

Spatial Sustainability Assessment of Green Stormwater Infrastructure for Surface Transportation Planning, Phase I

Center for Transportation, Environment, and Community Health
Final Report



by

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Spatial Sustainability Assessment of Green Stormwater Infrastructure for Surface Transportation Planning

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Abstract: Transportation authorities are responsible for managing the stormwater runoff that carries pollutants from the transportation-adjacent land and vehicles. The proper stormwater management approach like green infrastructure can help control flooding and the runoff pollutants that may impair water environment and threaten the ecosystem and human health. Furthermore, green infrastructure that can be applied at different spatial scales and decentralized arrangements, have been adopted and implemented in the transportation infrastructure design. However, such implementation is project-based without analysis at system level or sewer scale. A framework is needed to design and evaluate the integration of green stormwater infrastructure in transportations planning at systems level. The overall goal of the proposed project is to develop a modeling framework integrating hydrological simulation, water quality modeling, life cycle assessment (LCA) and cost analysis (LCCA) that can be used for design and planning for surface transportation with spatial implementation of green infrastructures. The phase I of the project was completed in the first year with the deliverable of a method for constructing an inventory of the implemented green infrastructure using Tampa as a case study area.

Keywords: Stormwater management, Green infrastructure, Spatial optimization, Human health benefits, LCA, LCCA

INTRODUCTION

National Pollutant Discharge Elimination System (NPDES) regulates that transportation authorities are responsible for managing the stormwater runoff that carries pollutants from the transportation-adjacent land and vehicles. The proper stormwater management can help control flooding and the runoff pollutants that may impair water environment and threaten the ecosystem and human health. Green infrastructure is a stormwater management approach with many economic and human health benefits including: flood mitigation, erosion control, improved water quality, groundwater recharge, reduced energy demand during construction, enhanced aesthetics and access to green space, and preferred aquatic (fish) habitat (US EPA 2007; 2008; Wright Wendel et al. 2011; Kozarek et al. 2010). Unlike grey stormwater infrastructure systems that are often large and centralized, green stormwater infrastructure can be applied at different spatial scales and decentralized arrangements. Green infrastructures like permeable pavements (Rowe et al. 2010), bioswales (Lucas et al. 2015), bioretention (Li and Davis 2009), and constructed wetlands (Gill et al. 2014) have been adopted and implemented in the transportation infrastructure design. However, such implementation is project-based without analysis at the systems level or sewer scale. A framework is needed to design and evaluate the integration of green stormwater infrastructure in transportations planning at the systems level. The *overall goal* of the proposed project is to develop a modeling framework integrating hydrological simulation, water quality modeling, life cycle assessment (LCA) and cost analysis (LCCA) that can be used for design and planning for surface transportation with the spatial implementation of green infrastructures. The entire project will be conducted in three phases. The phase I of the project is planned in the first year of the project aiming at developing a method for constructing an inventory of the implemented green infrastructure using Tampa as a case study area.

Phase I Project

Phase I project was completed with the deliverable of a constructed inventory of the implemented green infrastructure in Tampa. Four activities were performed in the Phase I and were summarized as below.

First, a literature review was conducted to compile information related to existing green infrastructure (names, type, mechanism, function, implementation scale, tools used to estimate cost, regions of great benefits, application in transportation planning, and examples), previous LCA studies related to green infrastructure, the decision tools developed to implement green infrastructure, and implemented green infrastructure mapping. Then, the method was developed for creating a GIS layer of existing green infrastructure that can be overlaid with transportation and grey stormwater infrastructure network through trial and error. The data used for green infrastructure mapping were collected, including the GIS data of road centerlines, stormwater management facilities, and high-resolution land cover map. Two case studies for green infrastructure mapping were attempted, which showed an acceptable mapping accuracy. After that, a study area was determined at the sub-watershed of Middle Hillsborough River-Spillway 20 (HUC12 code: 031002050503) with the consideration of recent flooding reports, diversity of land uses, and applicability of future hydrology model. Eventually, all green infrastructures within the study area were mapped as GIS features and identified with their types based on green infrastructure characteristics compiled in this project, and an inventory for the implemented green infrastructure in Tampa was created.

LITERATURE REVIEW

LCA Studies on Green Infrastructure

LCA studies on green infrastructures are limited. Four studies were reviewed including Wang et al. (2013), Flynn and Traver (2013), De Sousa et al. (2012), and Spatari et al. (2011). These studies investigated various types of green infrastructures or alternatives of green and gray stormwater infrastructure for sewer systems. The green infrastructures were generally favorable in terms of water quality improvement, lower energy and global warming potential, lower eutrophication potential, and economic costs. Spatari et al. (2011), however, pointed out that the annual savings as a result of the implementation of green infrastructures were relatively small, compared with the energy and greenhouse gas emissions associated with the materials for the construction of green infrastructures. If implemented throughout an urban watershed, the green infrastructure strategies may produce larger energy cost savings to municipal water pollution control facilities and less environmental impacts. The LCA studies on green infrastructure for transportation planning were generally lacking.

Decision-Making Tools on Green Infrastructure

Some decision-making tools were designed for green infrastructure. The Green Infrastructure Toolkit developed by Georgetown Climate Center (n.d.), helps integrate green infrastructure components into projects in small to midsize communities by maximizing the capture, treatment, and infiltration of street stormwater runoff, while including the legal concerns like regulations, incentives, and government operations. GrowNYC's Green Infrastructure Toolkit (GrowNYC, n.d.) was designed for the cities that have combined sewers to utilize stormwater management techniques minimizing the effects of rainfall on water bodies. Watershed Education for Communities and Officials (WECO) developed an economic fact sheet about trade-offs of LID in communities through the analysis of construction cost, life-cycle cost, and cost-benefit (Beggs & Perrin, n.d.). The Center for Neighborhood Technology (CNT) developed the National Green Value Calculator (GVC) to compare the performance, cost, and benefits of green infrastructure to conventional stormwater practices with the goal of runoff volume reduction (CNT, 2006). CNT also provided a guide for decision-makers to quantify and value environmental, social, and public health benefits of green infrastructure (CNT, 2010). NOAA Coastal Zone Management Program's tool helps identify green infrastructure strategy in order to reduce flooding in the coastal areas by assessing the costs and benefits of green infrastructures (NOAA, n.d.). Overall, the decision tools for green infrastructure implementation mainly focused on stormwater quantity control, with the primary drivers of costs, regulations, and sometimes community benefits.

Green Infrastructure Mapping

Total 17 peer-reviewed papers and four project reports on the topic of green infrastructure mapping were found and reviewed. All of the existing studies on green infrastructure mapping are intended to identify green infrastructure opportunities. There is no study focusing on either mapping the implemented green infrastructure or identifying the types

of green infrastructure based on the surface features. Only one project focused on green stormwater infrastructure polygon drawing that was developed by City of Philadelphia (2015), however, errors were found in terms of green infrastructure mapping and type recognition. A method is needed for mapping and identifying existing green infrastructure based on currently available datasets.

METHODOLOGY

Methodology Development

The methodology for green infrastructure mapping was developed and revised after repeated attempts. Figure 1 shows the main steps. All the roads within the area of interest are categorized into major roads (interstates, US highways, state roads, and county roads) and other roads. Both the major roads with cutted curbs or no curbs and the other roads with no inlets intersected within 60 feet are selected to create 60-ft wide buffering. The buffered areas overlapped with the regions of water, grass and tree in the land-cover image are identified as the potential green infrastructure (GI) sites. Google Earth street view pictures are used to confirm the identified green infrastructure sites. According to the unique visual characteristics of each green infrastructure type compiled in this project, the types of green infrastructures at the potential GI sites are identified, to eventually create the transportation-attached green infrastructure inventory.

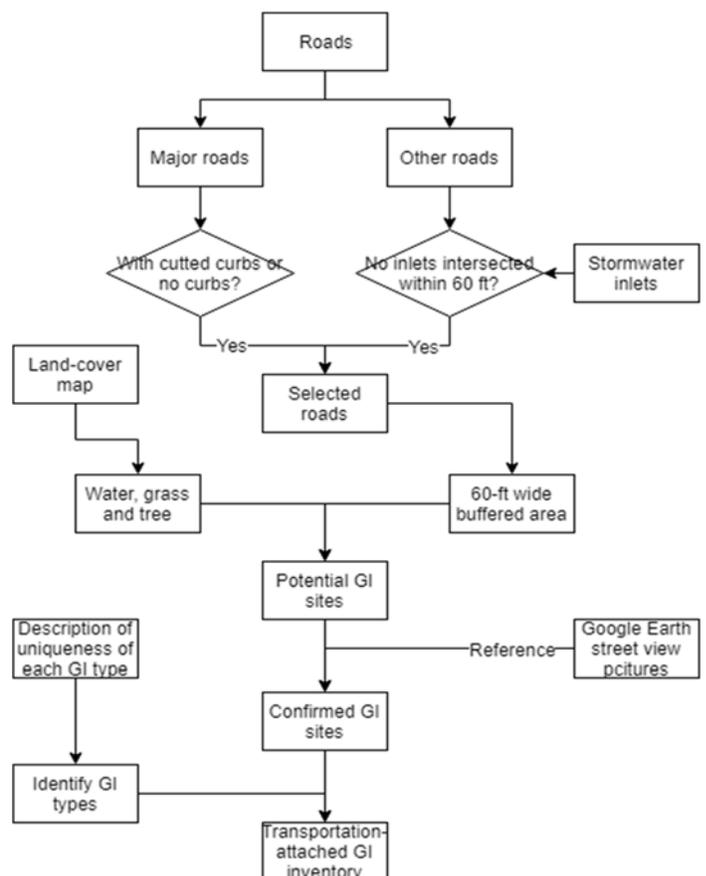


Figure 1. The process diagram to create the green infrastructure (GI) inventory.

Table 1. Data collected and the sources.

Data	Produced Year	Source
Road centerline	2017	City of Tampa GeoHub
Stormwater inlets	2017	http://city-tampa.opendata.arcgis.com/
Stormwater basins	2017	
Stormwater discharge points	2017	
Stormwater redline property	2017	
Stormwater detention areas	2017	
Stormwater gravity mains	2017	
Stormwater pressured mains	2017	
Stormwater open drains	2017	
Reported street flooding	2017	City of Tampa Transportation & Stormwater Services
Watershed Boundary Dataset	2009	U.S. Geological Survey
Tampa land cover	2011	USF Water Institute http://waterinstitute.usf.edu/map

Data Collection

Some GIS data were collected to map the implemented green infrastructure in Tampa. Table 1 lists the collected data and their sources. All the data of road system and stormwater management facilities were formatted as shapefiles and available to the public with the open data link. The reported street flooding provided by City of Tampa Transportation & Stormwater Services recorded the flooding locations during 2015-2017. The Watershed Boundary Dataset by U.S. Geological Survey (USGS) defines the national hydrological boundary at six different geographical levels from regions to sub-watersheds. The non-public raster image of Tampa land cover was created with a rule-based object-orientated classification method utilizing high-resolution imagery, LIDAR data and ancillary GIS data by USF Water Institute. It has a 1-foot-by-1-foot resolution, providing extremely high accuracy as a reference map. All the data were adjusted to the GCS_North_American_1983 coordinate system. During the data collection, the connections with the city government and USF Water Institute were established.

Methodology Testing

Two regions were selected for testing the green infrastructure mapping methodology developed in this study; including Central Tampa and New Tampa (see Figure 2). Central Tampa is a typical residential area that was constructed before the 1950s. Relatively few green infrastructure or best management practices (BMP) were utilized in this area for stormwater management. Most of roads and streets are attached to gray infrastructure or no stormwater infrastructure. New Tampa is a newly constructed area with most of the constructions built in the past two decades. Gray and green infrastructures were both widely adopted in New Tampa. Figure 3 shows the green infrastructure mapped in Central Tampa and New Tampa. The mapped green infrastructures were double checked with the Google Earth street view pictures and the mapping accuracy is acceptable. Specifically, as shown in Figure 4 for Central Tampa, a circle-shape dry pond (a type of green infrastructure) is surrounded by both the no-curb ramp from the I-275 exit and the curb-with-inlet streets. Using the methodology developed in this project, it was successfully identified and mapped even under such complicated condition. Figure 5

shows a section of I-75 interstate highway and its street view pictures. There are several inlets between the two-way lanes with some grassland on both sides of the road. The grassland provides functions for stormwater control but is considered as a general BMP which is broadly defined as management practices addressing water quantity and/or quality stressors caused by stormwater, rather than green infrastructure that focuses on stormwater source control using small-scale practices disseminated throughout the watershed (Fletcher et al. 2014).

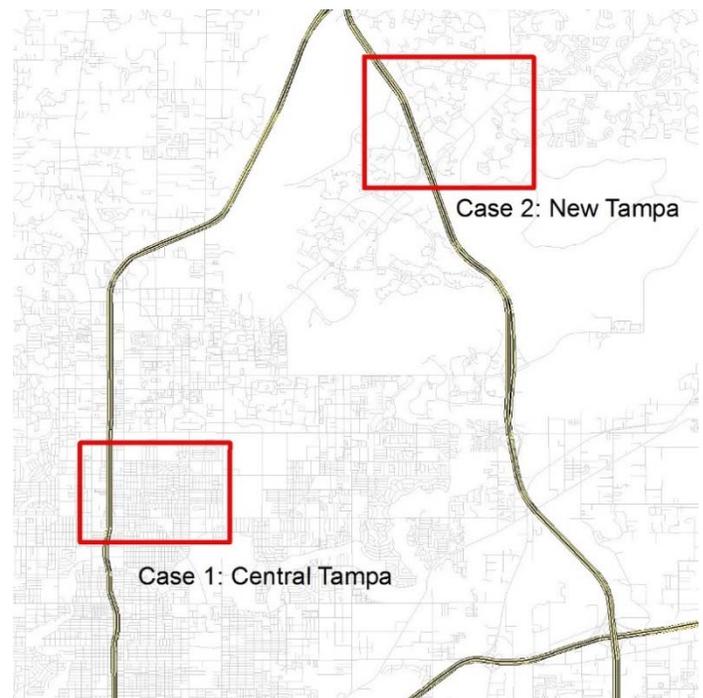


Figure 2. Locations of the two case studies.

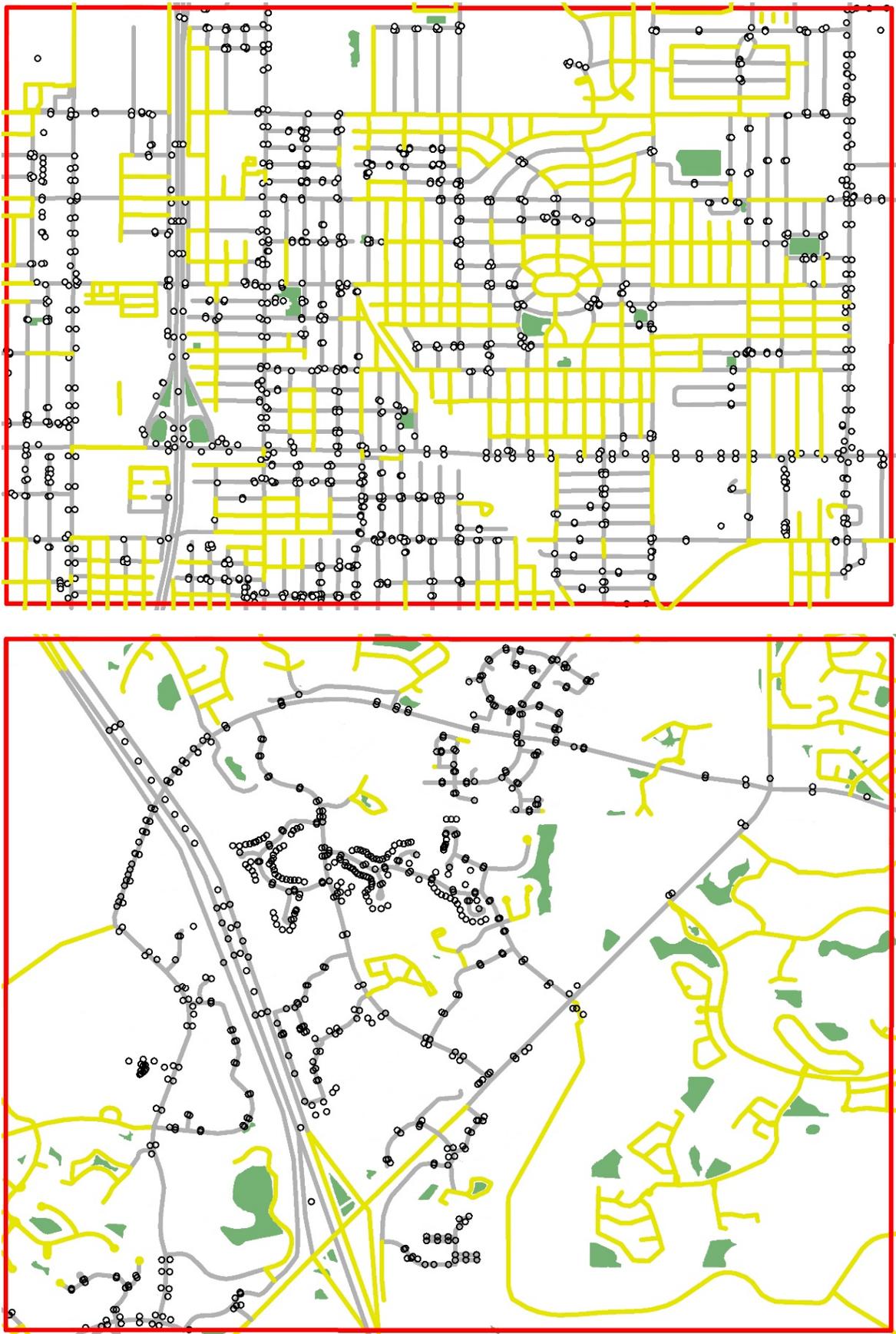


Figure 3. The green infrastructure in Central Tampa (upper) and New Tampa (below). The yellow lines display as the selected roads, the gray lines as the other roads, the dots as the stormwater inlets, and green polygons as green infrastructure.



Figure 4. A specific green infrastructure in Central Tampa and its street view picture.

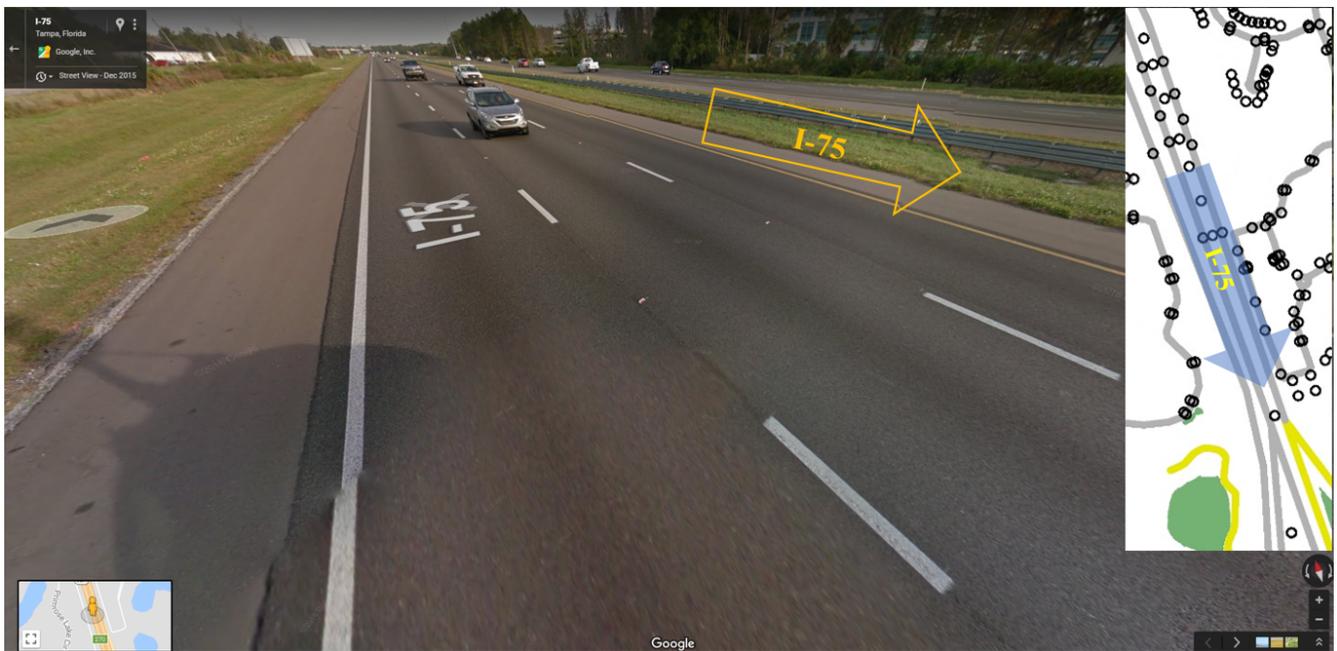


Figure 5. A best management practice (BMP) in New Tampa and its street view picture.

STUDY AREA

To define the study area for creating the green infrastructure inventory, some rules were taken into consideration:

1. a limited area for acceptable workload;
2. a region under flood risk;
3. an area consisted of diverse land uses;
4. an area could work as input to future hydrology model, like SWMM5 by USEPA.

To meet the requirements, the Middle Hillsborough River-Spillway 20 subwatershed area (HUC12 code: 031002050503)

was selected for this project (see Figure 6). It covers an area of 125 km², approximately 30% area of Tampa City. According to the reported street flooding in the last three years, about half of the study area has been suffered from the flooding incidents and better stormwater management is a need in the area. Adjacent to the downtown Tampa, most of the study area is for urban use, including business, commercial, residential, recreational and some other community mixed uses. Moreover, the subwatershed area could be imported into SWMM5 as a standard hydrologic unit input. The inventory of green infrastructure was created for this study area as a representative of Tampa City and Hillsborough County.

However, the framework of creating green infrastructure inventory, as well as of integrating hydrological simulation, water quality modeling and sustainability assessment related to surface transportation with spatial implementation of green infrastructures (Phases II and III), is transferrable and can be applied to other areas.

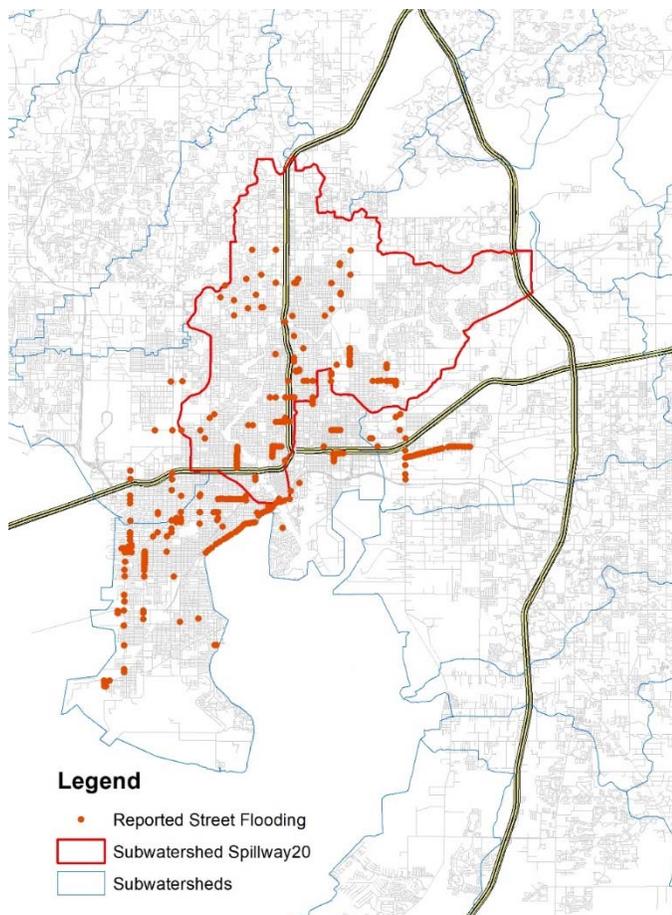


Figure 6. The study area (marked as red) in this project.

FINAL OUTPUTS AND DISCUSSION

To create the inventory of the implemented green infrastructure, all green infrastructures within the study area were mapped following the method developed in this project, and then identified with their types according to their visual features.

Identify Green Infrastructure Types from Visual Features

To help with mapping green infrastructure, a list of differences between them was compiled. This listing focuses first on obvious visual features (such as shape or size) to identify the infrastructure types (see Table 2). To further differentiate between the infrastructures in cases where the different types share many obvious features, features such as vegetation types and water retention times were identified.

Table 2. Visual features of different types of green infrastructure.

Green Infrastructure	Visual Features
Rain barrel	Not necessarily shaped like a normal barrel, but generally round; are approx. 2-3 feet in diameter
Rain cistern	Much larger than rain barrels, also have a greater range in diameter since their sizes have a larger range (a few thousand gallons up to around 40,000 gallons), diameters being around 4-10 feet; generally have a more industrial looking appearance
Bioretention cell	Lower than its immediate surroundings; generally has more precise border geometry than anything natural (e.g., sharp angles, long straight edges, or perfectly circular)
Rain garden	Typically smaller than bioretention cells; they often have more varied vegetation since they are used for aesthetics as well
Dry swale	Full of rocks and gravel, often contains little to no vegetation, generally linear in shape; lower than immediate surroundings
Wet swale	Linear in shape as well, full of vegetation however instead of rocks and gravel; also lower than immediate surroundings
Constructed wetland	Will contain similar aquatic plants to normal marshes, but the border geometry will generally be fairly artificial in appearance, having distinct boundaries and straight edges
Infiltration basin	Very similar to dry ponds. Sometimes is not grassy on bottom though, may just be large rocks and gravel
Infiltration trench	Generally linear in shape, or will follow the edge of some other development (e.g., a road); less vegetation in them, possibly none, consists of gravel and rocks of various sizes
Vegetated filter strips	Areas bordering developments that are slightly lower than immediate area, are covered in grass or other types of vegetation
Sand filter	Appears in similar shapes and places to the vegetated filter strips, except only contains sand and little to no vegetation
Riparian buffer	Located along the edges of streams, so their border geometry may vary; high amounts of vegetation, generally including trees as well
Pervious concrete	Relative to normal concrete, upon close inspection it will have larger aggregate sizes with clear gaps between them
Porous asphalt	Similar to the pervious concrete, just black in color
Permeable interlocking pavers	Will appear like standard brickwork, but the bricks will have noticeable gaps between them that appear to be filled with gravel as opposed to seamless mortar
Downspout disconnection	Will have some kind of regularly shaped structure around its base, usually some kind of channel to direct the water flow into an area of lawn, also may be surrounded by large rocks and gravel to aid in the filtration; often on the corners of buildings
Urban tree canopy	Usually line roads in highly developed areas that do not have space for greenery on their own
Green roof	Located on the roofs of building, significant amount of vegetation will cover the roof

Create the Green Infrastructure Inventory

Using the methodology developed, total 105 green infrastructures were mapped within the study area (see Figure 7). The urban area in Tampa expanded from south to north, indicating the communities in the north were newly built. In line with the characteristics of city development, most of the green infrastructures as new practices of stormwater management were detected in the north of the study area. A limited number of green infrastructures were implemented along the major roads. It indicates that the transportation related stormwater infrastructures in Tampa are mainly gray infrastructure. For the business districts at the southern corner of the study area, green infrastructures were rarely detected due to the wide adoption of impervious surface in the downtown and its surrounding areas.

All the green infrastructures detected were identified with their types (see Table 3). Most of the green infrastructures are

wet ponds with a relatively larger surface area, followed by urban tree canopy. The green infrastructures with ground vegetation, such as bioretention, rain garden, or vegetated filter strip, were implemented to a very limited extent.

Table 3. Different types of green infrastructure identified.

Type	Count	Average Area (1,000 ft ²)
Dry Pond	5	93.0
Bioretention/ Rain Garden	3	1.7
Urban Tree Canopy	16	15.6
Vegetated Filter Strip	4	15.4
Wet Pond	77	91.8

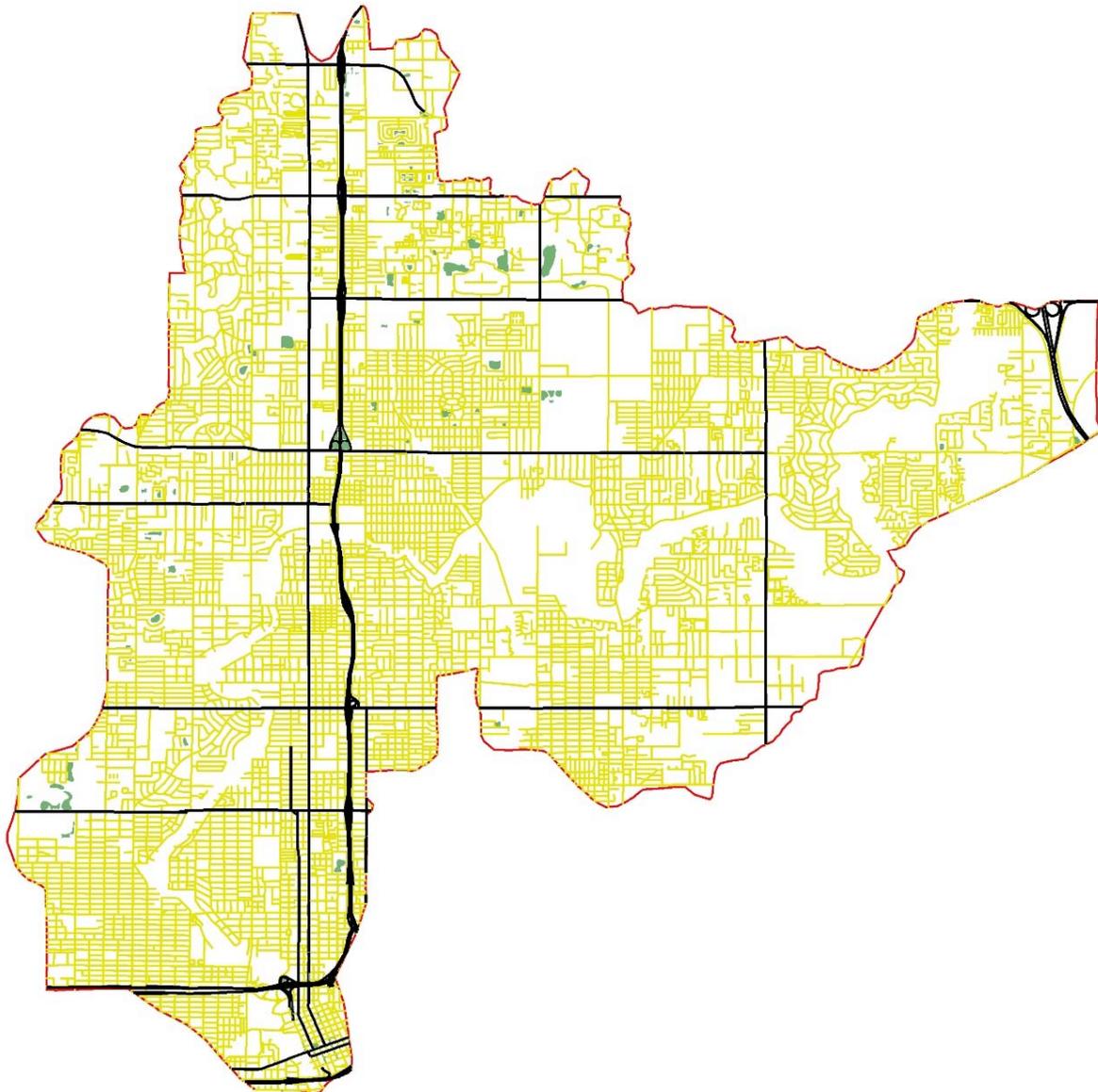


Figure 7. Green infrastructure mapped in the study area. The black lines display as major roads and green polygons as green infrastructure.

CONCLUSION

According to the previous studies, green infrastructures as an alternative stormwater management strategy could provide significant benefits such as energy saving and environmental impact reduction, especially when implemented at a large scale (e.g., watershed). However, the spatial implementation of green infrastructures and their potential environmental benefits for transportation planning requires further evaluation, which is part of the contribution from this project.

The method for green infrastructure mapping in this project was developed based on GIS techniques and remote sensing data, filling the research gap in green infrastructure mapping. It is transferrable and can be applied to other locations besides the study area of Tampa Bay in this project.

Within the study area, the green infrastructures were implemented to a very limited extent for urban transportation stormwater management. Among the green infrastructure mapped, most of them are the ones with large surface area (e.g., wet or dry ponds). Some small green infrastructures such as bioretention systems or vegetated filter strips haven't been applied widely in the study area; even they were demonstrated to have great benefits in terms of water quality controls.

FUTURE RESEARCH

The green infrastructure inventory created in the Phase I will be the input to the Phase II of the project focusing on the integration of hydrological and water quality modeling for scenario analysis of a combination of transportation planning and green infrastructure design. Human health aspect will be highlighted in both water quality control and impact assessment. The trade-off between environmental, human health and economic impacts will be investigated to provide suggestions for both existing streets' green infrastructure upgrades and future roads' stormwater management design.

REFERENCE

- Beggs, P., & Perrin, C. (n.d.). Low Impact Development -an economic fact sheet. Retrieved from https://www.ces.ncsu.edu/depts/agecon/WECO/nemo/documents/WECO_LID_econ_factsheet.pdf (December 20, 2016).
- Center for Neighborhood Technology. (2006). Green Values National Stormwater Management Calculator. Retrieved from <http://greenvalues.cnt.org/national/calculator.php> (December 20, 2016).
- Center for Neighborhood Technology. (2010). The Value of Green Infrastructure: A Guide to Recognizing Its Economic, Environmental and Social Benefits. Retrieved from http://www.cnt.org/sites/default/files/publications/CNT_Value-of-Green-Infrastructure.pdf (December 20, 2016).
- City of Philadelphia (2015). Stormwater Management Practice Polygons. Retrieved from <https://www.opendataphilly.org/dataset/green-infrastructure-constructed-project-polygons> (August 15, 2017).
- De Sousa, M. R. C., Montalto, F. A., & Spatari, S. (2012). Using Life Cycle Assessment to Evaluate Green and Grey Combined Sewer Overflow Control Strategies. *Journal of Industrial Ecology*, 16(6), 901-913.
- Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.L. & Mikkelsen, P.S. (2015). SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, 12(7), pp.525-542.
- Flynn, K. M., & Traver, R. G. (2013). Green infrastructure life cycle assessment: A bio-infiltration case study. *Ecological Engineering*, 55(0), 9-22.
- Georgetown Climate Center. (n.d.). Green Infrastructure Toolkit. Retrieved from <http://www.georgetownclimate.org/adaptation/toolkits/green-infrastructure-toolkit/introduction.html> (December 20, 2016).
- Gill, L. W., Ring, P., Higgins, N. M., & Johnston, P. M. (2014). Accumulation of heavy metals in a constructed wetland treating road runoff. *Ecological Engineering*, 70, 133-139.
- GrowNYC. (n.d.). Green Infrastructure Toolkit. Retrieved from <https://www.grownyc.org/gardens/green-infrastructure-toolkit> (December 20, 2016).
- Kozarek, J. L., Hession, W. C., Dolloff, C. A., & Diplas, P. (2010). Hydraulic complexity metrics for evaluating in-stream brook trout habitat. *Journal of Hydraulic Engineering*, 136(12), 1067-1076.
- Li, H., & Davis, A. P. (2009). Water quality improvement through reductions of pollutant loads using bioretention. *Journal of Environmental Engineering*, 135(8), 567-576.
- Lucas, S., Clar, M., & Gracie, J. (2015). A Green Street Retrofit in a Chesapeake Bay Community Using Bioswales. In *Low Impact Development Technology: Design Methods and Case Studies*, American Society of Civil Engineers, Reston, VA.
- NOAA. (n.d.). NOAA Office for Coastal Management | The National Coastal Zone Management Program. Retrieved from <https://coast.noaa.gov/czm/> (December 20, 2016).
- Rowe, A. A., M. Borst, & T. O'Connor. Environmental Effects of Pervious Pavement as a Low Impact Development Installation in Urban Regions - Chapter 13. Chapter 14. In *Effects of Urbanization on Groundwater: An Engineering Case-based Approach for Sustainable Development*, American Society of Civil Engineers, Reston, VA.
- Spatari, S., Yu, Z., & Montalto, F. A. (2011). Life cycle implications of urban green infrastructure. *Environmental Pollution*, 159(8-9), 2174-2179.
- US EPA (2007). *Reducing stormwater costs through low impact development (LID) strategies and practices* (Report No.: EPA 841-F-07-006). Environmental Protection Agency, Washington DC.
- US EPA (2008). Managing Wet Weather with Green Infrastructure. Retrieved from <http://cfpub.epa.gov/npdes/greeninfrastructure/information.cfm#enviroben> (December 20, 2016).
- Wang, R., Eckelman, M. J., & Zimmerman, J. B. (2013).

Consequential Environmental and Economic Life Cycle Assessment of Green and Gray Stormwater Infrastructures for Combined Sewer Systems. *Environmental Science & Technology*, 47(19), 11189-11198.

Wright Wendel, H. E., Downs, J. A., Mihelcic, J. R. (2011). Assessing equitable access to urban green space: The role of engineered water infrastructure. *Environmental Science & Technology*, 45(16), 6728-6234.