GIS-Enabled Rain Garden Design:
A Case Study in Austin, Texas

GIS in Water Resources (C E 394K-3)

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1. Abstract

Green stormwater infrastructure (GSI) can be used in place of traditional gray infrastructure to convey stormwater runoff, while also slowing down the flow velocity as well as removing contaminants and debris, as opposed to gray infrastructure. Rain gardens are a form of GSI that can be used for residential and commercial properties to collect and filter all of the drainage that goes to that area. A rain garden can be easily designed within a geographic information system (GIS) by combining Python coding and widely accessible data. By integrating all of the design parameters into a GIS one can perform all of the design calculations in one interface rather than by using multiple programs as well as manual calculations and retrieval. The rain garden design tool allows city engineers and planners to quickly and easily create a design for a rain garden based on site characteristics. The tool allows for time and cost savings as city engineers and planners will be able to simply select a point and all of the calculations needed in less than an hour. The overall objective of this project is to adapt a vegetated swale design tool to design a rain garden in Austin, Texas.

2. Introduction

2.1 Background

Geographic Information Systems (GIS) are used to integrate mapping and data analytics together in one interface. By using a GIS, one can bring together various forms of spatial data to produce maps and other forms of outputs. By incorporating various forms of data including: land cover usage, digital elevation models (DEM), and precipitation data; an engineer can quickly get approximate designs for various forms of stormwater infrastructure.[1]

Stormwater infrastructure can be defined as any kind of structure or system that is used to convey (or retain and slowly release) all of the precipitation to a desired location. Traditional stormwater infrastructure is made of concrete and/or metals, which quickly transports all of the runoff from the point that it hits a surface, as well as any debris, trash, or particles, to the outlet. Examples of traditional "gray" infrastructure can be concrete or steel culverts, concrete ditches, and roads. Gray infrastructure does not slow down or remove anything from the water therefore all of the water and debris carried by the water will enter the waterbody at extremely high velocities, volumes, and contamination levels.[2] Stormwater runoff results in changes in stream behavior and characteristics, such as volume, flow pattern, and water quality.[2] Due to these effects of gray stormwater infrastructure on the receiving body of water, a new conveyance method needs to be implemented while also having the same ability to transport and/or store and release runoff.

Green Stormwater Infrastructure (GSI) is an environmentally-friendly alternative to gray infrastructure. GSI is better for the environment because instead of transporting all of the water from stormwater runoff with all of the debris and contaminants, GSI allows the runoff to infiltrate into the groundwater table, as well catching and filtering out trash and contaminants.[3] With many areas in the Southwest United States trying to determine ways to find more potable water, groundwater recharge through GSI is a viable option to aid the process because of how the GSI filters the water before allowing it into the groundwater table. Some of the forms of GSI include: rain gardens, vegetated swales, infiltration strips, etc.

There are many challenges for people to design GSI efficiently. One of the main challenges is that it takes time to learn how to design GSI.[4] Another challenge is the amount of time that it takes to collect (and process) all of the necessary data needed to efficiently design GSI.[4] The novelty in this project is that it not only generates plan sheets detailing the design of the rain garden, but it also recommends what kind of plants to install based on what plants are native to the region and weather tolerant.

It is important to know that implementing a single piece of GSI, especially if used at one home, will not collect as much water as would be draining to that area, but would rather, the GSI would fill up taking the first flush of contaminants and debris while the remaining water would be carried away as it normally is through gray infrastructure. One of the novelties of this project is the ability of the GIS to be able to perform all of the design calculations in one interface as well as the ability to design multiple types of infrastructure based on what the user desires.[5, 6, 7]

Rain gardens are designed to collect all of the water that is draining to that area and filter it before it goes back into the groundwater table. Rain gardens have been chosen as the GSI to design because of their versatility in use. Rain gardens can be designed for residential or commercial use.[8] Rain gardens allow for infiltration and filtration of stormwater into the groundwater.[4] Depending on the depth of the rain garden as a whole and the depth of the individual media layers, a rain garden can filter out large debris, heavy metals, pathogens, among other contaminants.[8]

2.2 Project Objectives

This project creates an innovative way to use a GIS to design and give recommendations on how to implement a rain garden, which is a kind of GSI for either residential or commercial use. The main focus of this project is to convert a framework and tool designed and used by Greer et al. to design a rain garden rather than a single barrel concrete culvert. The study will mirror Greer et al.'s to expand the work that is being done by first author, Ashton Greer, Ph.D. Candidate at The University of Alabama. In Figure 1, a framework adapted from Greer et al. shows the general flow of the tool.

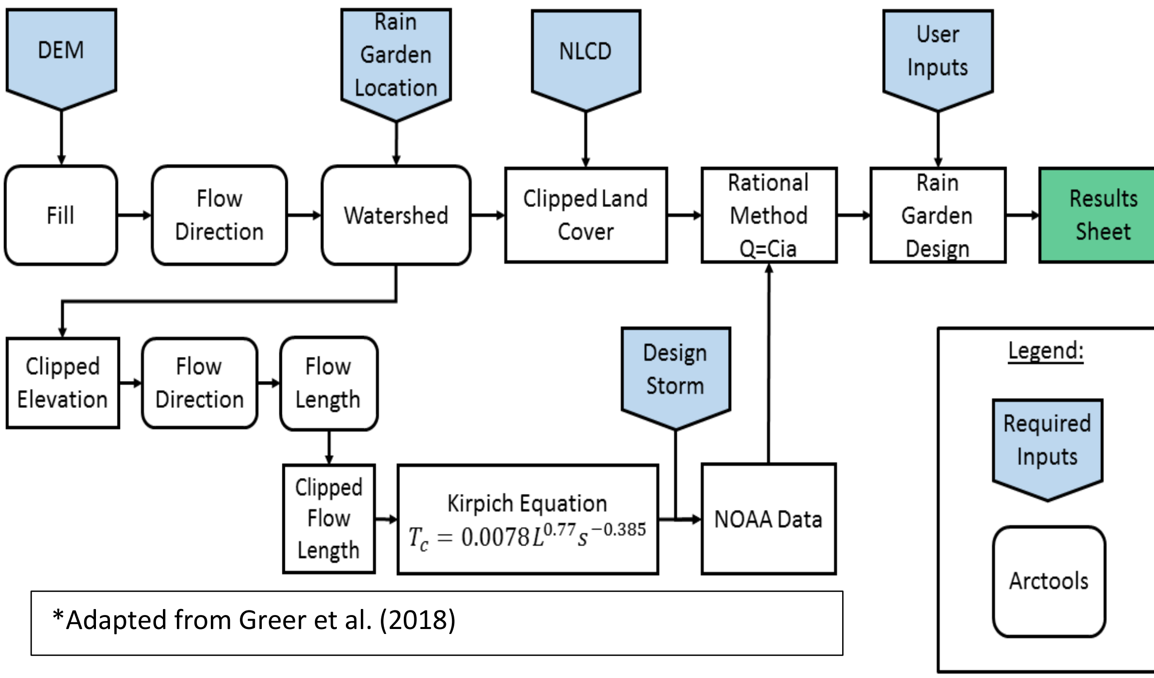

Figure 1: Rain Garden Design Tool Flow Path

3. Methodology and Data:

3.1 Data Sources

The only data needed to run the Rain Garden Design Tool are the Digital Elevation Model (DEM) for the area and the most recent National Land Cover Database (NLCD). The most current NLCD is NLCD 2011, but at the end of 2018, the NLCD 2016 will be released. The DEM needs to be at a maximum 10 meter resolution, but a 1 meter resolution DEM can be used especially if the tool is being used for a small area. Figure 2a shows the 10m resolution DEM for the City of Austin, and Figure 2b shows the NLCD 2011 for the City of Austin. A hydrologic soil group (HSG) map from the United States Geological Survey (USGS) can also be used for some steps in site selection.

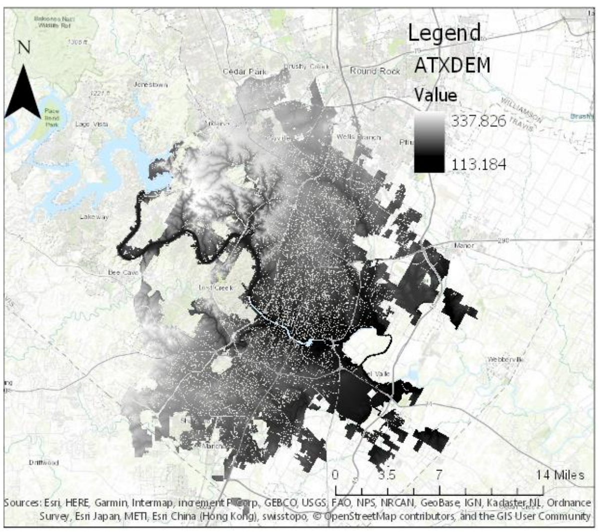

Figure 2a: 10 meter DEM for Austin, Texas

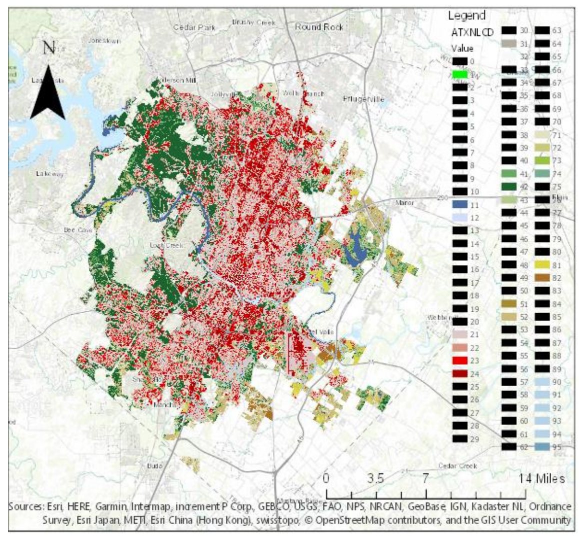

Figure 2b: NLCD 2011 for Austin, Texas

3.2 Current Design Methodology

The current methodology to design rain gardens varies across not just state lines, but also city boundaries. With no standard design methodology, it is important to follow the handbook that is provided for the region. Following the City of Austin's Environmental Criteria Manual (COAECM), the rain garden requires a large amount of steps to ensure that it designed to collect all of the stormwater draining to that area without overtopping. To design a rain garden, a city engineer or planner needs to do three preliminary steps: (1) Desktop Study, which is using published reports to estimate the site's soil characteristics, (2) Field Sampling, which is to physically take soil samples to determine the site's characteristics from the lab, and (3) In-situ Testing, which is to perform a percolation test at the site to see how the results correspond to steps (1) and (2).[8] Optimization of this phase is crucial, because of how long it would take the city to actually determine the infiltration rate of the soil at the site. Step (3) of this phase is very weather-dependent, since it cannot be raining or have recently rained when performing the percolation test. The runoff amount can be determined by determining what design storm, at least a 25 – year frequency storm, produces how much precipitation in inches per hour, then multiplying by the runoff coefficient, which is determined from the percent impervious and pervious area, and the size of the drainage area being designed for. [9] The Rational Method, while not completely accurate, is used widely in industry and is chosen as the equation to determine the peak flow rate. The EOAECM then designates how much surface area should be used for the rain garden and then, assuming a circular rain garden in being designed, the depth required for the volume of water from the 25 – year storm can be found. [9] The final output would be a plan sheet then seen in Figure 3. All of this work, which will take several days once the steps for determining the infiltration rate are accounted for can be optimized by using the Rain Garden Design Tool, which uses the equations from the COAECM.

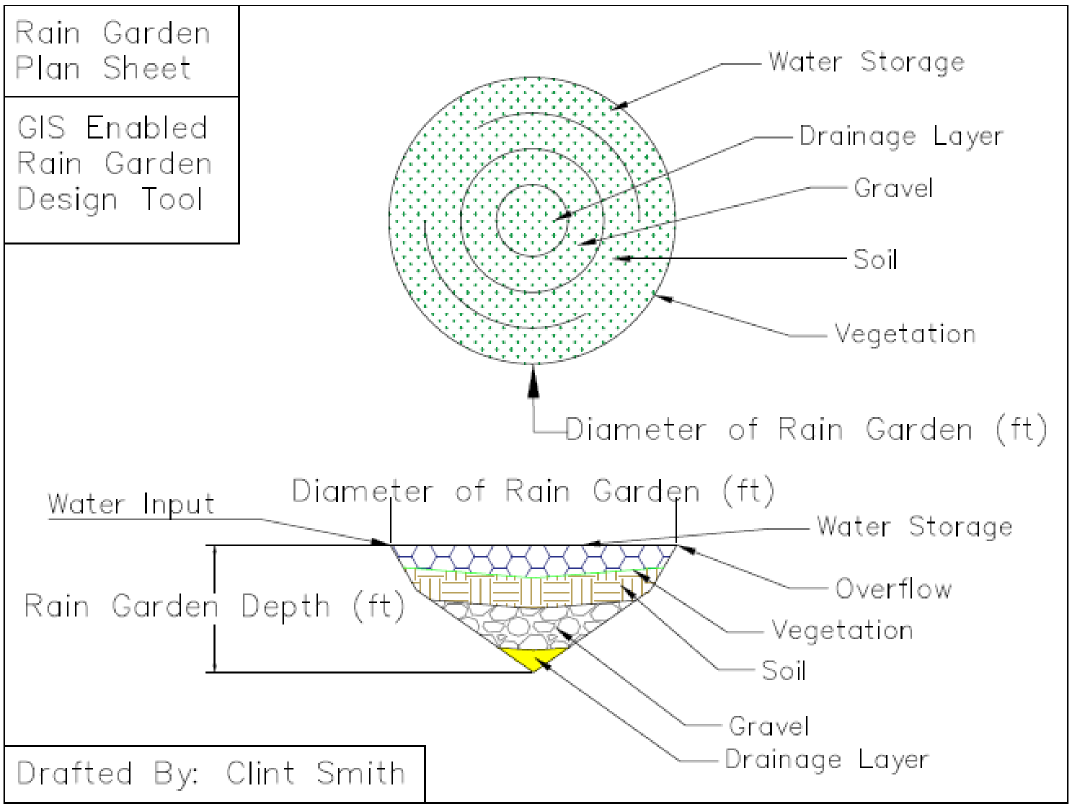

Figure 3: Rain Garden Plan Sheet

3.3 Proposed Design Methodology

To optimize the design process for rain gardens, a HSG map can be made to determine the infiltration rate of the soil at the site that the rain garden will be built. The infiltration rate of the soil could be determined from the map because of known relationships between infiltration rate (inches per hour) and HSG, which the map shows what group the majority of the soil in the area.[9] All of the design calculations rather than being performed in multiple programs, coupling ArcGIS and HEC-HMS or HEC-RAS or EPA SWMM, can be performed within ArcGIS without manual retrieval of data from the National Oceanic and Atmospheric Association (NOAA) for precipitation data.[1] The Rain Garden Design Tool performs all of the watershed delineation and flow routing rather than each tool having to be ran separately, saving the user time using the tools and time to learn how to do general hydrologic modelling. In Figure 4, the data being processed can be seen as clips of the rasters generated. Having this process automated for the user eliminates a space where human error could be present. The Rain Garden Design Tool will iterate the equations outlined in the COAECM until the minimum requirements (surface area and depth) are met.

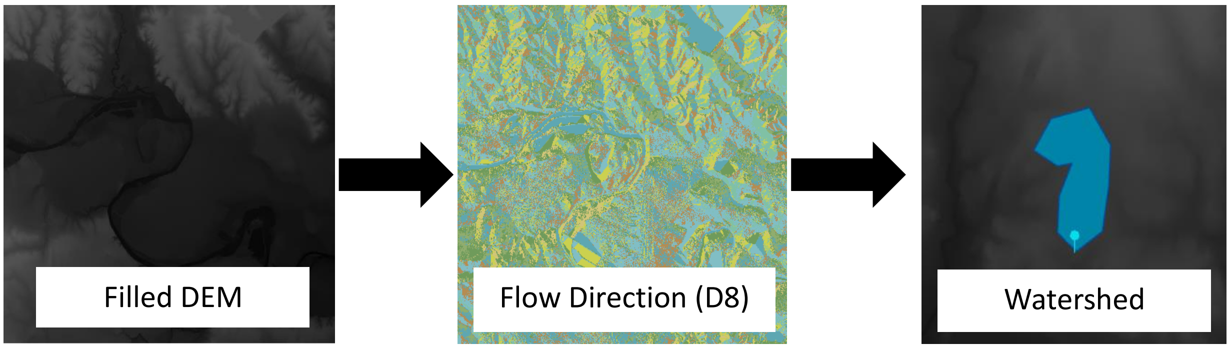

Figure 4: Partial Progression of Rain Garden Design Tool

3.4 Application of Tool

The tool can be applied in Austin, Texas only because of the design calculations used. If the design equations are specific to the COAECM, rather than just the Texas Commission on Environmental Quality (TCEQ) or the United States Environmental Protection Agency (USEPA). While the design equations can be changed easily for city guidelines that is being designed for, the application of the tool presented would only be applicable in Austin, Texas. Figure 5 shows the tool being used with the City of Austin's DEM and NLCD 2011 datasets.

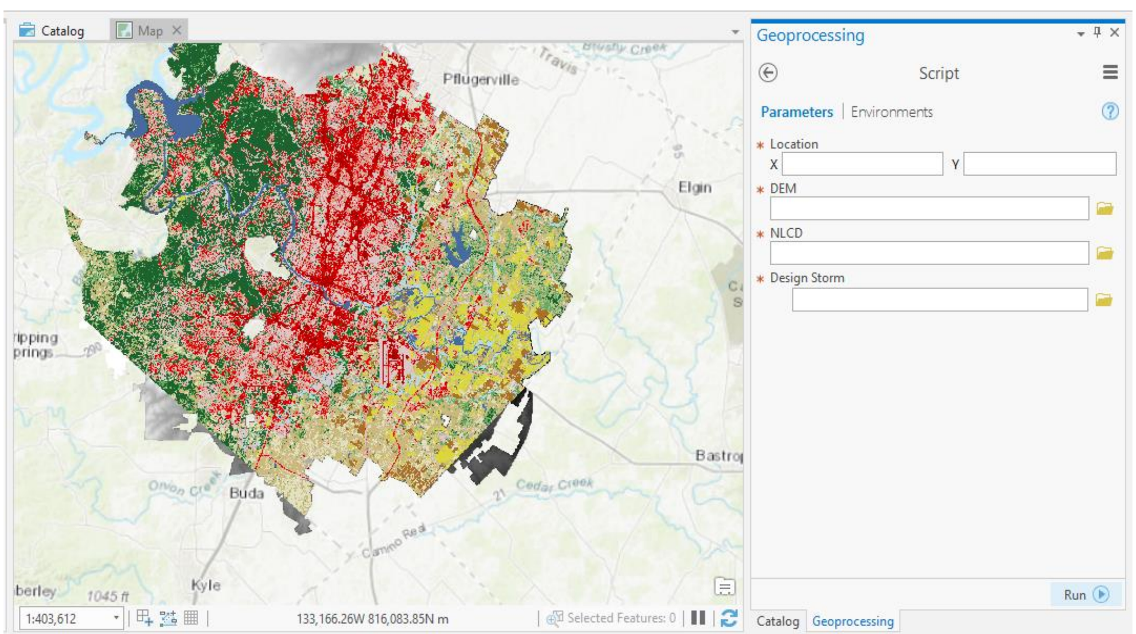

Figure 5: Rain Garden Design Tool Application in Austin, Texas

Results and Conclusions

4.1 Tool Results

The tool once ran will show the results, Rain Garden Surface Area (ft^2) and Rain Garden Depth (feet). Figure 6 shows the Rain Garden Design Tool in a close up view. The DEM is used for watershed delineating and to determine the amount of runoff going to the rain garden. The NLCD is used to determine the runoff coefficient for the rational method to determine the volume of runoff. The location of the rain garden can be input using *x*, *y* terminology. The original version of the tool allowed for the user to simply select an area, and the tool would run, but implementing the Python Add-In Tool was not achieved in the time frame of the project. The design storm can be changed for whatever year is desired (1, 2, 5, 10 …). All these inputs are needed for the tool to run. The output of the tool would then be the plan sheet with the depth and the surface area of the rain garden. An example output can be seen in Figure 7. Notice the only two differences between the standard and the output are the Surface Area and the Depth of the Rain Garden.

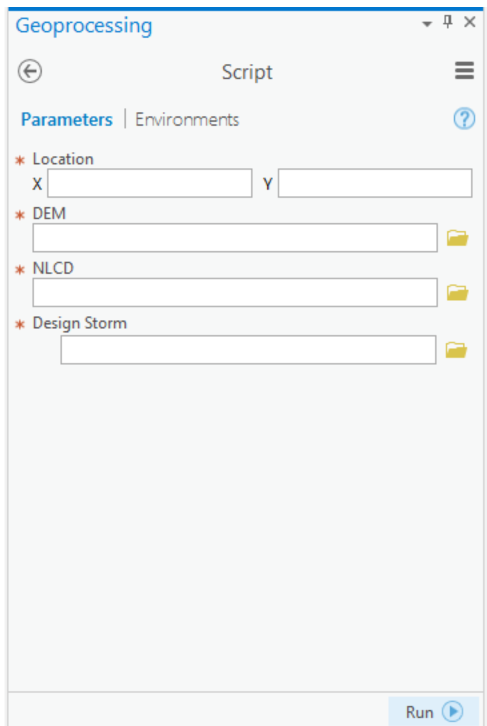

Figure 6: Close Up View of Rain Garden Design Tool

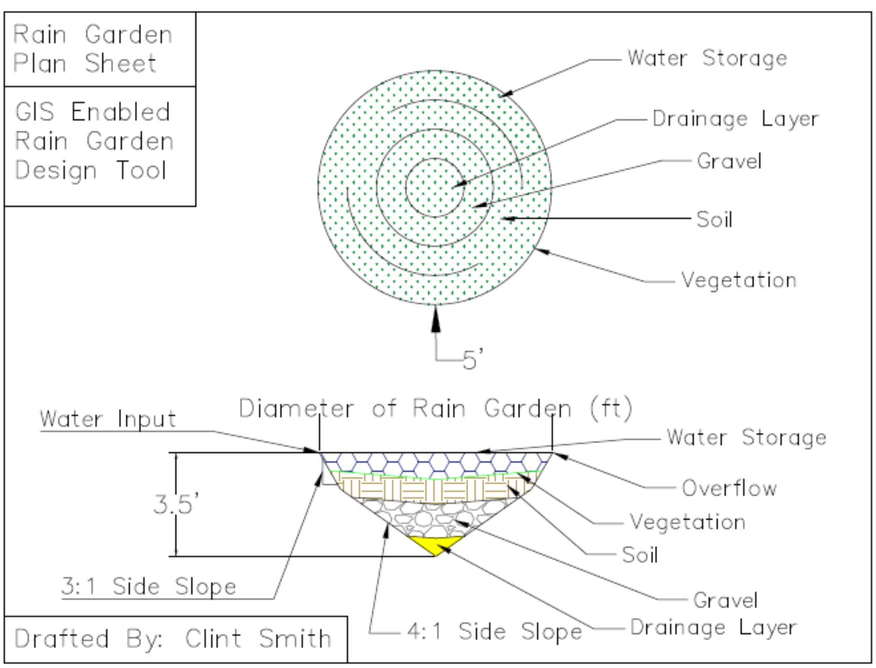

Figure 7: Rain Garden Design Tool Output

4.2 Tool Limitations

The tool has several limitations in that since rain garden design is not optimized across the country, the equations used are only for Austin, Texas and may not be the same as another city's or state's design equations. The tool also assumes that the soil in the area is a well-draining soil, and it does not use the HSG in the design. Since the tool does not account for the HSG, the volume of water is overestimated in the design rather than subtracting the amount that would go into the groundwater table. Another challenge is that the tool could iterate the design to a depth and surface area that is unreasonable (for example a depth of 7 feet and surface area of 20 ft^2). Adding a cap to the surface area and depths iterated would be ideal so then a rain garden that is unreasonably large would not be designed. The tool itself also assumes that any size rain garden will fit in the area, whereas the site could only allow for the first initial flush of runoff and not capture all of the stormwater that would actually drain to the area. The main limitation of this Rain Garden Design Tool, not the Culvert Design Tool used by Greer et al., is that the feature of clicking a point is not present.

4.3 Conclusions

GIS-Enabled GSI design is an iterative process that can be done completely within ArcGIS rather than using multiple programs and manual data retrieval. The process can be further optimized so then the design equations would be accessed from a table for the city or state that the rain garden is being designed in rather than having the tool only able to design rain gardens in Austin, Texas. The tool is useful for city engineers and planners, but more consideration and checking needs to be input to ensure that the design output is reasonable for the area. A rain garden can be designed by using widely available data from the USGS, NOAA for soil type and precipitation and the DEM and NLCD for Austin, Texas by the Rain Garden Design Tool. By using the Rational Method to determine peak flow the volume of water going to an area, the rain garden depth and surface area can be determined. The site dimensions and characteristics need to be known for the full-scale implementation of the output of the design tool. There are significant time savings to using the Rain Garden Design Tool because the research and time spent learning how to design is imbedded within the tool, as well as, the time spent retrieving and processing the data to get the final design. Thus, the Rain Garden Design Tool overcomes some of the barriers to implementing GSI. The template for the rain garden plan sheet is already developed as well, so the plan sheet would not need to be made either. Overall, the Rain Garden Design Tool is a tool that allows for city planners and engineers to quickly and easily design rain gardens in Austin, Texas using the COAECM design equations. Full-scale implementation has not been done or tested of this specific tool but has been tested by the Culvert Design Tool used by Greer et al. The Rain Garden Design Tool allows for more wide-scale implementation of GSI to replace gray infrastructure in stormwater treatment.

Works Cited:

1. Greer, A. D., Wilbanks, Z. B., Clifton, L. D., Wilson, B., & Graettinger, A. J. (2018). Advances in Civil Engineering GIS Enabled Culvert Design: A Case Study in Tuscaloosa, Alabama.

2. Walsh, C. J., Fletcher, T. D., & Burns, M. J. (2012). Urban stormwater runoff: a new class of environmental flow problem. *PLoS One*, *7*(9), e45814.

3. “Overcoming Barriers to Green Infrastructure.” EPA, Environmental Protection Agency, 22 June 2018, www.epa.gov/green-infrastructure/overcoming-barriers-green-infrastructure.

4. “Green Infrastructure and Ground Water Impacts.” EPA, Environmental Protection Agency, 22 June 2018, www.epa.gov/green-infrastructure/green-infrastructure-and-ground-water-impacts.

5. Maidment, D. R. (1996). “GIS and hydrologic modeling-an assessment of progress.” In *Third International Conference on GIS and Environmental Modeling, Santa Fe, New Mexico*.

6. Sample, D. J., Heaney, J. P., Wright, L. T., & Koustas, R. (2001). “Geographic information systems, decision support systems, and urban storm-water management.” Journal of Water Resources Planning and Management, 127(3), 155-161.

7. Sui, D. Z., & Maggio, R. C. (1999). “Integrating GIS with hydrological modeling: practices, problems, and prospects.” *Computers, Environment and Urban Systems*, 23(1), 33-51.

8. “ENVIRONMENTAL CRITERIA MANUAL City of AUSTIN, TEXAS Codified through Rule No. 161-18.05, Enacted June 12, 2018. (Supp. No. 8-2018).” *Municode Library*, City of Austin, 8 Sept. 2018, library.municode.com/tx/austin/codes/environmental_criteria_manual.

9. Viessman, W., Lewis, G. L., & Knapp, J. W. (1989). Introduction to Hydrology.