may take a long time to spread John's idea among the public. With modern technologies, it is possible for an individual to distribute his/her wisdom or idea over the world quickly, such as the success of Facebook, Wikipedia, Twitter, and Flickr. Overall, there have been many successful volunteered information cases ranging from the 19th century to the Internet era. We note that the spatial property enabled by today's Web 2.0 technology can be regarded as a special enhancement for volunteered information, which is under the umbrella of VGI.

1.1.2 the importance of VGI

Emergency management cannot live without geographical data and tools (Goodchild and Glennon 2010). Stormwater management, an urban planning sub-category, and also an important flood mitigation measure, also relies on certain traditional authoritative information from agencies or corporations; such as Federal Emergency Management Agency (FEMA) and U.S. Fish & Wildlife Service (USFWS). However, governments are no longer willing to pay the increasing mapping costs, and often seeking source of income from map users now (Goodchild 2007). In reality, mapping actually has been in decline for several decades (Estes and Mooneyhan 1994). Clear evidence is displayed sluggish through updating process of FIRM data (FIRM, a product of FEMA, Floodplain Insurance Rate Map), and until now there is still no FIRM data available in many areas across the country. Besides, the US Geological Survey no longer attempts to update its maps on a regular basis (Goodchild 2007). Although mapping was replaced by remote sensing for many purposes, satellites are unable to sense many of the phenomena traditionally represented on maps, including labeling of features (Goodchild 2007). While compared to the costs of mapping and the disadvantage of remote sensing, VGI can compensate for both weaknesses (Table 1). Spatial information that is generated by VGI users not only reduces the costs of mapping, but also creates and updates the contents by itself. The most successful example for applying these previous ideas is OpenStreetMap, whose contents are generally created by the volunteers. VGI is an important alternative data source for stormwater management, and the application of VGI will be a great aid to the emergency management.

Table 1 Comparison of mapping, remote sensing, and VGI

	Mapping	Remote Sensing	VGI
Cost	expensive	expensive	less expensive
Time	consuming	consuming	less consuming
Limitation	geographically limited	geographically limited	less spatial limitation and more flexible
Accessible to public	less	less	accessible
Function	fundamental database	fundamental database	alternative database

1.1.3 VGI and crowdsourcing

Crowdsourcing is the practice of gaining needed services, concepts, or content by soliciting contributions from an Internet community, rather than from common employees or suppliers (Crowdsourcing 2014). VGI methods are a type of crowdsourcing, and the discussion between VGI and crowdsourcing cannot be divided. The practice of VGI will most likely improve the theory and methodology of crowdsourcing. This theory could also be a guide for using VGI methods. In addition, the crowdsourcing data generated by VGI users can provide invaluable results for decision-making.

1.2 Environmental monitoring and management

1.2.1 the meanings of environmental monitoring and management

Monitoring plays a very important role in the environmental management process. With the exception of the warning phase, monitoring accompanies all phases of the disaster management cycle (Poser 2010), providing essential information for the rescue response and substantial phases, such as mitigation planning. Environmental monitoring and management cannot be divided because of their interdependency. Environmental monitoring provides necessary information to decision makers of each phase during the environmental management process, enabling incremental optimization of the management process. Conversely, the feedback from each phase during environmental management process requires more accurate information and faster data collection, which require new technologies to be adopted and tested. In general, VGI, a new technology in environmental monitoring that can compensate the weaknesses of mapping and remote sensing, will play a significant role during environmental management in the future.

1.2.2 Methods in environmental monitoring and management

There are two methods for environmental monitoring and management (Table 2). One is the top-down/bottom-up method, and the other is the VGI method. The top-down/bottom-up method has been widely used, and most agencies or corporations are familiar with it. Many datasets and educational tools are developed for the top-down/bottom-up method, and it is a dominant method for addressing environmental issues. While the VGI method is relatively new, many methodologies and technical issues are still unclear and remain undeveloped, but the VGI method has already shown great potential as an additional way for environmental monitoring and management since 2007.

Table 2 Pros and cons of traditional method and VGI method

	Top-down/Bottom-up method	VGI method
Technology methods	mapping and remote sensing	e-government, interactive GIS, mobile apps and other crowdsourcing tools
Importance	dominant	subordinate
Practices	widely used and long history	methodologies and technical issues stay unclear or remain undeveloped
Potential	already reached its limitation	great potential and opportunity in the future
Users	familiar by most of agencies and corporations	a few group or people have heard
Support	supported by many dataset and tools	less support

1.3 Current gaps and weaknesses of environmental monitoring and management

1.3.1 Gaps and weaknesses in the early stage of Internet

The top-down/bottom-up is the dominant method for environmental monitoring and management, and it uses authoritative databases from agencies or corporations. Due to the costs and other limitations of mapping, agencies or corporations are no longer willing to maintain those databases or update the data. An alternative way of using VGI was brought into environmental monitoring and management, allowing users, whether citizens or scientists, to create new databases or maintain and update existing databases. However, existing databases are typically not user-friendly and hard for inexperienced users to access. First, the user interface of existing databases are outdated because most database websites were built in the early stage of the Internet; and their web-interfaces are not capable for advanced devices, such as smart phones or tablets. Second, some existing databases are massive, if users want to access the data, they must follow the instructions on the websites, download the data, and then open it with professional tools. In addition, although the US Environmental Protection Agency (USEPA) has developed many web and mobile applications for promoting environmental awareness among the public in recent years, the USEPA's application categories lack green infrastructure (Table 3). Someone may argue that some of the USEPA My Green Apps cover several different topics, such as water issues and air issues, but the majority of data collected by these applications contains very limited green infrastructure reports since none of them are specialized for green infrastructures. In summary, the outdated user interface of database website, a very complicated process for accessing the massive data, and lacking of the green infrastructure category in government applications are the three main gaps that were solved in this research.

Table 3 Categories and numbers of USEPA My Green Apps

CATEGORY	NUMBER
Air	71
Emergencies and Cleanup	11
Human Health	43
Pollution Prevention	97
Regulatory and Industrial	8
Reaserch, Analysis, and Technology	36
Soils and Lands	66
Species	48
Substances	9
Water	45

1.3.2 Address the gaps and weaknesses in Web 2.0 era

While some users may just want to browse rather than modify data, the learning process required by accessing existing databases may reduce user's motivation, and be very time consuming. For example, if a user wants to check whether their backyard is in the 100-year flood zone when standing outside their house, the user doesn't need to undergo extensive research on FEMA's website until they are able to open data by ESRI's ArcMap program (ESRI, Environmental Systems Research Institute). Instead, they can simply access FEMA data on their smartphones anywhere and at any time. The enabled Web 2.0 technologies and the study of VGI can resolve previous mentioned issues, reconstruct websites to be capable with smart devices, and transfer databases to crowdsourcing clients, which would largely benefit environmental monitoring and management.

CHAPTER 2 LITERATURE REVIEW

2.1 VGI in environmental cases

2.1.1 Advantages to traditional method

The top-down/bottom-up method is a traditional way for governments to deal with environmental issues. It uses authoritative information and tools from agencies and corporations. Although authoritative information and tools, such as remote sensing data from NASA (NASA, National Aeronautics and Space Administration) or NWI data from USWFS (NWI, a product of U.S. Fish & Wildlife Service), are accurate, of high resolution, reliable. However, they are expensive, time consuming, inaccessible, and geographically limited. In contrast, using VGI to aid environmental monitoring and management does not require expensive updating and maintenance for high-resolution remote sensing data every year. This is because users, instead of agencies and corporations, will update the map. It also does not require the cost of building large databases such as census database, because once the VGI system is carried out, it will function as a data-driven website (data-driven website, one of the types of dynamic web pages), much like Zillow.com (Zillow.com, a product of Zillow, Inc., an online real estate data-driven website). In addition, VGI can also bridge the chasm between citizens, scientists and governments. The application of VGI in environmental monitoring also enables neogeography, which emphasizes the importance of participants in knowledge production, reducing existing gaps between the public, researchers, and policymakers (Peluso 1995; Bailey et al.2006; Mason and Dragicevic 2006; Parker 2006; Walker et al.2007). Applying VGI in environmental monitoring enables access to potential public knowledge (Connors and Lei 2012), and it is only limited by user's spatial location, therefore it is more flexible than traditional methods in certain cases, such as flood rescue response and stormwater management.

2.1.2 Data quality and relative results

Compared to the authoritative data from agencies or corporations, the quality of data collected from VGI systems is usually a concern. However, it has been prove that there is no significant difference between data collected by scientists and volunteers, and actually volunteers can even enable broader societal benefits, vital for future research efforts (Rebecca 2012).

2.1.3 the effectiveness of VGI method

In general, the VGI method will not replace traditional methods, but it will be an alternative solution for environmental monitoring and management. The data collected by non-professionals from the VGI system is reliable, and can be an additional data source for environmental monitoring and management for many purposes, such as cost reduction.

2.2 Existing case studies

2.2.1 Background of “OakMapper”

Sudden Oak Death (SOD) is a serious problem in California and Oregon forests. In order to keep oak trees healthy, “OakMapper” was built in 2001. Before “OakMapper,” the inspiration for the original site was the USGS Earthquake Mapper site, where participants can report a shake in their neighborhood. Because there are so many residents walking in forests every day, “OakMapper” extended the original site, with further allowed communities to monitor SOD. Although this idea came from hazard reporting and alerting in neogeography, it has also worked well in the past ten years in other agricultural subjects. “OakMapper” has successfully explored the potential synergy of both citizen science and expert science efforts for environmental monitoring in order to provide timely detection of large-scale phenomena (Connors and Lei 2012).

2.2.2 Problems of “OakMapper”

“OakMapper” is a VGI system that has been running since 2000 (Karin 2003). By 2014, it has collected 3,246 reports. However, most of these reports are in California, and “OakMapper” is not a full real time reporting system. Submitted data can only be displayed if it contains a specific address (Karin 2003), and the authentication required by “OakMapper” discourages new user from reporting.

2.3 Stormwater and green infrastructure management

2.3.1 Definition of stormwater

Stormwater comes from rainfall or snowmelt. If stormwater does not infiltrate into soil, it becomes runoff. Since stormwater runoff will be absorbed into the ground or flow into waterbodies, such as rivers, lakes, or wetlands, it can pollute both soil and water in neighborhoods and communities. A large amount of runoffs can also cause flooding or increase flood risks in neighborhoods and communities.

2.3.2 Definition of green infrastructure

President Bill Clinton’s first termed the words green infrastructure during his council on Sustainable Development in 1999. Green infrastructure was identified as one of five strategic fields of sustainable community development (President’s Council on Sustainable Development, 1999). Since that time, there has been no universal definition of green infrastructure, and several common accepted definitions have been given by agencies and organizations, such as USEPA and American Society of Landscape

Architects (ALSA). Although most of these definitions are aligned with the original concepts of the council's definition, some may cause confusion; the scale at which the most common differentiation being green infrastructure management is implemented (Allen 2012). There are three different spatial scales for green infrastructure planning and implementation. They are landscape-scale, regional-scale and site-scale. Current practices in green infrastructure planning try to link and coordinate planning and implementation across those three scales (McDonald et al., 2005). Although these scales are different, there is a similar relationship between landscape-scale green infrastructure planning and the site-scale implementation, this can be seen within the USDA Forest Service's Urban and Community Forestry program (Allen 2012). These similar relationships can also be seen among their definitions. For instance, the Center for Neighborhood Technology defines green infrastructure at the landscape-scale as "an interconnected network of open spaces and natural areas, which includes greenways, wetlands, parks, forest preserves, and native plant vegetation, that naturally manages stormwater, reduces the risk of floods, captures pollution, and improves water quality (Wise 2008)." Later, they define the site-scale as "a network of decentralized stormwater management practices, such as green roofs, trees, rain gardens and permeable pavement, that can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways (Allen 2012)." The site-scale stormwater management strategies can actually serve landscape-scale functions as well; they can also stand on their own merits, called site-scale green infrastructure benefits, which reduce costs over conventional stormwater reduction methods (Jaffe 2010).

While USEPA adopted these concepts mentioned previously and makes it as a policy approach, and developed their green infrastructure site-scale definition, which is widely accepted for most green infrastructure planning and implementation in America today. The definition for green infrastructure by USEPA mainly focuses on site-scale stormwater management. "USEPA defines green infrastructure as an approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities. Unlike single-purpose gray stormwater infrastructure, which uses pipes to dispose of rainwater, green infrastructure uses vegetation and soil to manage rainwater where it falls. By weaving natural processes into the built environment, green infrastructure provides not only stormwater management, but also flood mitigation, air quality management, and much more" (USEPA 2013).

2.3.3 VGI is suitable for green infrastructure management

In order to prevent and reduce stormwater runoffs, green infrastructure strategies have been applied to neighborhoods and communities for many years. Besides its positive environmental effects, green infrastructure can also improve landscapes in neighborhoods and communities. Many citizens build green infrastructure projects such as rain gardens and rain barrels in their backyards to improve the environment surrounding their homes. Municipal departments are also interest in building green infrastructure projects to reduce the cost of stormwater management. In general, the green infrastructure sites are widely spreading in neighborhoods and communities now, and if there is information about these green infrastructure sites, stormwater management may take benefits from it. However, the extent of green infrastructure projects that are widely applied through neighborhoods and communities is still unclear, and a grassroots approach of collecting the essential green infrastructure information for stormwater management is a viable solution. While with the development of Web 2.0 technologies and VGI research, this approach has been realized. Utilizing VGI for green infrastructure management is very suitable. First, VGI is designed for grassroots and volunteered reporting, and the green infrastructure strategies also target grassroots operation at the site-scale level; Second, economic issues always take priority of environmental issues, green infrastructure management isn't commonly regarded as a necessary need for communities, especially when there is a financial crisis. In an overview, people actually consider green infrastructure management as an unnecessary priority, but which does improve quality of live in the community. These contradictory thoughts result in people are not willing pay much time on green infrastructure management, however VGI can help a community to gain more attention on green infrastructure management, balanceing an individual interests with environmental concerns; Third, once more people add their green infrastructure projects to VGI systems, the green infrastructure culture will be more prominent in the stormwater planning process, increasing the input of social efforts in communities through VGI. In general, the concept of VGI has a similar marketing target group as green infrastructure management; they all depend on the same fundamental support from grassroots. It also balances the necessary environmental needs and personal benefits well, and it also generates social efforts for promoting green infrastructure strategies in communities.

2.4 E-Government and Interactive GIS

2.4.1 Definition of e-government

The discussion around the concept of e-government started with the World-Wide-Web boom during the early stage of the Internet, and e-government is narrowly defined as the production and delivery of government services through information technology (IT) applications. However, it can also be defined broadly as any way IT is used to simplify and improve transactions between governments and other roles, such as transactions between citizens, businesses, and governmental agencies (Sprecher 2000). For instance, Means and Schneider define e-government as the relationships between governments, their customers (businesses, other governments and citizens), and their suppliers (again, businesses, other governments, and citizens) by the use if electronic means (Means 2000). Similarly, for Hernon, e-government is using IT to deliver government services directly to the customer 24 hours a day and 7 days per week. The customer can be a citizen, a business or a government entity (Hernon 1998).

2.4.2 Interactive GIS

Over the last 10 years, technologies have improved greatly, and government websites are more than just several static pages. The concept of e-government is now widely accepted by the public than before. Many municipal departments were being pressured by citizens to provide more interaction on their website, and nearly half of planning directors reported that they were receiving pressure from citizens to provide more e-government (Cowley 2006). The growth of e-government has provided a great opportunity for citizens to communicate with planners; citizens now have the ability to become more engaged with planners through the Internet. E-government interaction tools are frequently used by citizens to communicate with planners and governments. With the development of geographical information technology, GIS has become an interactive tool for communication through government websites.

On a planning department website, the highest level of user-directed information is provided by interactive GIS. Between 2004 and 2005, the adoption of interactive GIS increased from 23 to 42 percent, and forty-two percent of planning directors have stated that they want to add interactive GIS to their website by the end of 2011 (Cowley 2006). Interactive GIS is becoming increasingly welcomed by government websites. Although interactive GIS provides a great convenience for citizen, business and government agencies, it still can’t cover all the needs for its users. For example, interactive GIS is often a one way visualization concept for clients. However a dual way interaction that exchanges data between citizens and governments may be required, and interactive GIS can’t fill such kind of gap. VGI has become a new type of communication tool and a new part of e-government. VGI can also integrated with other interactive tools for e-governments, such as blogs, forums that are hosted on government websites. In general, VGI can be considered as a great aid to interactive GIS both as a new tool and a new method for the diffusion of e-government concepts.

2.5 Research goal and product

2.5.1 Research goal

The main research goal is to develop the mobile information platform “US Green Infrastructure Reporter” that can allow citizens to report the sites and activities of stormwater management and green infrastructure initiatives. Compared to “OakMapper,” the “US Green Infrastructure Reporter” system is a real time reporting system, which includes a web-server, a GIS-server, mobile applications and websites. The “US Green Infrastructure Reporter” VGI system also does not require any authentication for the reporting process. It is also a reporting system for national grassroots efforts. In order to attract as many users as possible, the mobile application supports both iOS and Android. The research has also created a new green infrastructure database. The main data sources include public websites, third parties, nonprofit organizations, and municipal departments.

2.5.2 Product

The goal is to generate the following deliverables: a nation wide green infrastructure VGI system, including the U.S. Green Infrastructure Portal (USGIP) website, U.S. Green Infrastructure Reporter (USGIR) mobile applications, and a Green Infrastructure database.

CHAPTER 3 STUDY AREA FOR USING VGI IN STORMWATER MANAGEMENT

3.1 Study area

The study area of this research is based on the US Urban Water Project in City of Omaha, Nebraska. Two pilot study areas were chosen to develop the mobile tools for citizen engagement in urban water management.

3.1.1 First site: Little Papillion Creek Basin

The first study area is the Little Papillion Creek Basin (defined as subcatchment number: LP-25 in the CSOmaha Program; referencing to the "Saddle Hills Neighborhood") at the intersection of Blair High Road and Crown Point Avenue (Figure 2). This area is covered by a 20-year neighborhood (named Saddle Hills) that includes a variety of ethnicities and income levels. The site is approximately 60 acres in size (larger when accounting for the run-on contributed by the adjacent neighborhood to the east). The area drains down to a single outflow at the bottom of the neighborhood, a vacant car dealership. In order to limit the amount of silt-laden runoff loading onto his property, the dealership owner has explored numerous options to remedy the situation. Initial proposed solutions were expensive and unsuccessful, because they failed to address the upstream causes of the problem. Therefore, a more comprehensive approach was formulated to address stormwater runoff from the entire watershed. The runoff from Saddle Hills discharges directly to the Little Papillion Creek, rendering itself an ideal location for a living laboratory. It is an ideal site to conduct the water quality monitoring-assessment-education-outreach programs because the basin naturally divides into two distinct drainage areas where green infrastructure structure and educational programming can be analyzed for their contribution to water quality and quantity benefits. The long-term goal for the City of Omaha is to implement public green infrastructure only on the south drainage area to further analyze their benefits in water quantity and quality. Each of the drainage areas currently has monitoring equipment (a flow meter and grab sampler) installed by the City of Omaha during the late 2011 in order to establish a baseline on stormwater runoff quantity and quality. Once the baseline data is established, both drainage areas will receive stormwater and green infrastructure educational programming such as rain and bioretention gardens, permeable pavement, and rainwater collectors. This will allow accurate data to be collected on the potential benefits and applicability of various green infrastructure practices as well as document and compare the impact between a watershed with implemented educational programming/green infrastructure and an adjacent similar watershed that is limited in educational programming.

3.1.2 Second site

The second study area is the Cole Creek Basin (defined as subcatchment Number: 202 in the CSOmaha Program). It covers approximately 101 acres between 72nd Street on the west, 67th Street on the east, Bedford Street on the north and Lake Street on the south (Figure 2). It is located in a combined sewer system (CSS) service area and encompasses a variety of land uses including commercial buildings, schools, and single-family houses. This area is an old neighborhood with a high percentage of minority and middle/low-income households living in a majority of 50-100 year-old buildings. This watershed drains to Cole Creek, which is located to the north and west of basin. Cole Creek has significant stream bank erosion, and it is of high concern to the City of Omaha due to its proximity to housing and the recreational YMCA facility adjacent to it. This site would provide great opportunities to evaluate the effectiveness of stormwater and green infrastructure educational programming in varying land use areas. Commercial land uses often have high percentages of their total land area covered by impermeable surface, the result of larger buildings and expansive parking lots. Establishing effective educational program will have multiple benefits, which includes: (1) Leading in behavioral changes in varying land uses; (2) Enhancing municipal education program; (3) Improving water quality and quality of life of the community. An existing outfall data for combined sewer overflow (CSO) outfall 202 was utilized in this project.

3.2 Study extent

This research is initialized from the two study areas in Omaha. Although it originally only focuses on these two sites, its methodologies and workflows can also be applied to other places in US. With the understanding of this potential, the research will extend its study areas from two sites to the nation wide, with research goals to be extended to promoting green infrastructure strategies and education through out the US.

3.3 Definitions of selected green infrastructure data values

Since this research focuses on site-scale level green infrastructure management, the USEPA's definition of green infrastructure is the primary reference for the development of data values. In addition, New York City (NYC) green infrastructure category was used as second reference, because its category was also developed for the site-scale level (NYC 2014). The NYC green infrastructure data can be accessed from the NYC OpenData website. USEPA divided green infrastructure strategies into eleven categories, where as NYC divided green infrastructure strategies into thirteen categories as what I was done (Table 4). While NYC's green infrastructure lists are not suitable for the research, they only stand for local green infrastructure type, and the meanings of its terms are overlaid and hard to understand by citizens, difficult for the average residents to determine. It is obvious that NYC's green infrastructure data values lists were designed for professionals, while the research is designed for both experts and non-experts. The only terminology that was preserved from NYC's green infrastructure category is constructed wetland, but this category term isn't wide enough apply this concept to nation wide, instead the term water conservation was used to replace it; water conservation includes both natural wetland and constructed wetland, with the hopes that this term will not cause confusion. For instance, there is a term defined as land conservation in the USEPA's green infrastructure category, since the meanings of land conservation is so wide that it is hard for people to understand. In general, the USEPA's green infrastructure category is merged with the NYC's green infrastructure category to define green infrastructure terms and categories for this research. In the research proposed green infrastructure category (Table 2), a new term was added called *green infrastructure industry*, which is defined as business network that relates with green infrastructure products, such as a factory that produces rain barrels. The newly added term can be considered a promotion for the diffusion of green infrastructure strategies from business aspects. All the definitions of the terms in the proposed green infrastructure category can be accessed through the web and mobile devices for educational purposes, and it is an essential part of the green infrastructure VGI system (Figure 3).

Table 4 Categories and numbers of USEPA's My Green Apps

USEPA's Green Infrastructure Category	NYC's Green Infrastructure Category	Proposed Green Infrastructure Category
Bioswales	Bioswales	Bioswales
Downspout Disconnection	Blue Roofs	Downspout Disconnection
Rainwater Harvesting	Bluebelt	Rain Barrel
Rain Gardens	Cistern	Rain Gardens
Permeable Pavements	Constructed Wetland	Permeable Pavements
Planter Boxes	Gravel Bed	Planter Boxes
Green Alleys and Streets	Green Roofs	Green Alleys and Streets
Green Parking	Pervious Pavement	Green Infrastructure Industry
Green Roofs	Rain Barrel	Green Parking
Urban Tree Canopy	Rain Garden	Green Roofs
Land Conservation	Rainwater Reuse System	Urban Tree Canopy
	Tree Pit	Water Conservation

CHAPTER 4 METHODS

4.1 System deployment method

System deployment includes two tasks; front-ends and back-ends. Front-ends are the client side of the system, such as desktop users and mobile users. Back-ends are the server side of the system. It includes two web servers and a GIS server. There are two types of front-ends. They are web front-ends and mobile front-ends. While web front-ends are web applications that allow Internet clients to request back-end services through a URL (Uniform Resource Locator) via web browsers, mobile front-ends are mobile applications that allow mobile clients to request back-end services through smartphones or tablets. The mobile applications can be downloaded and installed via Apple Store or Google Play. In a common situation, multi-requests happen when there is too many front-ends users visit the server simultaneously. Number of multi-requests from mobile clients is usually higher than the number of multi-requests from Internet clients, while that means the server back-ends should be optimized to take care of those differences. Besides the REST (REST, Representational state transfer) service hosted on a GIS server, there is also education information hosted on the backend. Education information is formatted into static web pages, and does not require communication with a GIS server. By adding an additional web server (Figure 4), the system can filter the client into two groups, those requires using GIS services and those that do not. Using this deployment method, the total number of multi-requests for the GIS server can be reduced significantly if a certain amount of clients are only browsing the education web page, while at the same time, the clients who are searching on the map or reporting data to the GIS server can still have a smooth experience. In short, this deployment method can reduce the peak number of multi-requests from clients, especially when there are many mobile users who are only viewing static information through the front-ends. A workstation was also added to the back-ends in order to give data access to professional users, such as GIS analyst (Figure 4). In addition, by publishing web map through ArcGIS online.com for related research, data can also be shared between other professionals, such as environmental scientists and planners (Figure 4).

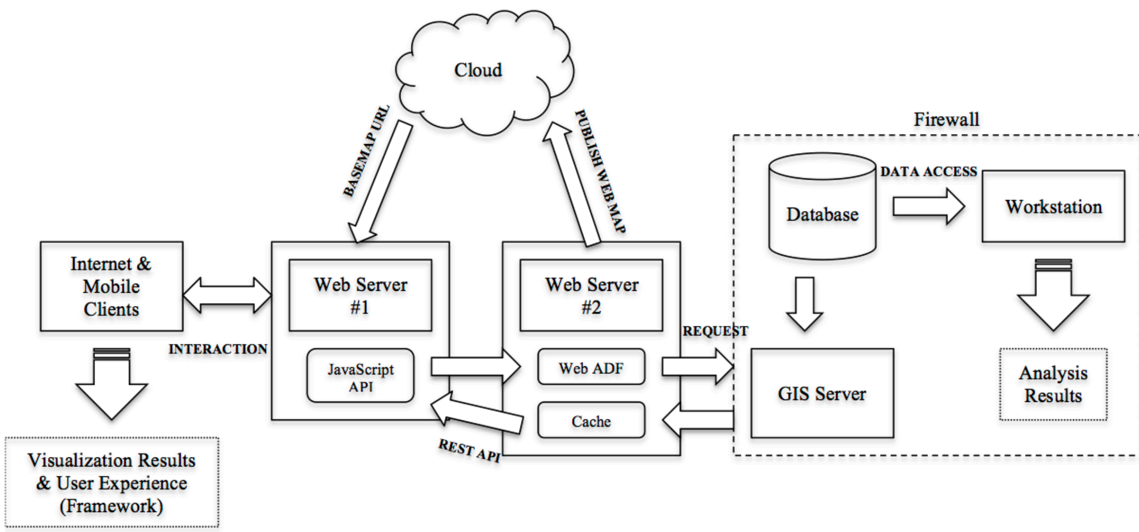

Figure 4 Deployment of front-ends and back-ends (Web ADF – web application developer framework)

4.2 System architecture development method

The key point of system architecture is using embeded Javascripts in Html (Html, HyperText Markup Language) (Figure 5). JavaScripts is a client side script language. Using embeded JavaScripts is an affordable way for deploying small business applications through clients, because most current browsers, such as Firefox, Safari or Chrome, support JavaScripts very well. Thus, it is possible for developing just one application and making it runable on different platforms. The PhoneGap (PhoneGap, a mobile development framework produced by Nitobi) has realized this possibility, and developers do not need to update their code frequently or develop applications for each different platform, which can significantly reduce the total cost of the system. The Html code with embeded JavaScripts can be wraped into the native environment on the client side, in that PhoneGap provides a bridge between native environment and web environment (Figure 5).

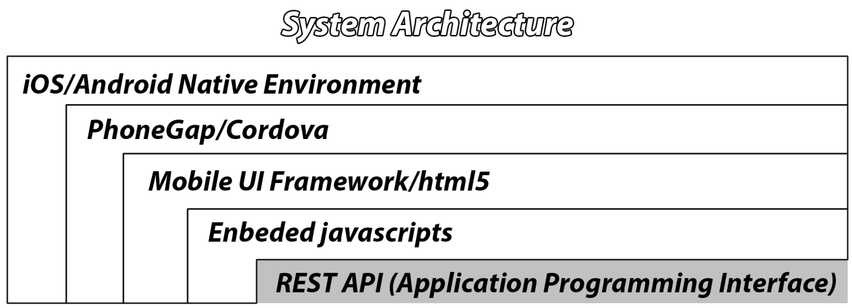

Figure 5 Architecture of front-ends and back-ends

4.3 Mobile front-ends design framework

Visualization results and the user experience includes five key features (Figure 6): (1) GPS reporting and mapping features will enable users to browse maps, send geocoded photos or data, and query attributes of geometric objects. (2) Publication and education features will be designed for novice technicians or students to studying green infrastructure strategies. Third party publications are also posted as a link in this feature. (3) With the linkage to social media, users, experts and advocators can share their ideas through social networks. Several popular social networks will be included, such as Twitter and Facebook. (4) News and research progress will be posted through research exhibition feature for environmental experts. (5) Users can also find reviews and contact information through feedbacks and contacts feature.

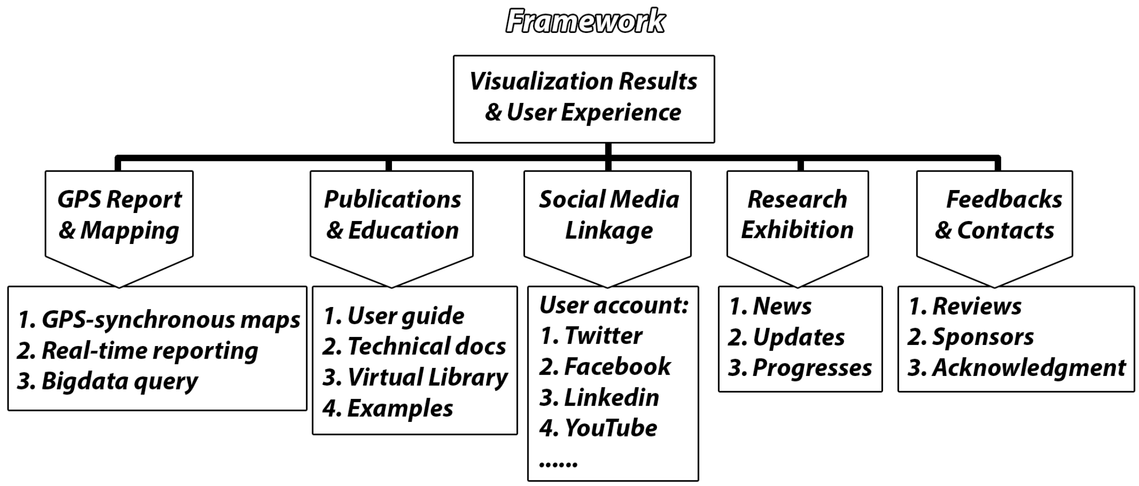

Figure 6 Design framework of mobile front-end

4.4 Data collection process

The data collection process includes two steps. The first step is collecting data from public webpages, forums and blogs, virtual earth products or other web resources of agencies or non-profit organizations, such as NYC Open Data, Google Map or Google Earth. The second step is collecting data from private professional databases such as the Philadelphia Water Department and the City of Lincoln. Some of the data from private professional databases are comma-separated values (CSV) or formatted as vectors, and some databases are embedded with a piece of Keyhole Markup Language (KML), and they are generated from the web. While vectors can be converted into Shapefile format, then they can be imported to spatial databases directly. The ERSI shapefile (SHP) is a geospatial vector data format for GIS software (Shapefile 2014). A shapefile stores non-topological geometric data and attribute information for the spatial features in a data set and the geometry of a feature is stored as a shape comprising a set of vector coordinates (An ESRI White Paper 1998). It is also an open data format and industry standard. Besides SHP, KML and CSV are additional open data standards that are also commonly used for sharing geospatial data (Thomas 2014). The KML files need to be converted to CSV format first, and then they can be imported into ESRI's ArcMap program, and then exported as vectors if they contain spatial information, such as street address or coordinates. KML has a similar language structure as Html. By simply replacing the structure symbols to commas in Text Editor or Excel, the KML files can be converted to CSV format easily. Some of the KML scripts may be embeded within Html, extracting the KML out of the Html may also be required before the converting process (Figure 7).

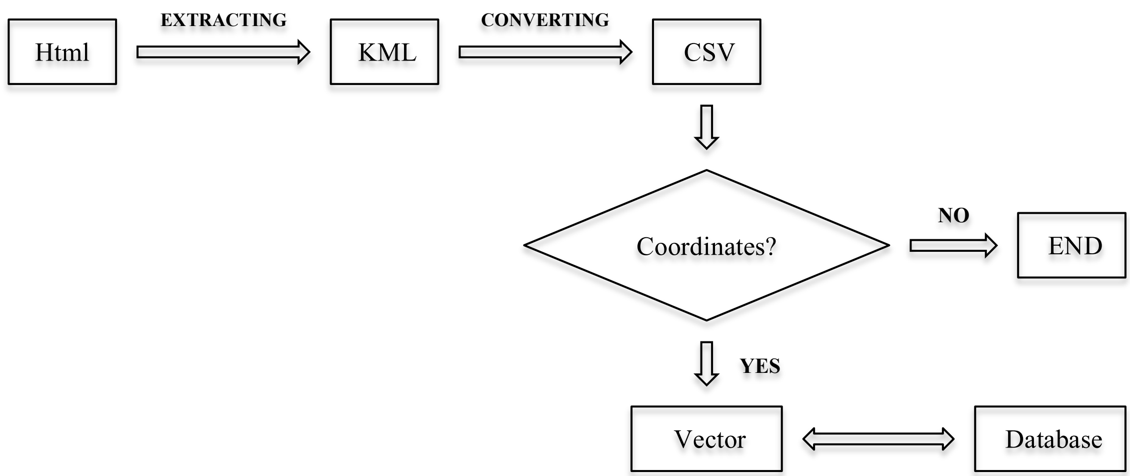

Figure 7 Workflow of the data collection process

CHAPTER 5 RESULTS

5.1 Development results

5.1.1 Mobile products

Mobile products include a series of mobile applications. Their names are MyRainBarrel, MyRainGarden, Omaha Green Infrastructure and the U.S. Green Infrastructure Reporter. MyRainBarrel and MyRainGarden are not real-time reporting mobile apps, but are very stable for reporting information within areas that do not have WiFi signal. MyRainBarrel and MyRainGarden use the same mobile app template, and they both provide educational interactions with users (Figure 8).

Omaha Green Infrastructure is designed mainly for educational purposes. The current app "Omaha Green Infrastructure" focuses on three key components: (1) green infrastructure education includes educational materials that have been transferred to the mobile platform. (2) Mobile-based real-time reporting. The stakeholders and residents can use their own mobile devices to report their green practices to the server. (3) Linkage with social media and other networks. This product contains many definitions of the typical green infrastructures in study areas (Figure 9). The education information not only provides fundamental knowledge of green infrastructure, but also tells the public how to build green infrastructure through communities and neighborhoods. This product provides social media linkage. The Omaha Green Infrastructure app also is not a real-time reporting app. It was created mainly for trained citizens and green infrastructure professionals. Its effort will be the major focus during the fall semester.

U.S. Green Infrastructure Reporter is the first real-time reporting product for green infrastructure (Figure 10). It absorbed advantages from previous mobile app products. It was designed for grassroots users, but still beneficial for professional users. All of these products are native mobile apps that developed by Objective-C language; their differences in functionality complement each other to promote green in different situations.

In general, by using this app development strategy, series of apps were created with an interdisciplinary approach increasing citizen engagement to stormwater management.

5.1.2 Website product

The website was designed with simplicity in mind, encouraging simple appearance, simple function and simple maintenance (Figure 3). We created the website by using a very popular WYSIWYG (WYSIWYG, what you see is what you get) web design tool, which is called Wix.com, an online web design tool that is very popular in recent years. Due to its ease of use, Wix.com is very popular among businesses to share ideas through rapidly created websites. This new type of tools also brought benefits to the planning and environmental fields, professional development skills are no longer required for a planner who wants to build a website. The website structure includes three parts: (1) local static pages and resources; (2) online resources; (3) spatial information from the GIS server. Educational information, such as terminologies, are published through the website and saved on the server. The website has the same educational information as the mobile products. In addition, VGI users can also submit their reports through the website.

5.2 Inventory mapping results

5.2.1 National overviews

Because the data was collected randomly from different sources or organizations, the green infrastructure inventory results in this research are still far from for analysis. Several green infrastructure categories are still left almost empty, since there are few reports from the public as of yet (Table 5). While some categories don't have much feedback, such as downspout disconnections and planter boxes, nearly half of the categories have over a hundred of reports, providing an overview of green infrastructure situation in the United States. In general, green infrastructure is popular among communities or cities that sit on east coast, west coast and the Great Lakes Region (Figure 11,12,13,14,15,16,17,18,19). This phenomenon can also be seen in almost each green infrastructure category.

Table 5 Numbers of each green infrastructure type in the database

Green Infrastructure Type	Number
Bioswale	152
Downspout Disconnection	7
Rain Barrel	4,671
Rain Garden	602
Permeable Pavement	169
Planter Box	13
Green Alley and Street	28
Green Infrustructure Industry	187
Green Parking	57
Green Roof	752
Urban Tree Canopy	86
Water Conservation	41
Others	82
Total Number: 6,847	

5.2.2 Results in study areas

This research finally collected study area information for 16 green infrastructure sites at Omaha, Nebraska (Figure 20). However, information for 383 green infrastructure sites from the Lincoln, Nebraska (Figure 21). Collecting information for a total of 433 green infrastructure sites for the entire state of Nebraska. Most of the green infrastructure types in Nebraska are rain barrels and rain gardens, proving to be very popular among communities and neighborhoods in Omaha and Lincoln.

5.3 Feedbacks

The Feedback from this research is surprising. The inventory results received 1,392 reviews on ESRI's website from professional users (Figure 22). The green infrastructure database also attracted some faculty members and students from other universities in the U.S.

In addition, the MBA students at the University of Nebraska-Omaha developed two separate class reports in May 2013. The major suggestions from the MBA students on iOS development are that the key target market should be beyond the neighborhood itself. It could be the citizens in the Omaha Metro area, including 81,000 citizens 20-34 years old, who may have smart phones. Apps can first address the professional groups, such as landscape architects and gardeners, as the target market, and can then expand it to the general residents. The professionals associated with the app may bolster promotional efforts. The applications must be free in the Apple App store. The applications should trigger interest and action by incorporating some fun functions that can attract users. The app should include the educational component and allow connections to new friends and co-workers. The social apps can encourage users to invite their friends and colleagues to help the site grow quickly. An effective grassroots campaign is the best way to promote this product. Making the most of its social nature will make the app seem credible while minimizing the promotion budget. A major drive for human behavior changes is the influence from others (Shope 2006). Some demonstration for environmental awareness in the community will be a good approach to promote those behavior changes.

Residents will find use in this mobile app in order to receive knowledge and news about green infrastructure and can also use the mobile devices to report their own green practices. Residents may be interested to access their reported sites on the web and mobile platform. Three key functions of this app that the residents can do are (1) receive green infrastructure knowledge and information; (2) use their own mobile devices to report their green practices to the server, building an online virtual photo library of green infrastructure sites through grassroots reports; (3) communicating through social media and other network regarding green infrastructure issues.

CHAPTER 6 IMPLICATIONS TO PLANNING FIELD

6.1 Implications for public engagement

Understanding user's needs are essential for using VGI methods in the planning field. In general, there are two kinds of needs; one is the urgent need, peak values, such as disaster or a hazard. The other is the daily need, such as reading the news every day or checking the weather every day. When designing planning apps, planners also needs to think about what kinds of needs the public has.

6.2 VGI methods for professional practice

Compared to the traditional methods, VGI has many advantages including saving costs and being flexible for stormwater management. The crowdsourcing data generated by volunteers can be an alternative data source for stormwater management, and there is only a marginal difference of quality between the data collected by experts and the data collected by non-experts. Additionaly, VGI can be used as an effective means to promote public awareness and engagement, compensating the weaknesses of traditional methods. While the VGI method will not replace the traditional methods, it will aid to the traditional methods for stormwater management. VGI can also be considered a new way to rapidly collect information from third parties, nonprofit organizations and municipal departments. The database created by VGI users can provide multi-beneficial effects for stormwater management in further studies, such as flood mitigation research. When designing an app for a VGI method, planners also need to think about the urgent and daily needs among people, which could be very helpful for planners to reach the public and improve citizen engagement. In addition, using VGI methods could also accelerate the planning process and save the costs since residents can implement a part of the planning process instead of the government.

6.3 Problems of using VGI methods

6.3.1 Problems with crowdsourcing

The VGI method has similar problems to other crowdsourcing practices. For instance, as mentioned in chapter 2, there is not a significant difference between the data collected by scientists and the data collected by citizens, the VGI method still has occasional data quality problems, especially when volunteers lack motivation to donate their knowledge to the VGI system. Some volunteers may not be willing to finish all the inventory questions when the results of the VGI methods cannot be seen immediately. A hindrance of environmental protections effectiveness that usually takes decades for people to see their effects after they have already made contributions to environmental stewardship. In addition to data quality issues, crowdsourcing also has following problems: (1) there is no time constraint for the data collection process when practicing the VGI method; (2) when using the VGI method, it is hard for planners to define or identify what the resident's motivations and interests are, and whether the motivation and interests will have a positive or a negative impact to the planning process; (3) how to prohibit intellectual property leakage for sensitive topics, such as when using the VGI method to collecting housing prices; (4) there are no standards for designing a VGI system now, so there is not much control over the development or the ultimate product; (5) when using the VGI method, planners also need to think about what things can be crowdsourced and what cannot, such as contents that have copyright issues; (6) public motivation.

Planners also need to think about how to appreciate the contributions from the public, and how to preserve existing VGI users. In general, applying the VGI methods to planning is not just building a VGI system, it is both a planning process and also a crowdsourcing practice, problems with the crowdsourcing can be considered as a new rising planning issue in the future, especially when e-governments will become more increasingly popular in the future.

6.3.2 Problems with current mobile technology

Although technology has improved greatly on mobile devices, there are still two technology problems that have an impact on adopting VGI methods. One is the signal coverage range and signal quality for mobile device; and the other is battery life. Most mobile devices can get good signals in urban areas, but in the rural areas, mobile devices could disconnect suddenly due to signal range and poor signal quality, potentially causing missing reporting results or producing erroneous data on the server. In addition, different information service providers have different signal coverage, even in the same city, the signal quality and strength varies greatly and VGI users may lose patience if their phone service isn't available in the area. The signal not only has an impact on the results of adopting VGI methods, it also has an impact on the volunteers. Adopting VGI methods also require users to have a better phone, although VGI developers and planners will try to cover as many popular devices as they can, and reduce memory requirements for mobile applicants. There still are some hardware limits that cannot be just solved by this, such as the battery life. If the VGI users are a group of professionals, they may use VGI apps on their mobile devices to collecting data the entire day, and the screen will be constantly refreshing, diminishing the battery life.

Another problem for adopting the VGI method is covering the entire mobile phone market. Currently Google and Apple have over 85% of the smartphone market (netmarketshare 2014). This is the VGI developer's best interest to have their apps deployed on both Google and Apple phones. This is not a simple task because Google and Apple have different policies for reviewing a developer's app. Google is an open source and allowing more freedom to access phone abilities, Apple is closed and is sensitive to access phone abilities, such as sensors. Trying to keep VGI apps working both on Google and Apple phones is a challenge for developers and planners. In general, Google and Apple, both provide a good development workflow for promoting VGI method because they have their own advantages and disadvantages.

6.3.3 Native app vs hybrid app vs web app

Mobile application, the front-end of the VGI system, has a great impact on attracting volunteers and promoting the VGI concepts to the public. Whether it appears user-friendly, and whether the key functional enhances the user experience. There are three different types of mobile apps: (1) native app, (2) hybrid app, (3) web app. All of these apps have their advantages and disadvantages when building a VGI system. Developers and planners also need to choose a suitable app type for their projects. It is difficult to assess which type is the perfect option for building a VGI system; planners and developers need to balance the development costs, time, and key functional features.

Native apps are apps that are developed by native programming languages, which is specified by a typical mobile operation system (OS), and a native app can only run on the mobile OS that it supported by. One immediate solution of a native application is that all the documentation can be done with or without Internet connectivity (Robert 2014). A native app can also run smoothly on the specified OS, and it usually has less bugs. However, a native app has disadvantages. Since the native programming language is used to develop native apps, it is hard for a native app to be cross platform. If planners or developers choose to develop a native app, they need to program on every OS platform by using different native OS coding languages, such as Objective-C and Java (Figure 23). In addition, updating the native app is also a problem since it requires different programming language knowledge. It cab be expensive and time consuming why to develop a native app for the VGI concept, but in some cases, such as local data analysis, choosing native app is a wise solution.

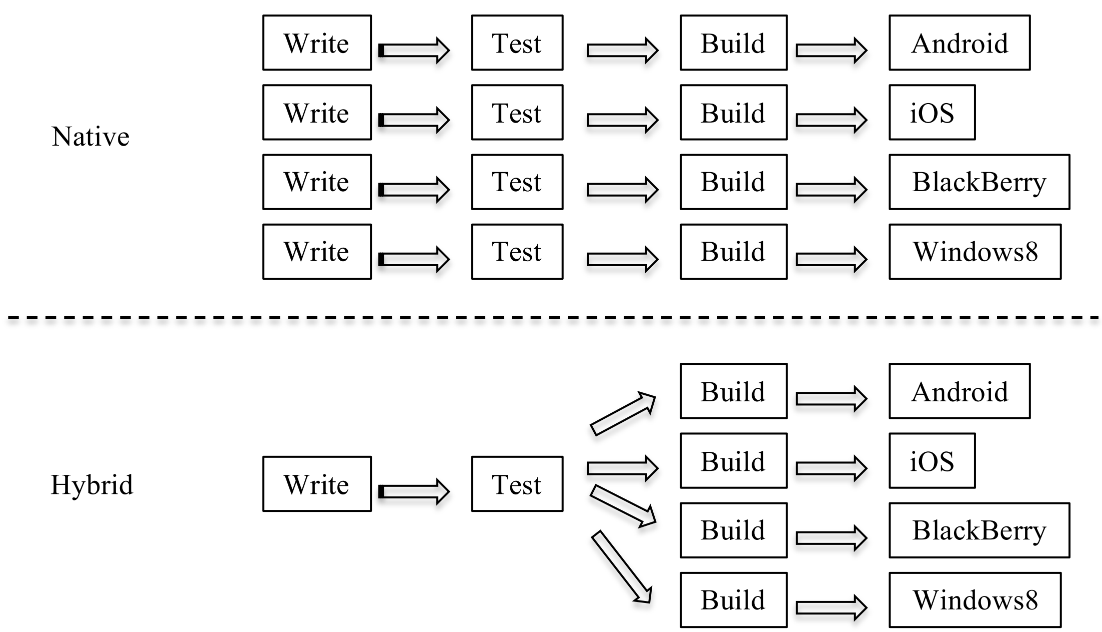

Figure 23 Comparison of the development workflows between a native app and a hybrid app

Web apps actually are website in mobile form, it relies on browser and Internet connectivity. It doesn't have native look, but it is much cheaper than native apps and hybrid apps. Web apps are not popular, because it requires users to remember its websites link. So in general, web apps are not suitable for promoting VGI concepts, it doesn't look user-friendly, and it often has a blurred user experience.

Hybrid apps are part native apps, and part web apps. Hybrid app development requires web experience, such as Html5 and JavaScript. Although it is not developed using native programming language, it can have a native look and can access the functionalities on the smart phone. The native appearance of a hybrid app relies on some open sourced or third party user interface (UI) framework, such as jQuery Mobile and Sencha Touch. So its performance may not be as smooth as a native app, but the cost and maintenance of the hybrid app is usually cheaper and easier than the native app workflow. In addition, choosing hybrid app doesn't require planners and developers to have native development experience; it only requires web development experience, making it easier for a hybrid app to be cross platform. Most of social media apps are hybrid apps, because they are easy to be distributed on different mobile OS platforms (Figure 21).

In general, choosing the right type of app for building a VGI system is very important, because it has a direct impact to the volunteers. It is hard to say which type of app workflow is better than the others; they all have their own advantages and disadvantages (Table 6).

Table 6 Comparison of web apps, native apps and hybrid apps

	Device Access	Speed	Development Cost	App Store	Approval Process
Native	Full	Very Fast	Expensive	Available	Mandatory
Web	Partial	Fast	Reasonable	Not Available	None
Hybrid	Full	Native Speed as Necessary	Reasonable	Available	Low Overhead

6.3.4 Privacy and public safety

Although 20 years have been passed since the first personal computer (PC) was invented in the early 1990s (PC 2014). The invasion of hackers is still a threat, and the same concerns extend to the mobile era. From the technological view, it is true that some smartphone systems have safety issues and hacking software target to smartphones is readily available. Utilizing VGI methods can also become a new opportunity for hackers to invade public privacy. With the risks in minds, users question the necessity of installing software on their smartphones that they don’t need to rely on or use everyday.

CHAPTER 7 CONCLUSIONS

The concept of VGI is not new, it has been applied to solving society issues for at least 200 years ago. Cutting edge web technology has made the possible of VGI widespread. As a way of crowdsourcing, its data provides invaluable results for decision-making. Like many advanced technologies created by human society, the idea of VGI finally came into the planning field with successful practice in the environmental field. VGI methods were used for monitoring the environment since 2007, and it has brought many benefits to environmental management, such as saving the costs for the projects and providing additional datasets for research. While from the view of government agencies or authorized information organizations, such as the USGS, NWI and official mapping service providers, VGI can compensate the weaknesses of traditional mapping and remote sensing, saving the costs of mapping and maintaining the databases, breaking through the spatial limitations of information availability, and also helping promote environmental awareness. Bringing public engagement into environmental management has been a critical issue due to the gaps that exist between the environment, citizens, and governments. While the goal of VGI studying fills the chasm, and is also a great aid to the traditional methods, the top-down and bottom-up, they were widely used in environmental monitoring and management.

In this study, we tested the VGI methods on a typical environmental issue, stormwater. Which includes stormwater management, green infrastructure education, and flood mitigation. Our research focuses on how to use green infrastructure ideas to reduce stormwater issues in two study areas in Omaha, NE. Green infrastructure has many benefits to the environment, along with creating a beautiful landscape though communities and neighborhoods, it also helps to reduce CSO and flood risks in the city. The current gap in this study is that the public is not familiar with green infrastructure, and the government also doesn’t know how to manage green infrastructure due to lack information. During this research, we created a grassroots VGI system for implementing green infrastructure inventory, and explored the VGI methods on this marginal area between the planning and environmental fields. During this research, the inventory was initialized from the two study areas to nation wide, the inventory results showed an overview of the green infrastructure situation in the United States. Green infrastructure is more popular among areas that sit on the East Coast, West Coast and the Great Lakes Region. A green infrastructure database was built mainly based on the data provided by third party organizations and agencies from the public, which implies that VGI methods could be a new way for helping government and institutions understand some uncertainties through the public. The analysis results of the green infrastructure data can bring multi-benefits for the planning fields, such as a trustable reference for a flood mitigation plan, or a sustainability plan.

Other VGI practices are included in this research for exploring VGI methods in the planning field. The problems and concerns that we have confronted during this exploration include data quality, technology, UI design issues and many other related factors. It has been proved that the data generated by VGI methods is believable if a large group of people participate in the data collection, however lack motivation can decrease the data quality if the VGI contents or ideas cannot meet the needs from the public exactly. When utilizing VGI methods, planners and developers also need to understand the public needs.

A variety of workflows were also tested in our research. There are three development workflows for building a VGI mobile app. Native apps and hybrid apps are suitable for developing the client side of a VGI system, and both of them has their own advantages and disadvantages. Choosing which technology workflow to utilize depends on the project requirements, and also depends on the professional skills of planners and developers.

At last, besides all the suggestions that previously mentioned, when utilizing VGI methods. Planners also need to think about other concerns, such as the value of the contributions from the public, how to encourage the governments, the marketing aspects of mobile apps, and all of the factors and knowledge that could be helpful to promote public involvement.

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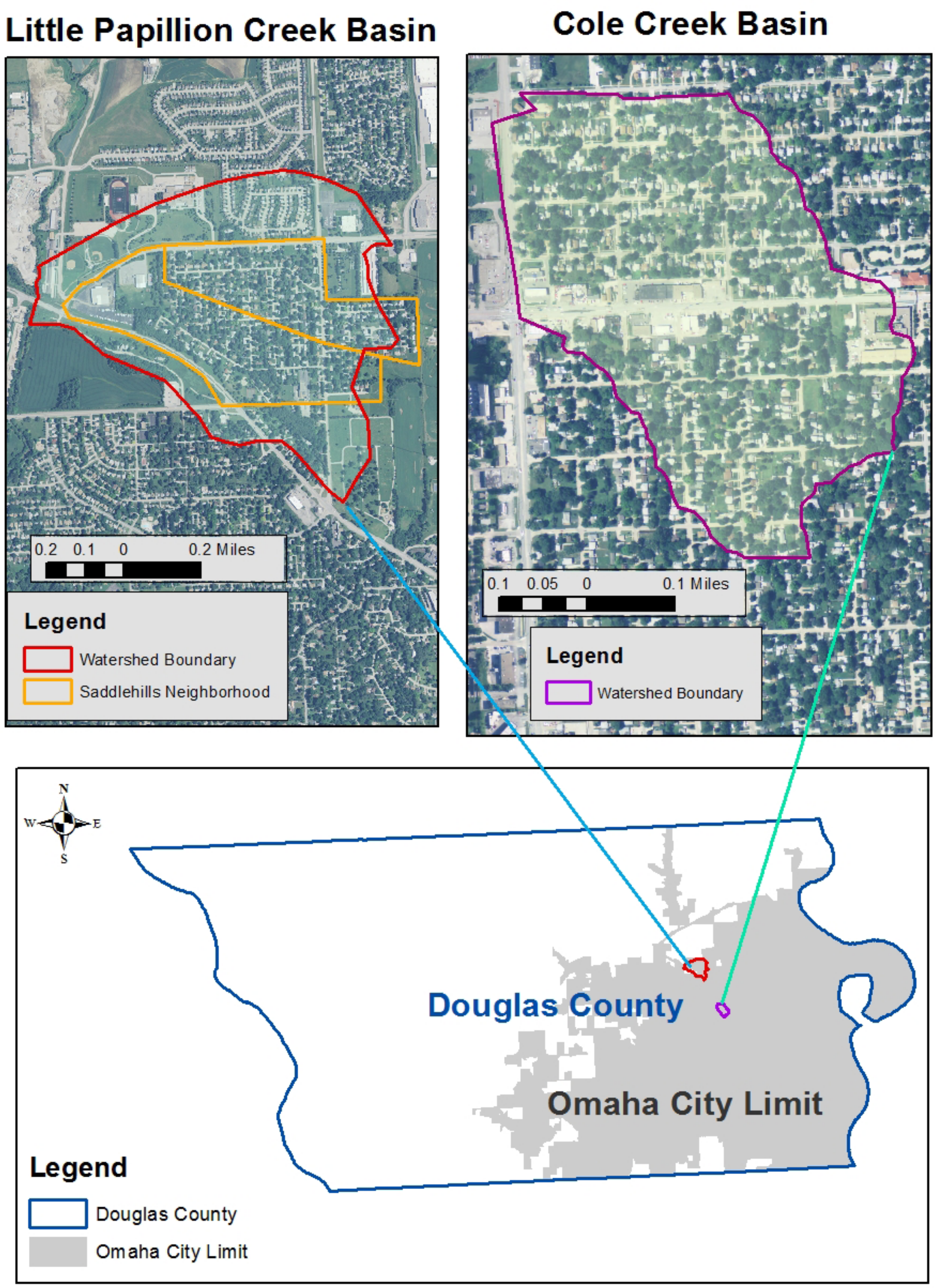
Appendices

Appendix A: THE ORIGIN OF VGI

Figure 1 Snow's cholera map

Appendix B: MAPS OF THE STUDY AREAS

Figure 2 Little Papillion Creek Basin and Cole Creek Basin



Appendix C: SCREENSHOTS OF VGI WEBSITE

Figure 3 Definitions of the terms in the proposed green infrastructure category can be accessed through web and mobile for educational purpose, and it is an essential part of the green infrastructure VGI system.

Appendix D: SCREENSHOTS OF MOBILE APPS

Figure 8 Screenshots of sliders in MyRainBarrel/MyRainGarden

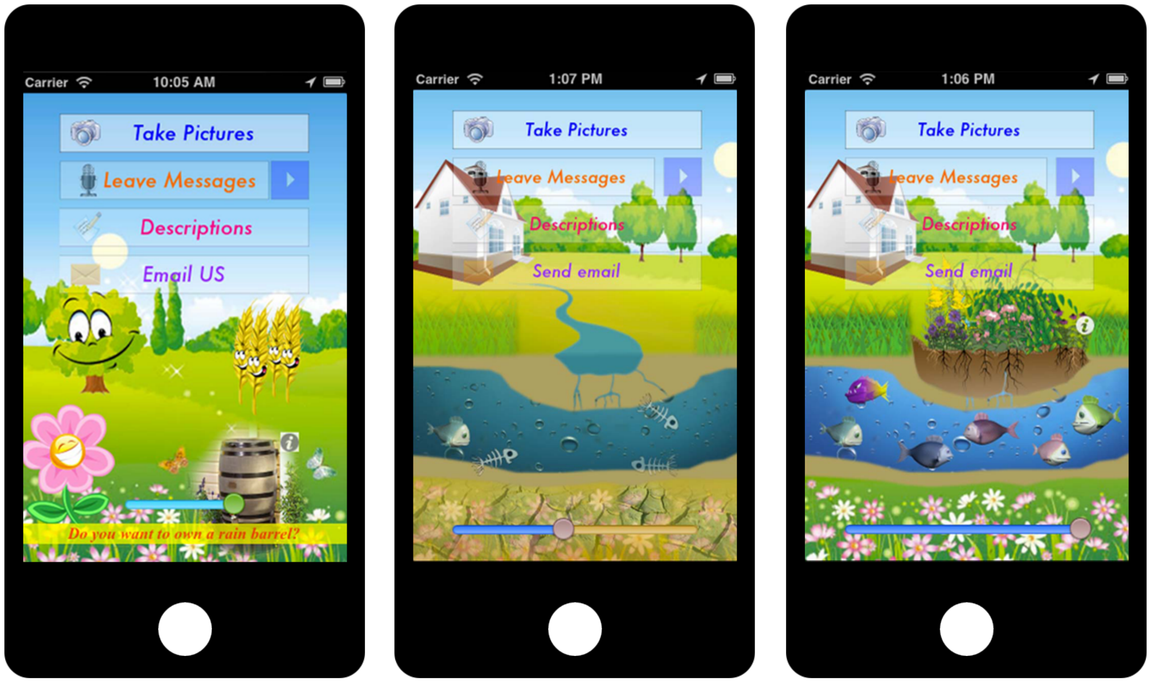


Figure 9 Screenshots of education pages in Omaha Green Infrastructure

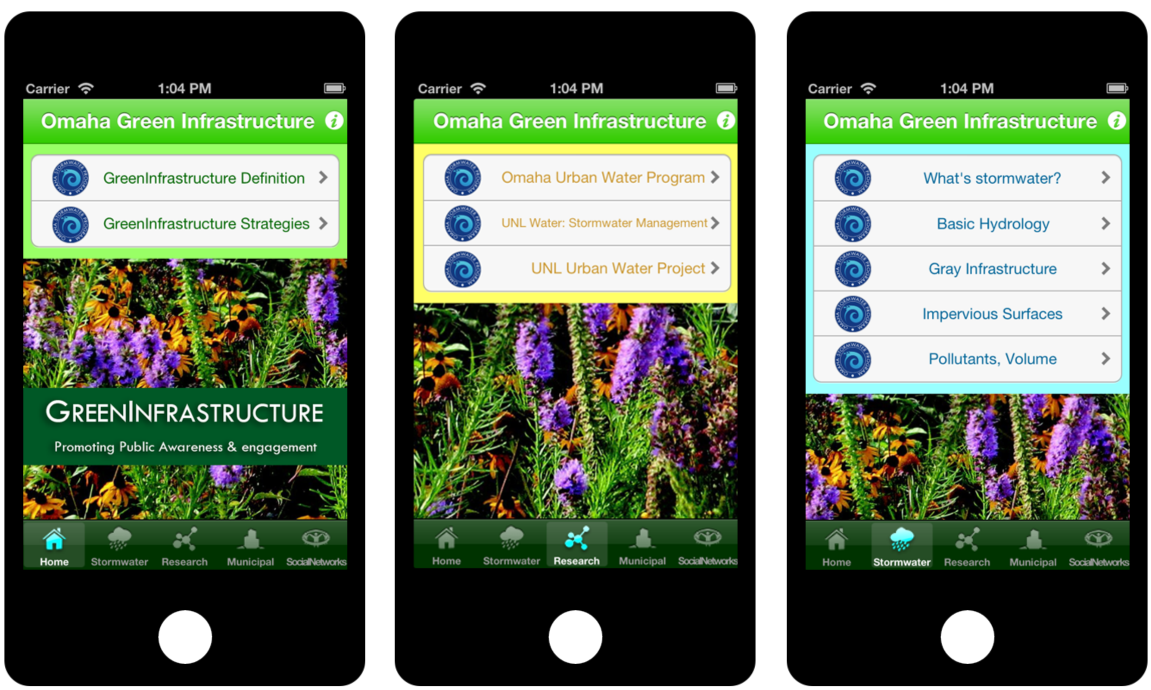


Figure 10 Sreenshots of U.S. Green Infrastructure Reporter

Appendix E: OVERVIEWS OF GREEN INFRASTRUCTURES

Figure 11 Green Infrastructures in America

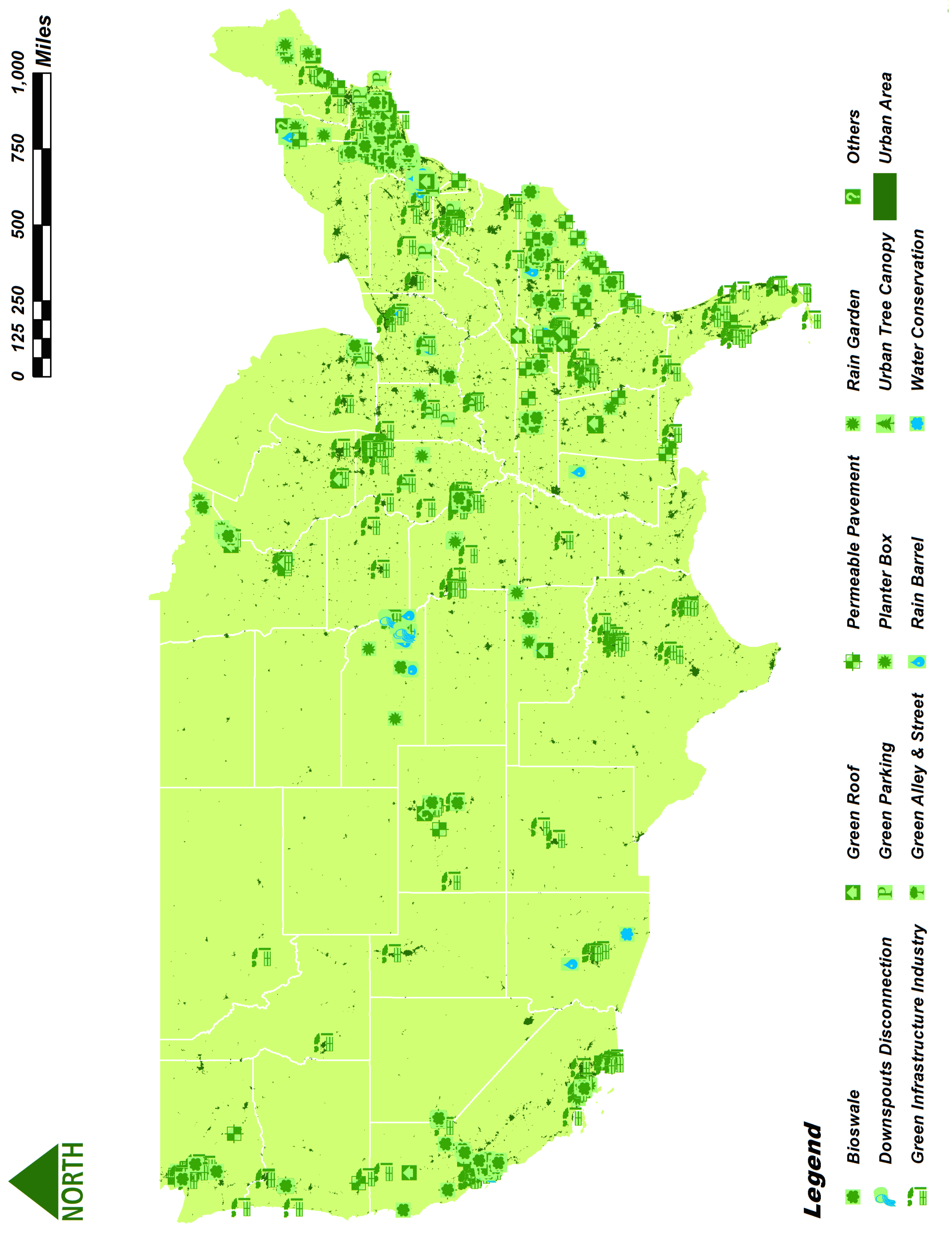


Figure 12 Bioswale in America

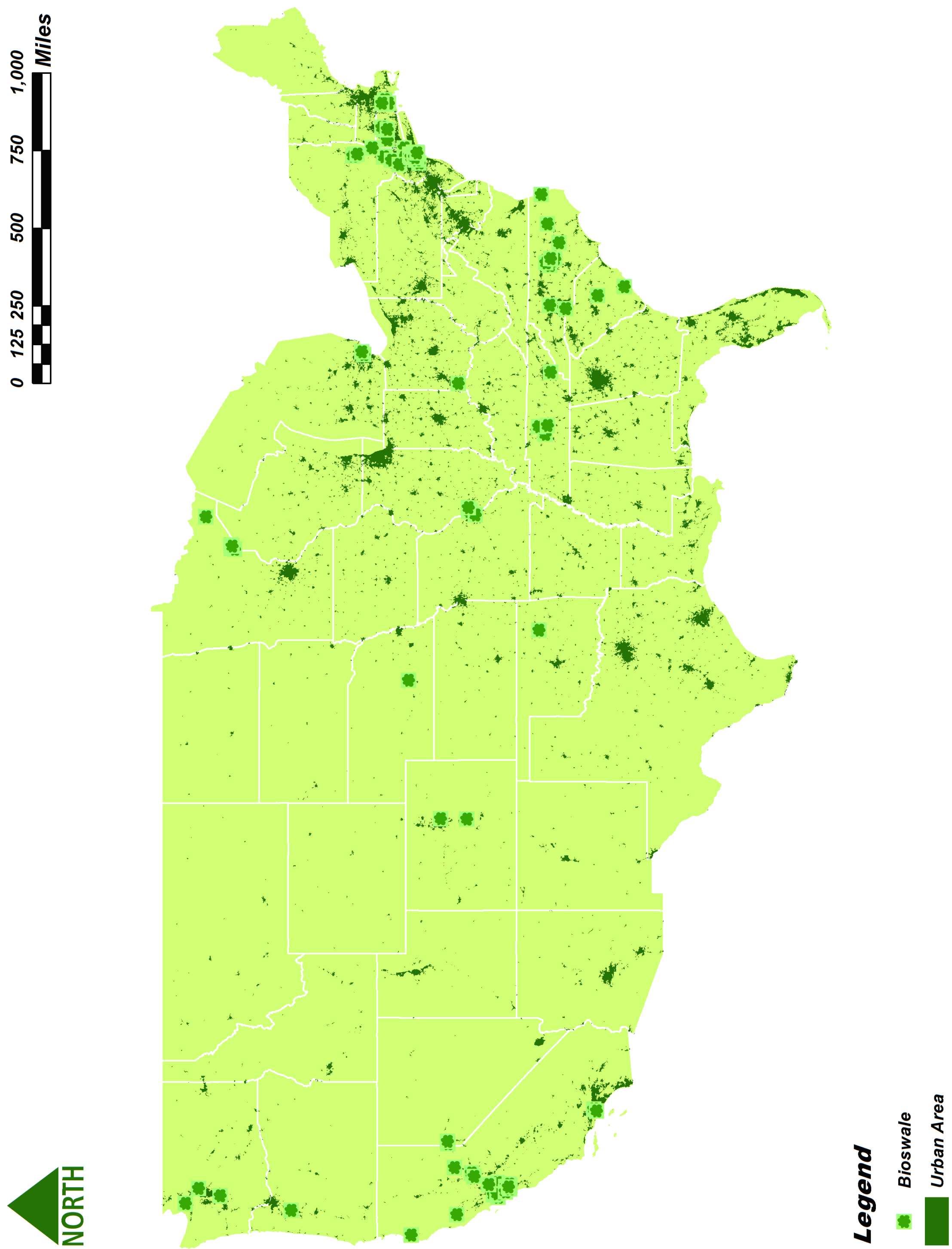


Figure 13 Green Infrastructure Industries in America

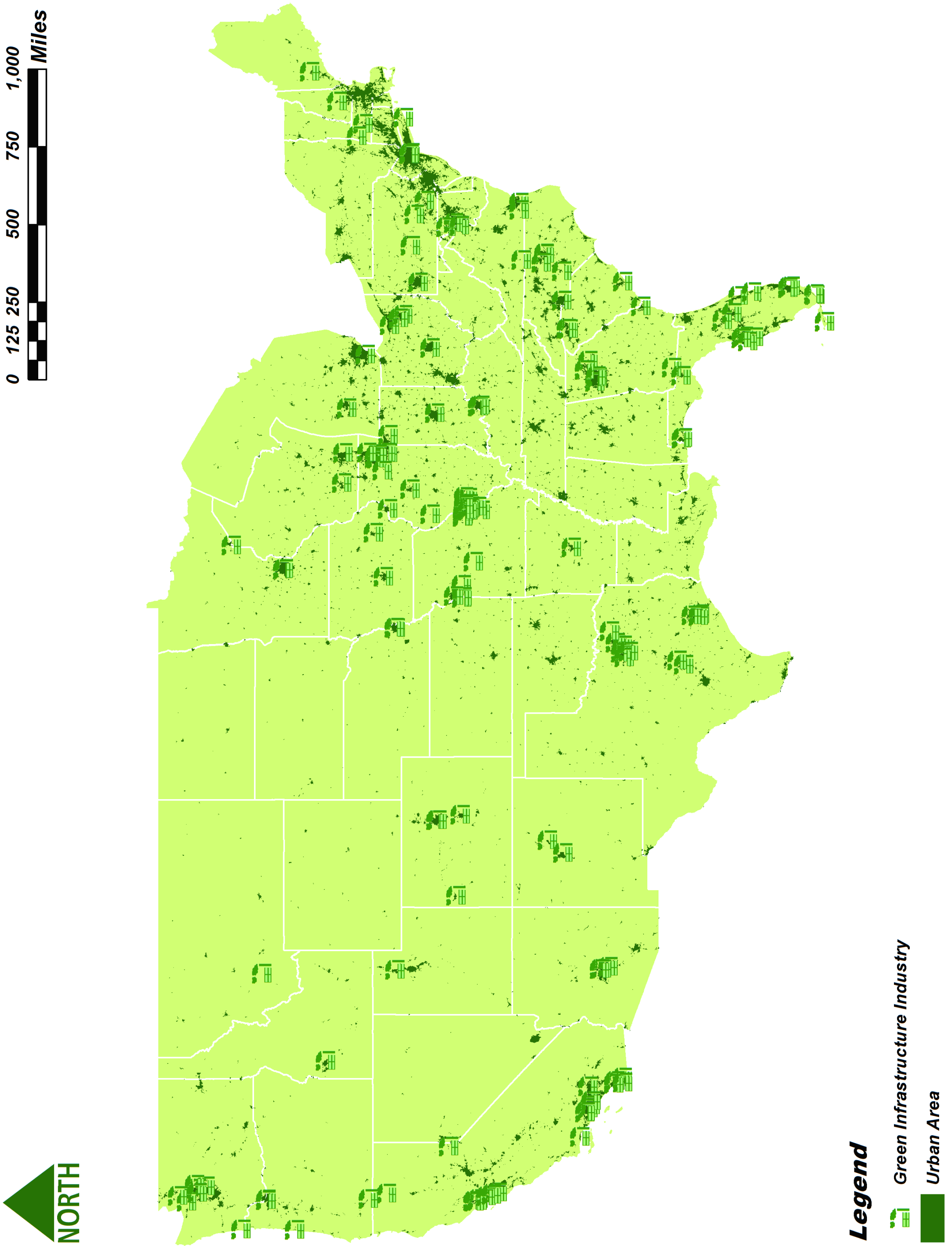


Figure 14 Green Parking in America

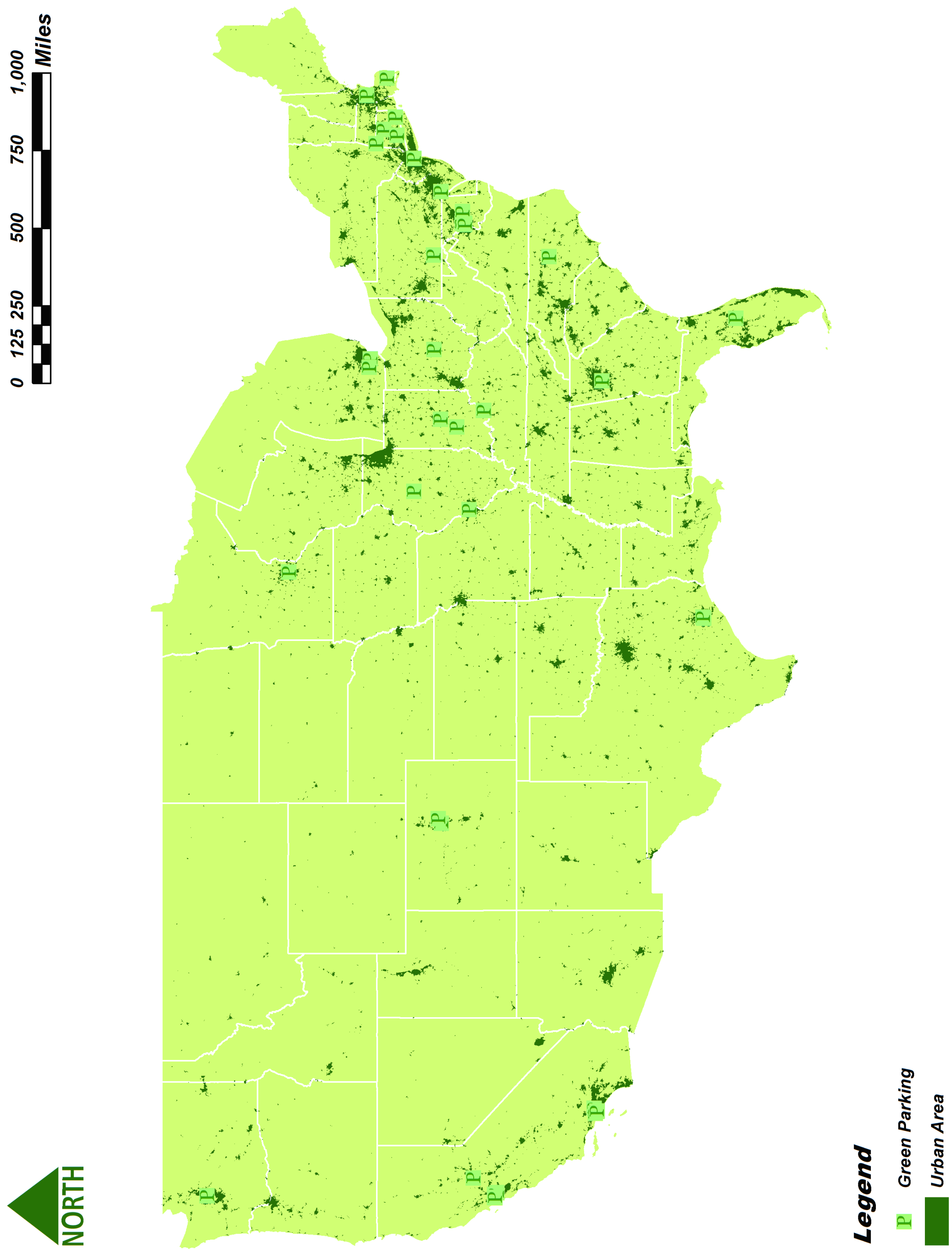


Figure 15 Green Roof in America

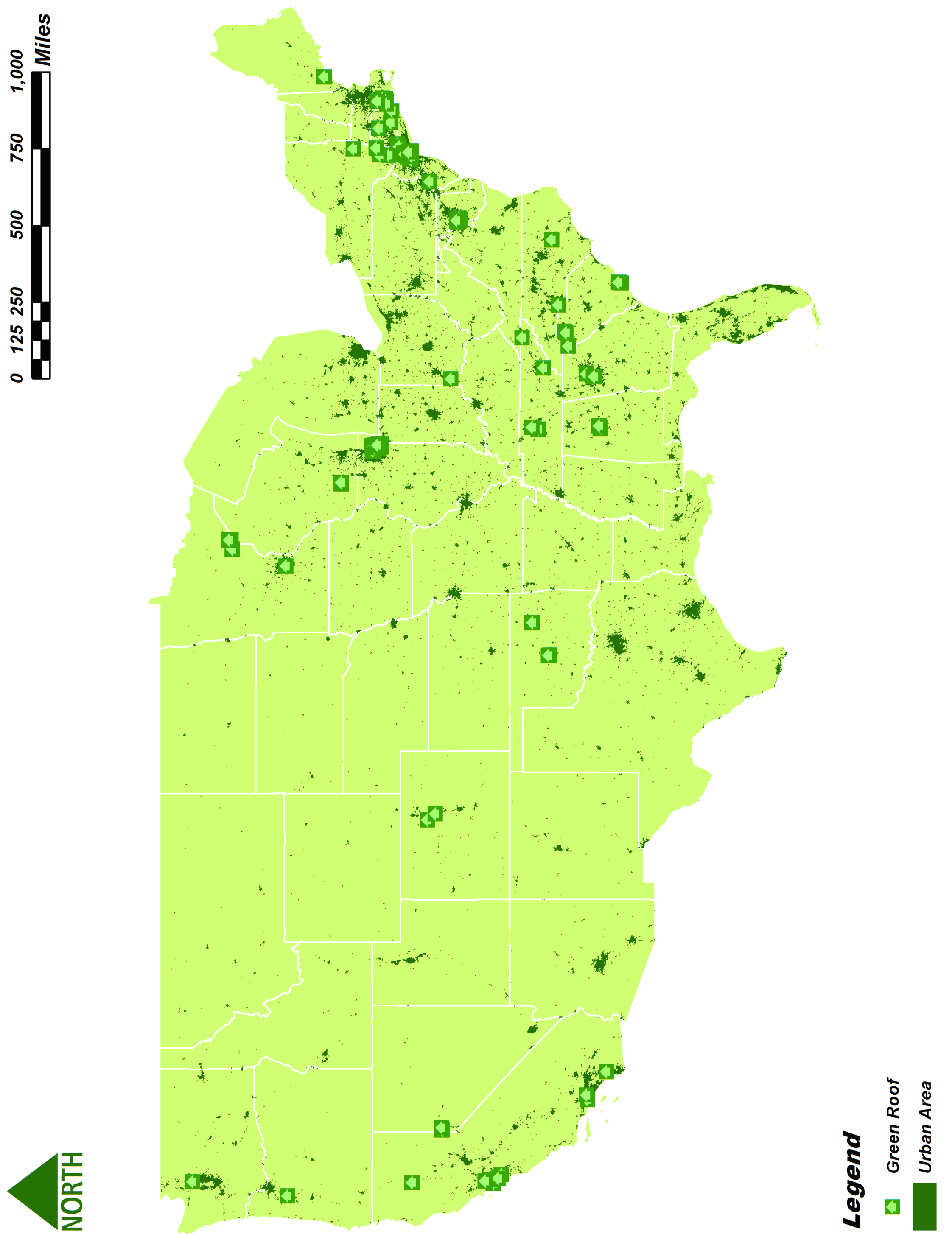


Figure 16 Permeable Pavement in America

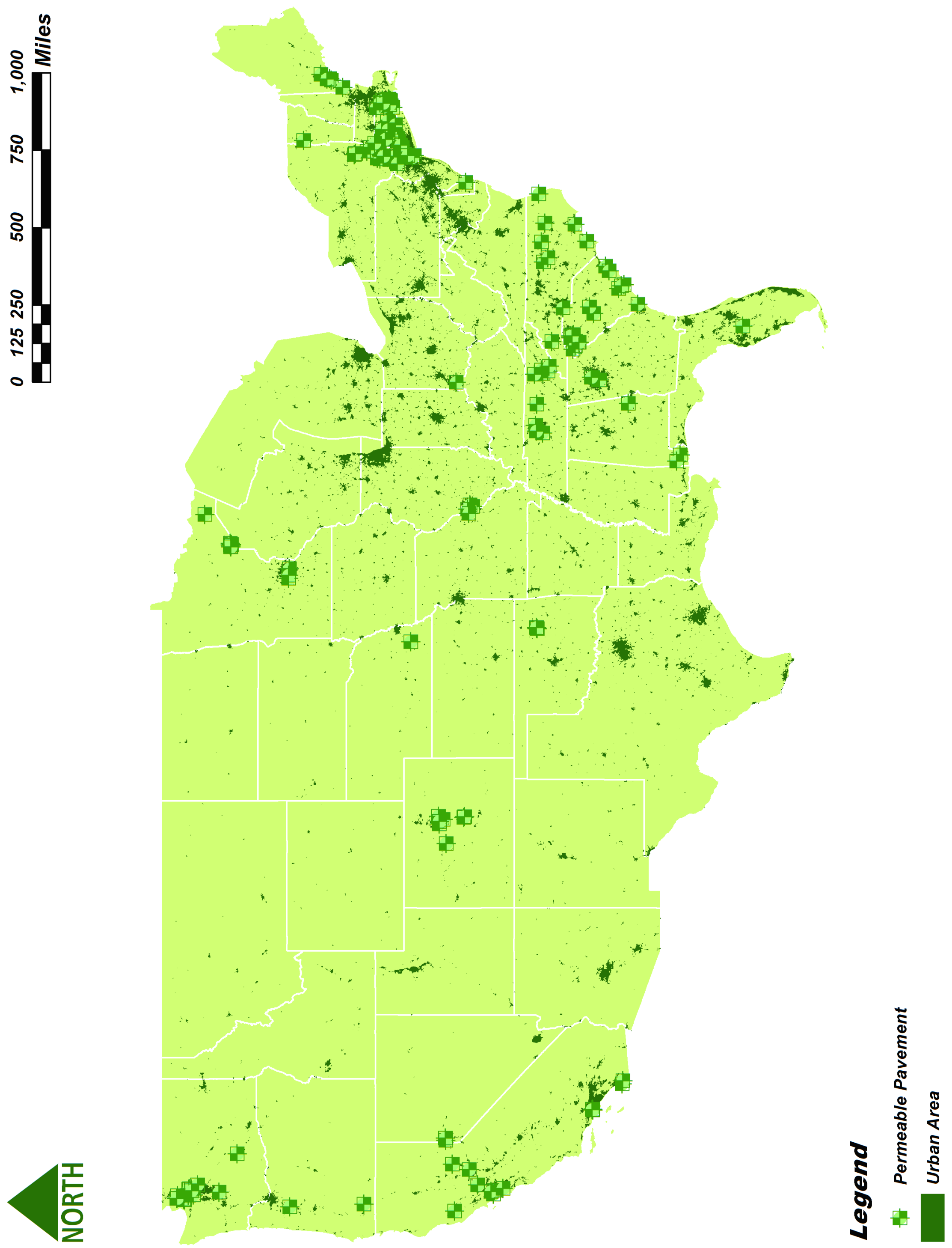


Figure 17 Rain Barrel in America

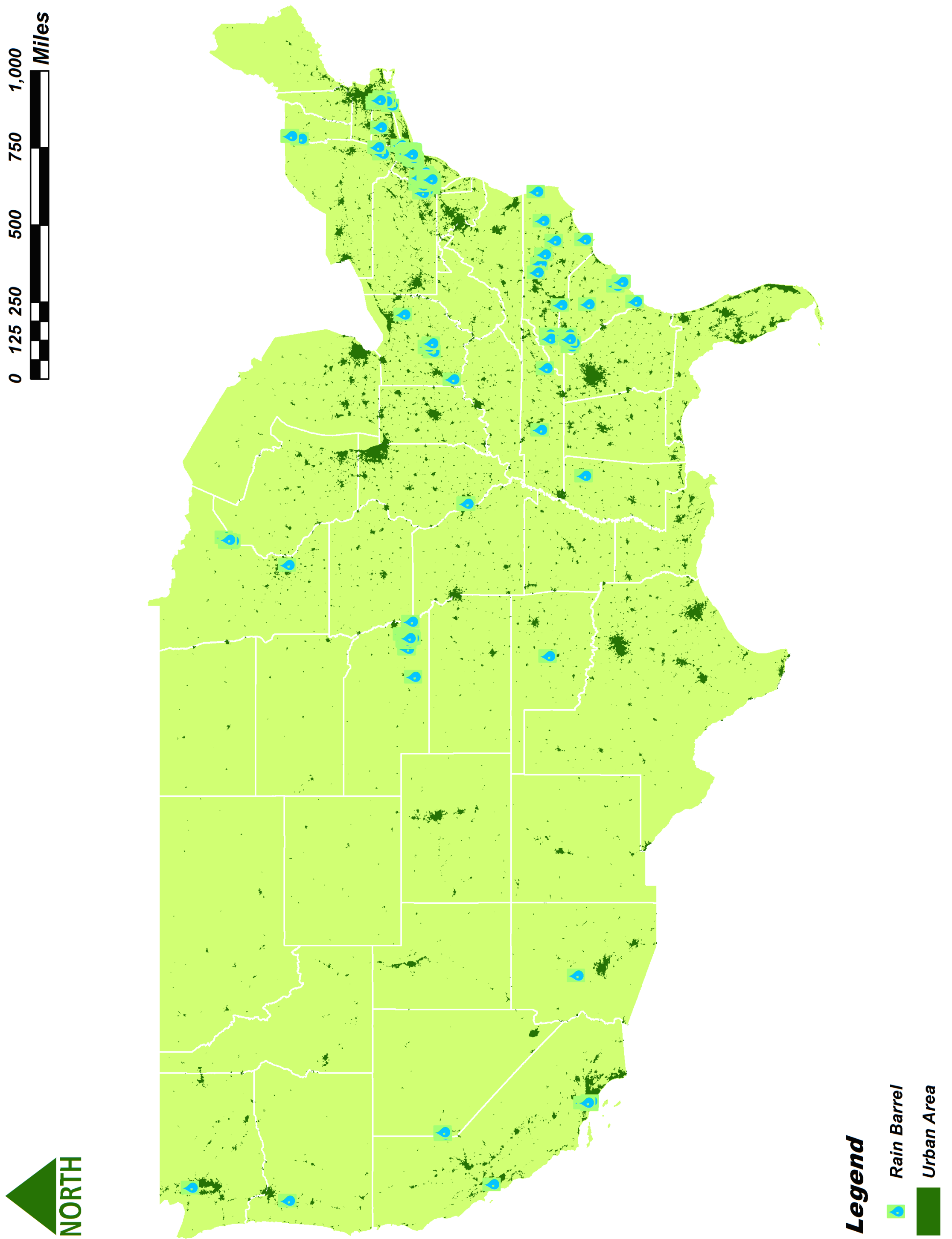


Figure 18 Rain Garden in America

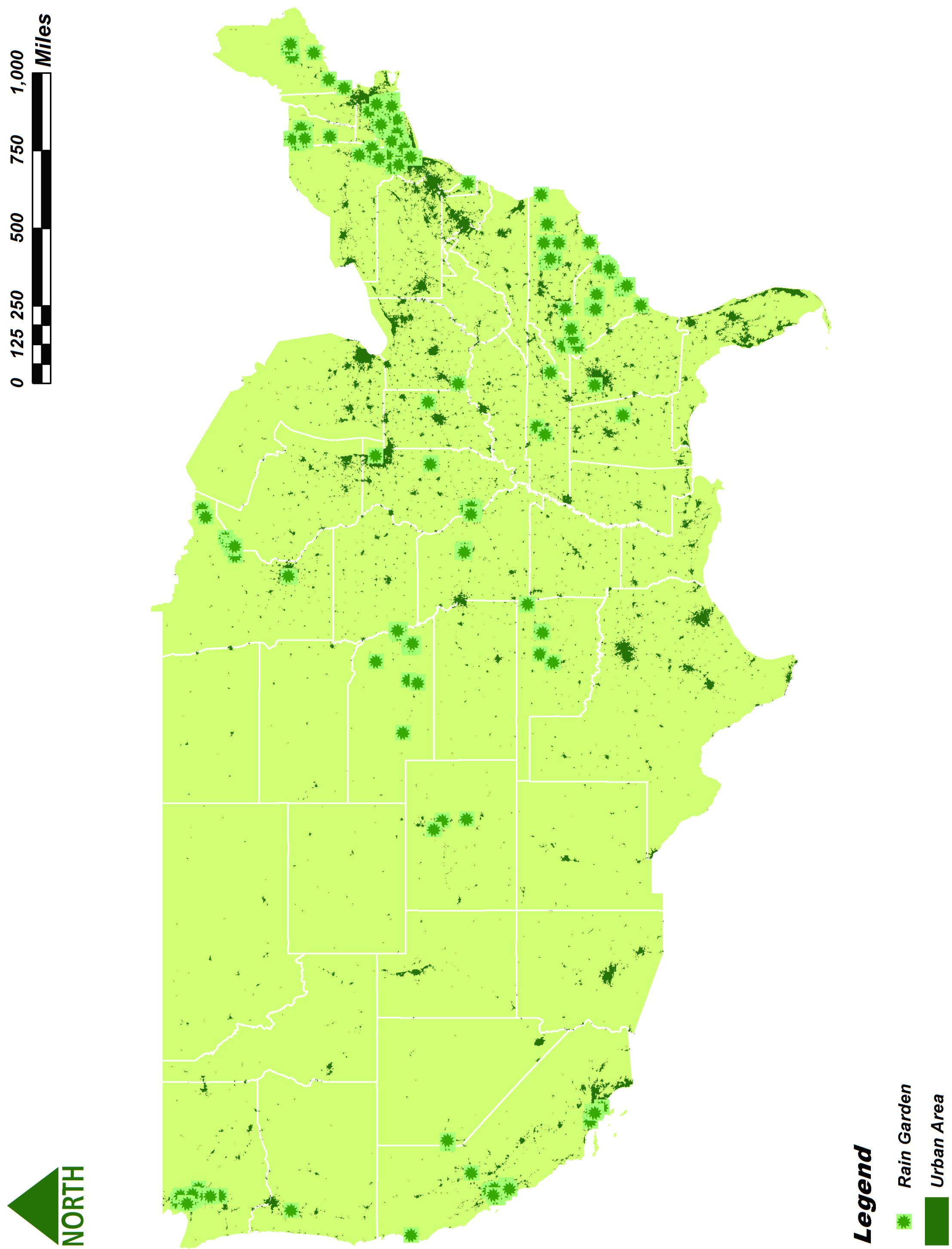


Figure 18 Water Conservation in America

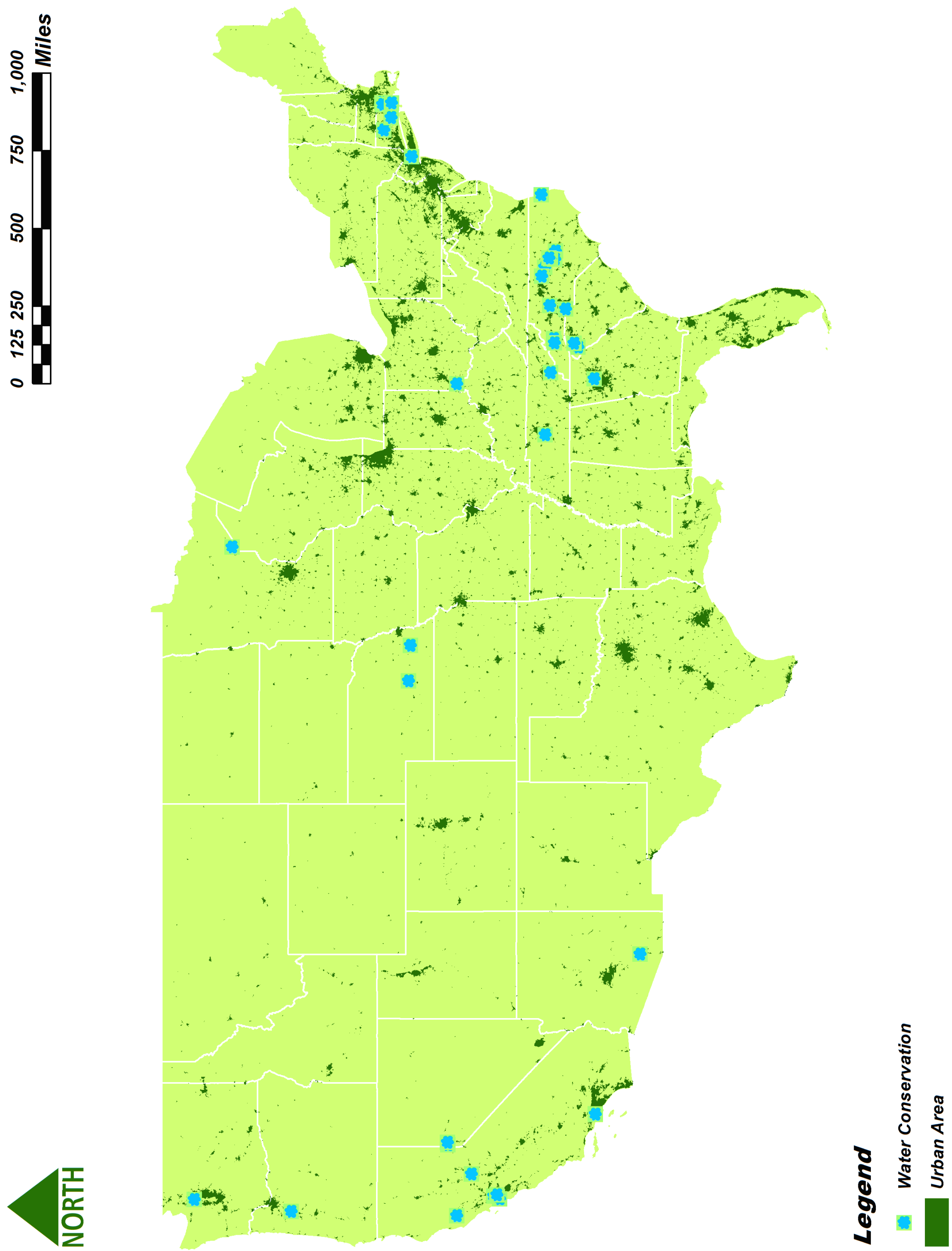


Figure 20 Green Infrastructure inventory results in Omaha, NE

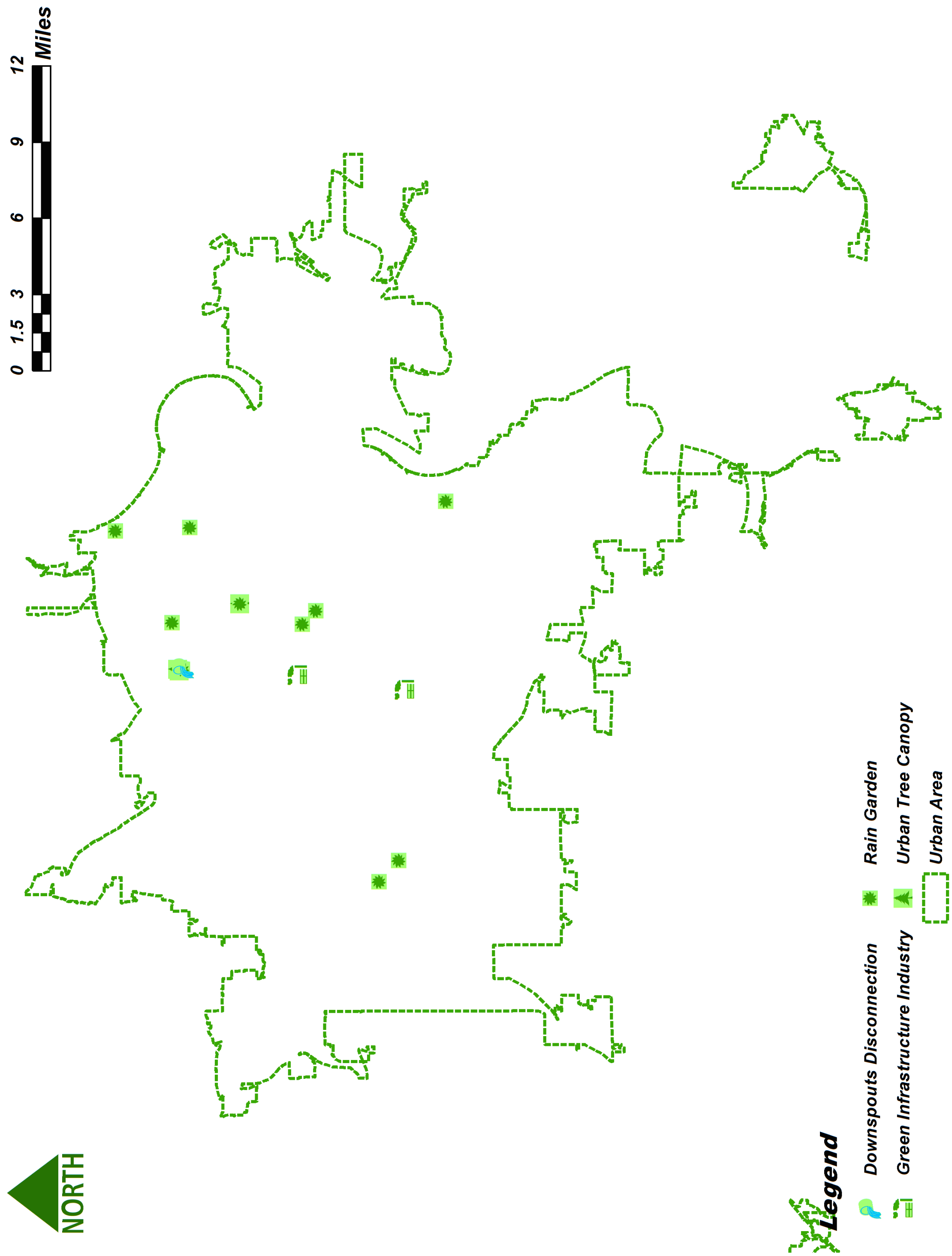
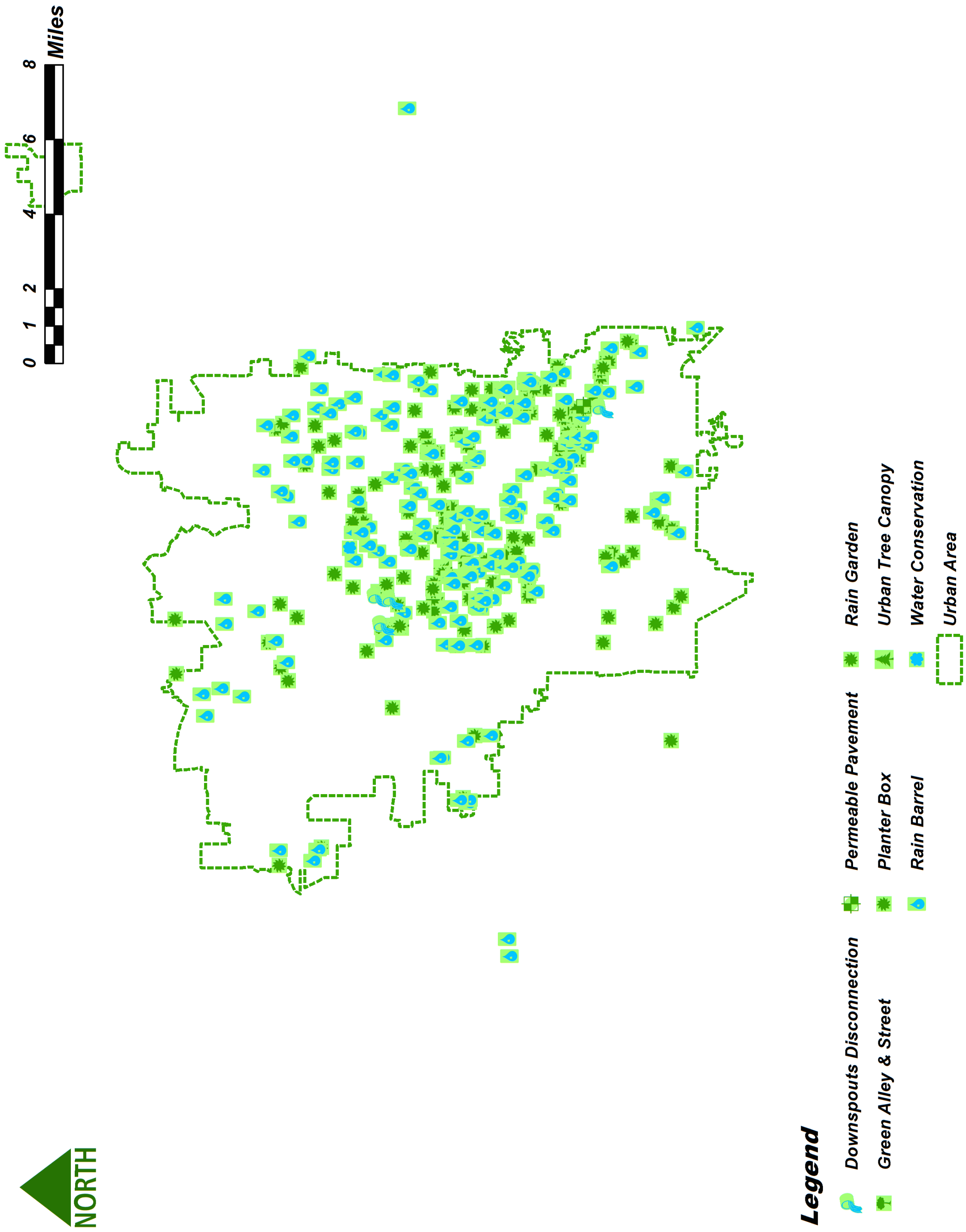


Figure 21 Green Infrastructure inventory results in Lincoln, NE



Appendix F: FEEDBACK

Figure 22 Feedback from professional users on ESRI's website