A GIS-BASED APPROACH TO GREEN INFRASTRUCTURE SOLUTIONS IN CHAMPAIGN'S GARDEN HILLS NEIGHBORHOOD

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1. Introduction

Garden Hills is a neighborhood within the near-northwest section of the City of Champaign, IL. The neighborhood consists of primarily single family one-story homes, approximately 60% of which are rental properties, and holds a median value of 38K, according to Realtor.com. This is well below Realtor.com's reported citywide median home value of 151K. The low values within the area are partially attributed to a lack of adequate infrastructure such as, street curbs, sidewalks, street lights and adequate stormwater drainage systems. The most pressing issue is the reoccurring flooding throughout the neighborhood. Therefore, this analysis focuses on the utilization of a GIS-based approach toward the feasibility of implementing green infrastructure to address the issue of flooding within the Garden Hills neighborhood. The project team used the definition of green infrastructure as described by the Illinois Environmental Protection Agency (EPA) as "Any stormwater management technique or practice employed with the primary goal of preserving, restoring, or mimicking natural hydrology". Green infrastructure was identified as a particularly attractive solution due to its low installation cost relative to traditional stormwater drainage infrastructure which includes underground pipe and sewer systems

2. Literature Review

Within the context of ongoing flooding issues in the Garden Hill neighborhood, the study team sought to work towards a GIS-based solution to identify areas best suited for GI with a goal of determining areas that would have the greatest impact on mitigating existing flood issues. The range of tools available in ESRI's ArcGIS software suite made paring down to a single approach a challenging task, therefore a review of existing literature that addresses the use of GIS software in determining site suitability for GI was conducted. One study in particular, by University of Nebraska's Ronald Marney titled *Creation of a GIS Based Model for Determining the Suitability of Implementing Green Infrastructure*, aligned closely with the goals of this study and was used as a primary source for structuring a suitability analysis. This study used ArcMap's "Weighted Overlay Matrix" tool to perform a multi-criteria analysis that weighted factors such as land cover, soil type, and proximity to buildings to determine site suitability for GI.

Marney's study integrated a range of sources related to planning for GI systems including public planning documents produced by the City of Omaha and New York City as well as a range of studies performed by the Environmental Protection Agency (EPA). Many of these plans were reviewed as potential secondary sources; however the majority consisted predominantly of best practices models and performance metrics for GI implementation, which offered more utility for a finer-grained plan on GI implementation rather than a neighborhood-scale GIS-based suitability study.

While Marney's paper was an integral guide for the eventual Garden Hills suitability study, there are several key aspects of this study's methodology that differentiate it from Marney's. Most notably, Marney's model assessed GI for the entirety of the Town of Berlin, Maryland whereas this study focused on a much smaller geographic area.

Additionally, this study included two criteria in the final analysis that were not factored into the Berlin, Maryland study.

3. Methodology

Conducting a GIS-study at the neighborhood-scale required several adjustments to Marney's model. Most notably the integration of a method for approximating the capacity of the neighborhood's current stormwater drainage infrastructure. This was done using the EPA's SWMM hydrology modelling program – a further discussion of how the SWMM model was used to produce a GIS layer to be used in the multi-criteria analysis is included in the next section. Additionally a criteria was added for land ownership, which was not a part of the Marney study. Because initial discussions with the City of Champaign indicated that publicly-owned lands offered particularly attractive sites for potential stormwater infrastructure and the potential to purchase vacant land for the same purpose existed, these criteria were given additional weight over privately-owned land. Further, instead of the Weighted Overlay Matrix tool, this study used the Raster Calculator tool to produce a final suitability layer due to the study team's greater familiarity with that tool and its ability to offer similar functionality.

These examples mark departures from the Berlin, Maryland study; however the majority of criteria used to determine GI suitability in Champaign were modeled on that study. Soil types were considered due the varying capacities for different soils to drain rainwater. Slope was considered due to its effect on the speed at which stormwater runoff travels. The role of land cover was a noteworthy similarity between both studies, with grasslands being viewed as most suitable for implementation of GI. In a slight departure from the Marney study, this study divided the “Distance from Buildings” criteria into two separate layers, with “Distance from Streets” being listed as an additional criteria which allowed different weights to be applied to each category. The resulting analysis provides a guide for the City of Champaign should decision makers decide to pursue GI implementation as a stormwater management approach. A more detailed discussion on the data used in this analysis and how the aforementioned criteria were input into GIS follows.

3.1 Data Acquisition

Data was collected from a variety of sources which were integrated into the data analysis in multiple ways. Soil type data was obtained from the United States Department of Agriculture’s Web Soil Survey. The original data used for land cover analysis was 2014 satellite imagery obtained from U.S. Geological Survery (USGS). This data allowed the project team to identify, classify and rate the various surface types. Slope data was obtained as LiDAR imagery from Illinois Height Modernization (ILHMP). Flood risk data was also derived from LiDAR imagery where it was used to create a Digital Elevation Model (DEM). The DEM is a three dimensional representation of elevation which visually communicates the spectrum of high and low points geographically. Data for the neighborhood’s existing drainage systems, distance from buildings and streets were obtained from the CIty of Champaign in the form of parcels and building footprint shapefiles. Land ownership data was also obtained from the City of Champaign in the form of shapefiles, highlighting which parcels were city-owned. The local storm data is acquired from EPA dataset.

3.2 GIS Based Analysis

3.2.1 Establishing parameters

Land cover was selected as one of the key criteria for this study. There are three types of land cover divided in this project: grasslands, trees and urban land. Urban land includes streets, buildings and all other impermeable structures and surfaces. Among all types of land cover, grassland was viewed as the most favorable land cover type as it is most suitable for the construction of green infrastructure. Usually it costs more time and money to remove existing trees and structures than to remove grasses.

Soil type was another criterion used. Soil type is made up of three categories, silt loam, silt clay loam, and urban land. These soils have different permeability due to different proportions of sand, silt and clay particles in the soil. The most preferable soil type would be silt loam in that it has the highest permeability which is easy for the green infrastructures to absorb and infiltrate stormwater.

Slope is also a key criterion. The parameter for gentle slope is 2 % or lower, while for steep slope it is 5.1-8 %. The ideal slope is moderate slope that has one foot change in elevation for every 20 to 50 feet. It prevents stormwater from accumulating in the area caused by the gentle slope or the flushing of stormwater resulting from the steep slope, which might add to the burden of the downstream pipelines.

Surface runoff caused by the storms is also an important factor that influences the site selection for green infrastructure construction. The three ranges of surface runoff are 1.95-1.24 cfs, 0.62-0.94 cfs, and 0.38-0.61 cfs. The area with the highest surface runoff represents that this area is most flooded by the stormwater and is most in need of GI, thus it is more favorable compared to other ranges.

The proximity to structures is used as another criterion taken into consideration. If GI is built too close to structures, it the potential for damage to building foundations becomes a risk. As a result, a ten foot buffer from all the buildings to avert unintended damages was established using ArcMap's buffer function. However, GI installed too far away from a building decreases its beneficial impact, therefore, the second non-favorable range was set as a 30 foot buffer from existing structures.

The criterion of city-owned parcels, vacant parcels and private parcels is a social and political factor based on the accessibility of the construction. City-owned parcels may be more easily used to construct green infrastructure, while privately owned parcels off the greatest obstacle to implementation as GI on a private land is based on the personal will of landowners.

3.2.2 Ranking parameters

The ranking of the aforementioned criteria were divided into three categories: high, medium and low. Different scores were assigned to each category, 3 as the most favorable, 2 as medium or somewhat favorable and 1 for low or generally unfacorable. Each criterion ranking is based on the established parameters written above. The full ranking system for the model is displayed in Table 2.

Table 2: Ranking of the Criteria

Rank Criteria	High 3	Medium 2	Low 1
Soil	Silt Loam	Silt Clay Loam	Urban Land
Slope	2.1%~5%	5.1%~8%	0~2%
Land Cover	Grasslands	Trees	Streets and Buildings
Runoff	0.95-1.24 cfs	0.62-0.94 cfs	0.38-0.61 cfs
Distance from Structures	10~30 Feet	>30 Feet	<10 Feet
Land Ownership	City Owned	Vacant Parcel	Private

3.2.3 Weighting the criteria

The weighing process is to give each criteria a numerical weight of less than one that add up to one with all weights combined. The higher the weighting coefficient, the more importance or emphasis applied to the criteria. Each criterion's weight were influenced by the Berlin, Maryland study. The applied weighing system can be seen in Table 3.

Table 3: Weighting of the Criteria

Criteria	Soil type	Slope	Land Cover	Runoff	Proximity to Structures	Land Ownership
Weight	0.20	0.20	0.20	0.20	0.10	0.10

3.2.4 The model

The Raster Calculator too was used to incorporate all rasterized criteria within the model. Each raster cell in the output follows the equation below.

$$\mathrm{Y} = \sum_{i=1}^{N} (WC_i)$$

Y stands for the final score of the location. W is the weight coefficient for a criterion. C is the The ranking number of each individual criterion. In this case, the subscript i would range from 1 to 6 because there are six criteria in total. This equation is to sum up each ranked criteria multiplied by its weight. N means end point which is six in this case.

3.3 Storm Water Management Model

Storm Water Management Model (SWMM) is a dynamic water simulation model for analyzing and planning related drainage systems and stormwater in the urban area of interest. In a time series, it tracks the stormwater runoff and water profile in drainage systems that within each catchment. In this project, SWMM is adopted to simulate the stormwater in the Garden Hills Neighborhood under the current status of existing drainage system. It not only evaluated the system capacity but also determined the location and time of flooding, which then produced the flooding risk layer that was used as a criterion in the multi-criteria analysis.

There are three components used in this SWMM is listed in the Table 1

Table 1

Components	Perimeters	Data Source
Existing Drainage System	Nodes and Conduits	City of Champaign
Water Catchment	Area, Outlet Nodes	LIDAR (Digital Elevation Model)
Precipitation Intensity	30 Minutes 5-year Storm	EPA (Figure 2)

The following assumption was made to simplify the system modeling: (1) The drainage system has the maximum capacity neglect of degradation. (2) The pipes are all made of concrete and the value of Manning's roughness coefficient is 0.013. (3) The slope of each pipe is in accordance with the surface slope above.

Based on the data from City of Champaign, the perimeters of manholes and the sewage pipelines were determined. (Figure 3) The structure was then set up in the SWMM model. In order to obtain the water catchment, the ArcGIS “Hydrology” tool was used to calculate the water basin and streams based on data from a digital elevation model of the neighborhood. (Figure 4, 5) Through trial and error, the suitable threshold for the designation of streams was selected, which a value of 1000 was determined to be suitable. Finally, the whole system was tested under the scenario of a thirty-minute five-year storm. Based on these results, the unit area of surface runoff was created as one of the criteria in multi-criteria analysis.

4. Site Visit: Accumulating the Ethnographic Flood Data

The rapid ethnographic study of the Garden Hills community consisted of a couple questions and a one-time drive through of the community with a person who has a longstanding knowledge of the neighborhood and the many issues within it, including the flooding areas.The question was asked for a tour of the areas which flooded. The physical response was one of confusion, while the verbal response stated “what do you mean? The whole neighborhood floods”. This posed a bit of a problem because taking photos of the entire neighborhood would not be sufficient for the purpose of our analysis. Therefore, the solution was to focus on the areas which experienced the most amount of flooding, where it disrupts the flow of traffic to the extent of the need to drive on an alternative route. The tour consisted of three areas where the informant was able to verify, and explain the extent of the flooding. All three of these areas were located in the streets, where it was evident that the topography of the street surface offered an ideal location for water to accumulate. These three areas included approximately 50 feet of Garden Hills Street near the south corner of Bradley, approximately 150 – 200 feet of Williamsburg Drive between the intersections of Thornton Drive Summit Ridge Road, and the entire intersection of Hollyhill Drive and Summerlin Lane. At all three of these locations, photos were taken and visual observations were conducted.

Once back in the computer lab, the project team followed the lab instructions from Task 3.2 of “Vineyard Suitability Analysis and Solar Potential with Spatial Analyst”, with slight modifications, to create the new shapefile correctly. During this process, the team aligned the site visit photos with google earth imagery to ensure the locations of the photos with its approximate location in ArcGIS. The accuracy of the shapefile polygons of the ethnographic flood areas are believed to be within 5-10 feet. Once all polygons were successfully created in a new shapefile, the output layer (Figure 1) was added to the general accumulation of data sources for further analyses applications.

For future ethnographic studies, the team would consider looking into having multiple informants who could describe and point out additional areas of importance. This would expand the study and verify previously obtained information from informants. However, for the purposes of this analysis, the three locations worked quite well. The added value from this shapefile is found within the verification of automated models of the SWMM application, as well as the identification of an ideal spatial point for the demonstration of the effects of implementation of a green infrastructure.

5. Results

5.1 Individual Criteria Analysis

5.1.1 Flooding Risk

Per the results of the SWMM model, the surface runoff in the Garden Hills Neighborhood reaches its peak value after twenty minutes during a five-year storm. At that time, flooding has taken place in roughly half of the neighborhood’s drainage system. Figure 6 shows the runoff in each water catchment and flooding by node, colored from blue to red. The warm color shows the higher runoff area and flooding nodes. The southwest area of the neighborhood has the largest runoff. On the other hand, compared with SWMM model, the map of unit area surface runoff shows the spatial correlation between runoff and the drainage system (Figure 6, 7), which indicates that the current flooding in the Garden Hill Neighborhood is due to the insufficient capacity of the drainage system. This may also be caused by degradation of the existing drainage pipelines which have been in place for over fifty years. In the flood risk analysis, the unit area runoff was weighted as 20 percent and divided into three classifications. From high value to the low value, the classification is from 0.95 to 1.24 cfs, 0.62 to 0.94 cfs, 0.38 to 0.61 cfs respectively.

5.1.2 Soil

Figure 9 shows the soil base in the Garden Hills Neighborhood. From the data retrieved from Web Soil Survey, there are a total of six different soil types present in the neighborhood. In order to simplify the process, the K-factor parameter was considered to determine the drainage characteristics for each of these soils. It turned out that all these types of soils can be summarized into three categories in terms of the characteristics of drainage: silt loam, silt clay loam and urban land. After the three categories were placed in the appropriate generalized type used in the ranking as shown before, the following map was generated to show the ranked soil types. The map helps to identify each criterion as well as visualize the ranking and locations of each soil type.

5.1.3 Slope

The neighborhood's exing slope characteristics are shown in Figure 10. The slope layer was created from the DTM model retrieved from LiDAR, which has a resolution of one meter. Rather than simply designing all the criteria to the soil types, the layer of slope required to reclassify all the floating point values in the raster dataset, which was easily accomplished by the properties function of the raster set and the reclassify function in ArcMap. The map helps to identify each of the particular criterion of the percent slope as well as easily visualize the ranking and locations of each ranking of percent slope.

5.1.4 Land Cover

Figure 10 was created from the satellite image data as followed. This map contains the ranked land cover criterion based on the established parameters discussed in the previous ranking of criteria part. The raster layer of land cover was built by creating manual training dataset and then utilizing the maximum likelihood function in ArcMap. By this method, more precise land cover of the area would be defined, which helps for further analysis with other rankings of criterion. The map helps to identify each of the particular criterion of the land cover as well as easily visualize the ranking and locations of each ranking of land cover.

5.1.5 Proximity to Structures

The proximity to structures layer is shown in Figure 11-12. Here the structures include streets and buildings, which were retrieved from the City of Champaign. After considering the parameters of how proximity to structures might affect the installation of GI, the layers of proximity to streets and buildings were created through a series of buffers using the multi-ring buffer function in ArcMap. Buffers were created for 0-10 feet, 10-30 feet, and >30 feet. The maps enable ease of viewing for this particular criterion for either streets or buildings and were necessary as a visualization to show the ranking criterion and the locations of each ranked buffer or distance. With the help from the criterion in different places, unintended damages can be averted from existing structures.

5.1.6 Land Ownership

Figure 13 shown below demonstrates the ranked land ownership including public parcels, vacant parcels as well as private parcels. This map was created out the established parameters based on the discussion in the part of ranking of criteria. This map was created with land use data from the City of Champaign. Publicly owned land is easily and efficiently applied with building green infrastructure while vacant parcels are also convenient to get transformed. Therefore, public and vacant land received a higher ranking than private land. The map helps to identify each of the particular criterion of the land ownership as well as easily visualize the ranking and locations of each ranking of land ownership.

5.2 Weighted Sum Analysis

Figure 14 shown below provides the study’s final analysis. The map was created from all the layers of all the established parameters from the previous discussion. The weighted sum analysis combined all these parameters and shows the final consideration for suitable development area for green infrastructure. The weighed sum can be accomplished by utilizing the raster calculator tool in ArcMap and using the model as shown before to come up with the equation. This map provides a floating-point value map for green infrastructure in the study area.

5.3 Targeted Area

After controlling the classification range and threshold values, the suitable areas for green infrastructure were mapped in Figure 15. It shows that there are several places suitable for installing GI in the neighborhood. A test case for studying the impact of GI implementation in one of the areas determined to be most suitable was conducted based on the findings of the multi-criteria analysis. A discussion of the test case study follows.

5.4 Test case

Based on the suitability analysis, the most representative location, where the longest drainage pipeline is, was chosen for the test case. The street green infrastructure is applied into the test case and tested in SWMM. Under the concept of water balancing, the green infrastructure is functioned as storage unit in the system. The weirs that can control water depth is adopted at the end of the green infrastructure. Therefore, it can store stormwater indefinitely. Compared to the results in Figure 17 and Figure 18, under the same storm conditions, the flooding has been alleviated and the extra water is stored in the green infrastructure after the storm. With further adjustment, the green infrastructure can handle the flooding more efficiently, which also have economic advantage compared with the replacement and maintenance of a large area of the drainage system. The further research is required to reveal the feasibility of the different types of green infrastructure in the Garden Hill Neighborhood.

6. Conclusion

The findings of this study indicate a high probability that green infrastructure presents a viable approach to mitigating existing flooding issues in Garden Hills. By weighing factors such as soil type, flood risk, and existing buildings, this multi-criteria analysis offers results based on a comprehensive range of existing neighborhood conditions. However, it is important to note this study is only a first step in moving toward a solution to the flooding issues that face Garden Hills. While the City of Champaign and other decision makers must weigh a number of factors when considering how to use limited public resources to confront and eventually correct stormwater drainage issues, the use of GIS software offers the ability to factor a range of site conditions to determine a path forward for implementation solutions. Green infrastructure was the focus of this study due to its potential as a quick and cost-effective solution, and based on the findings of this study, GI also offers an effective solution to mitigating flooding as well. This study's authors hope the conclusions of this study will help to better inform local decisionmakers as they tackle the difficult task of improving the built environment of the Garden Hills neighborhood.

APPENDIX

Figure 1: Site Visit Ethnographic May Layer

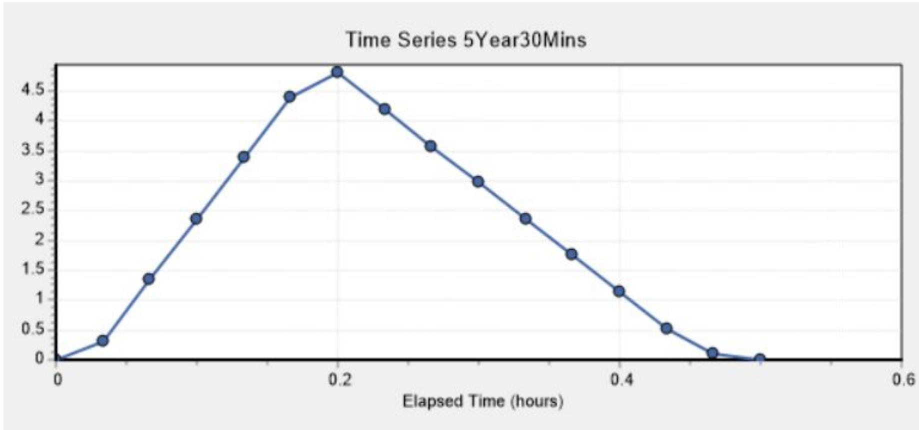


Figure 2: The five year thirty minutes storm in City of Champaign

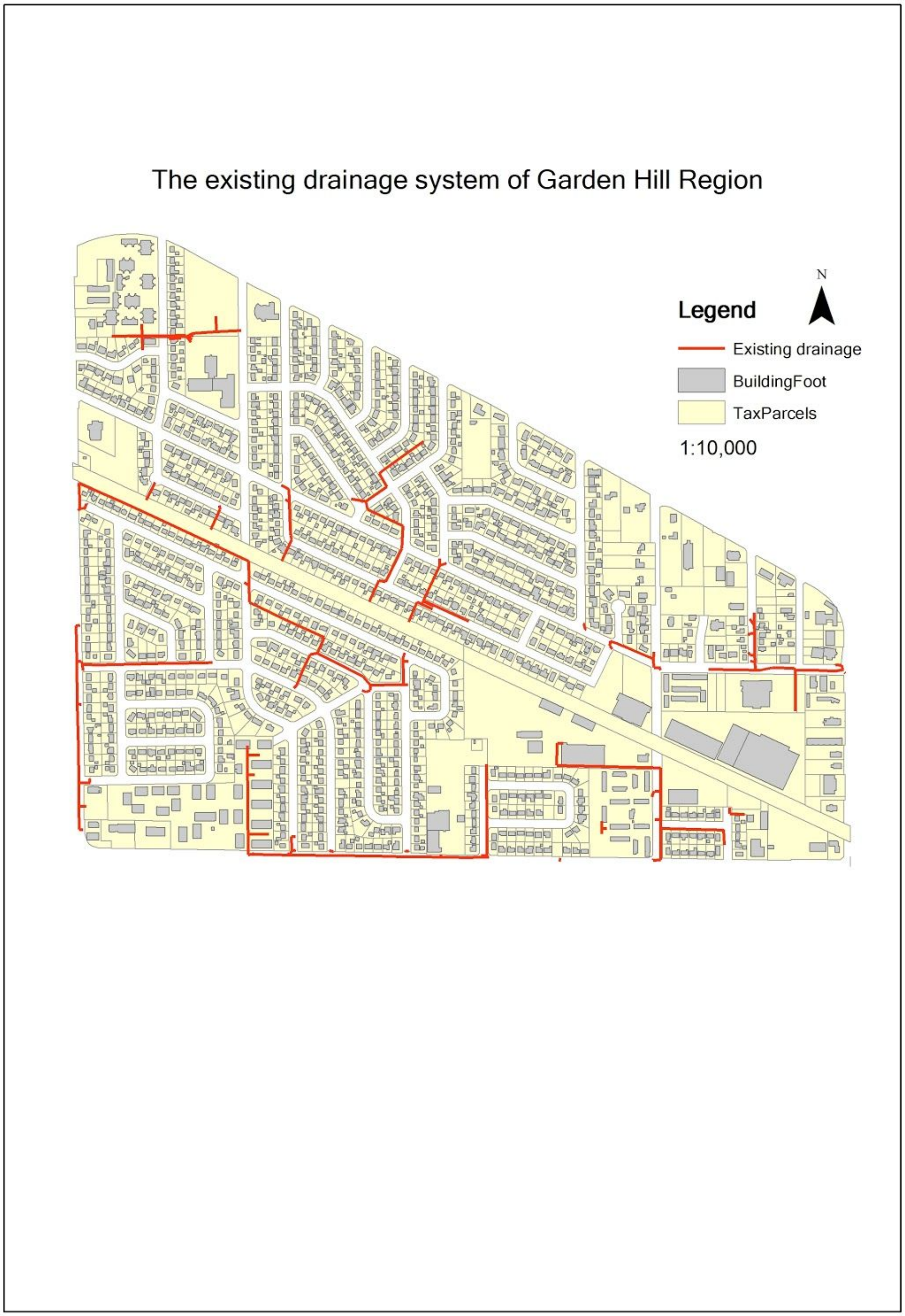


Figure 3: The existing drainage system of Garden Hill Region

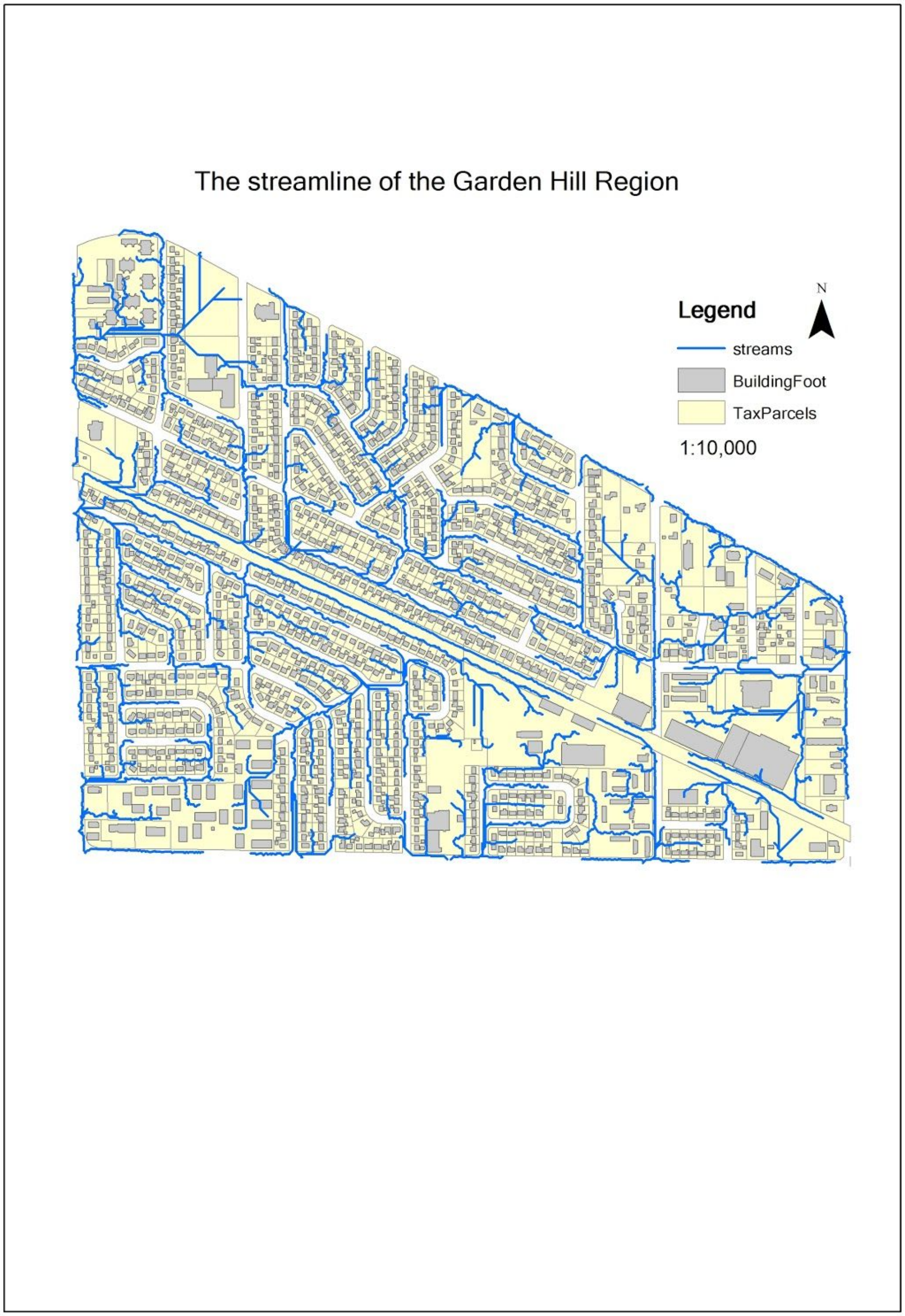


Figure 4: The stream within the Garden Hill Region

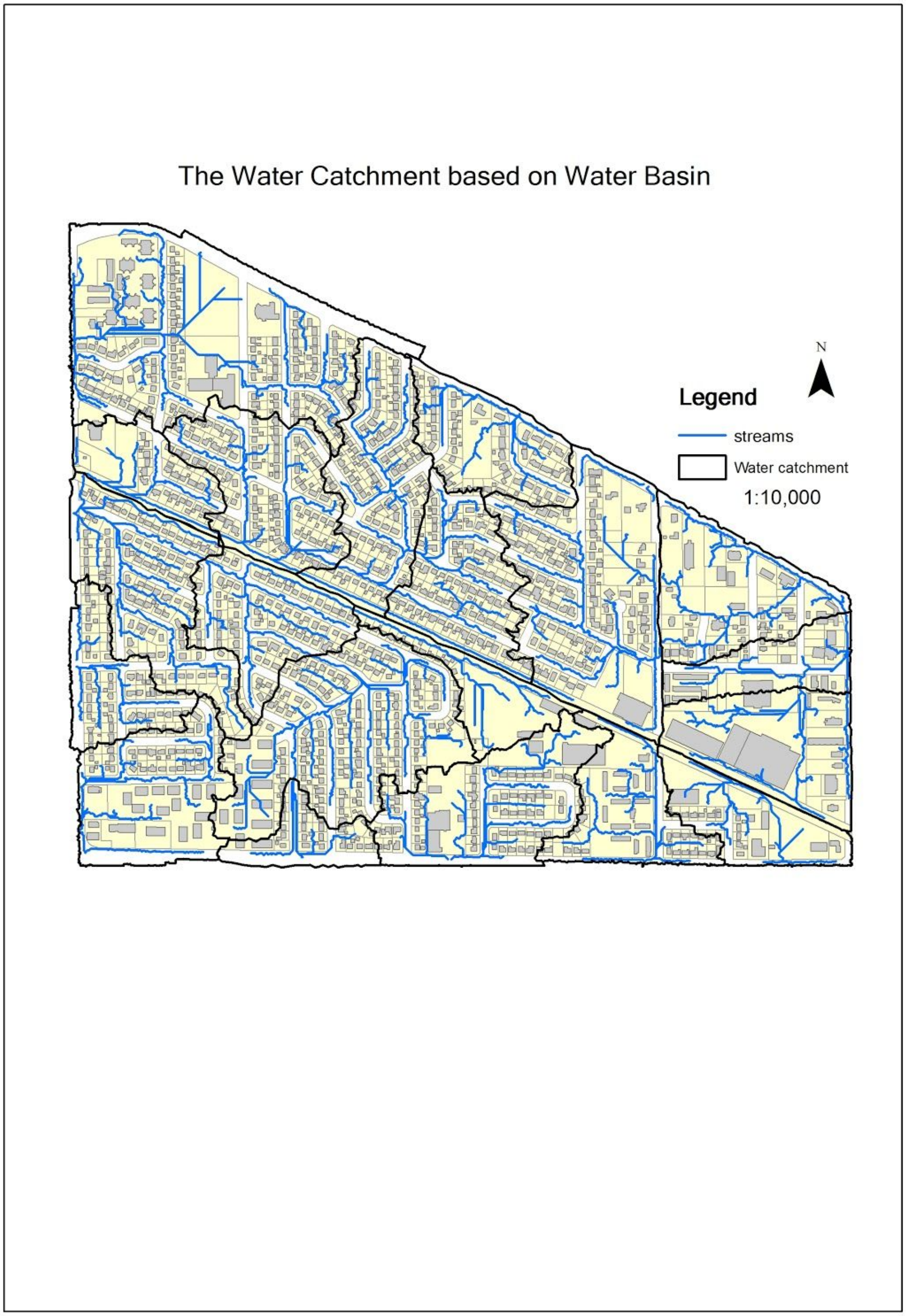


Figure 5: The water catchment in the Garden Hill Region

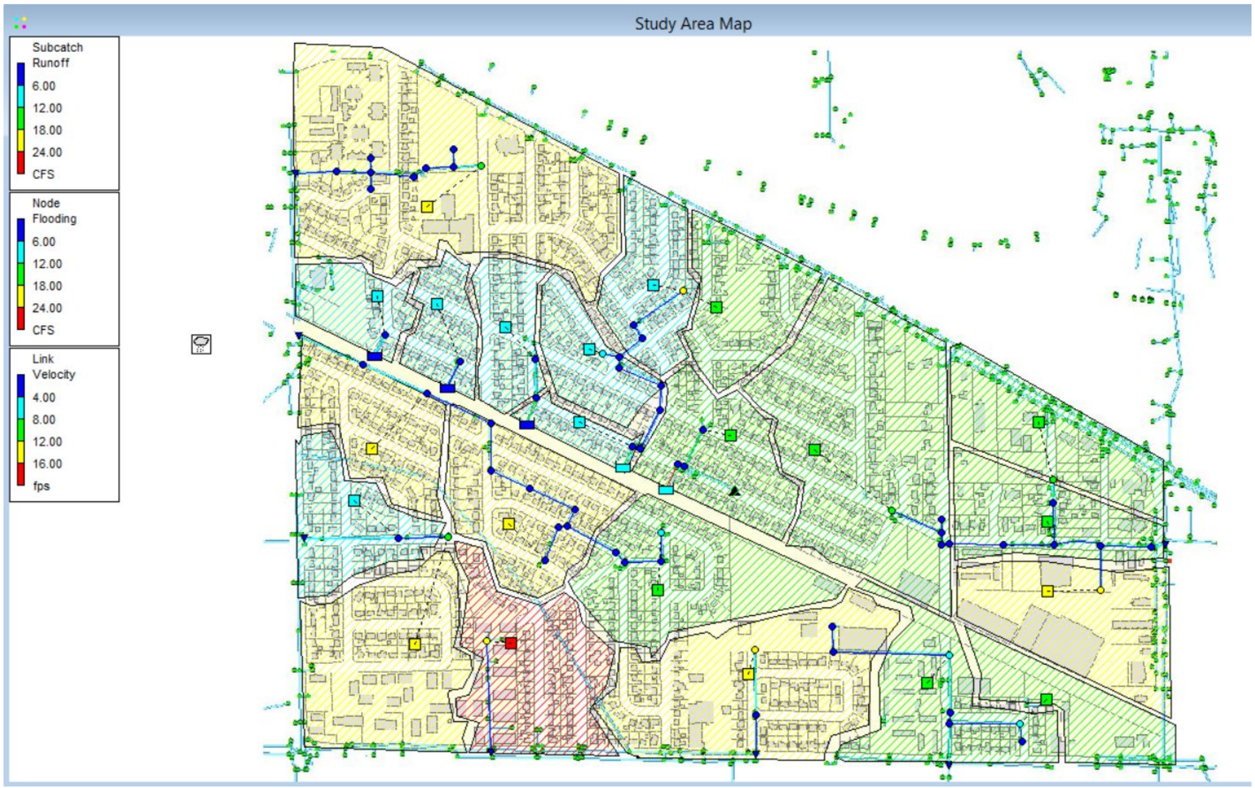


Figure 6: The 20-min storm result in SWMM

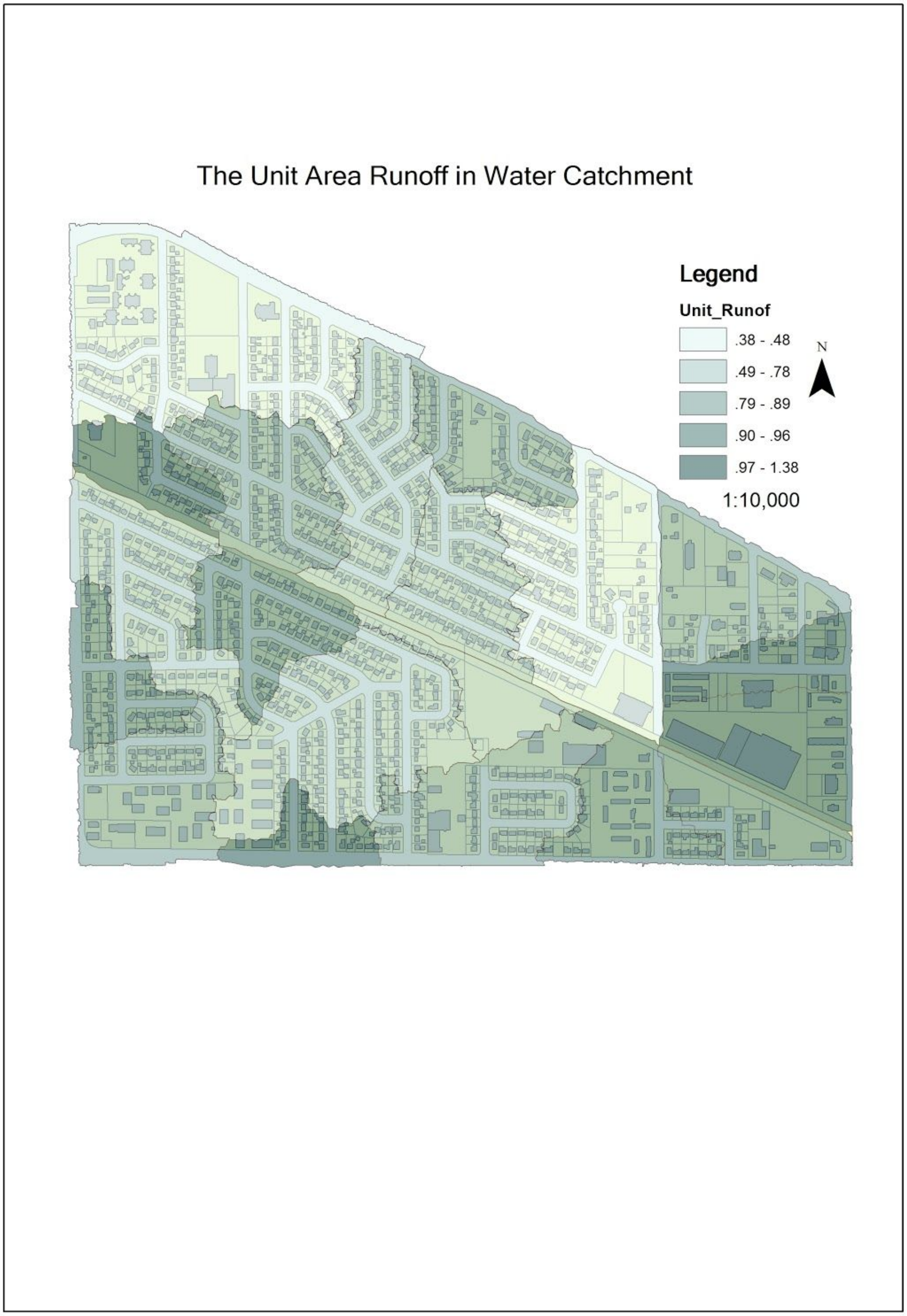


Figure 7: The unit area runoff in water catchment

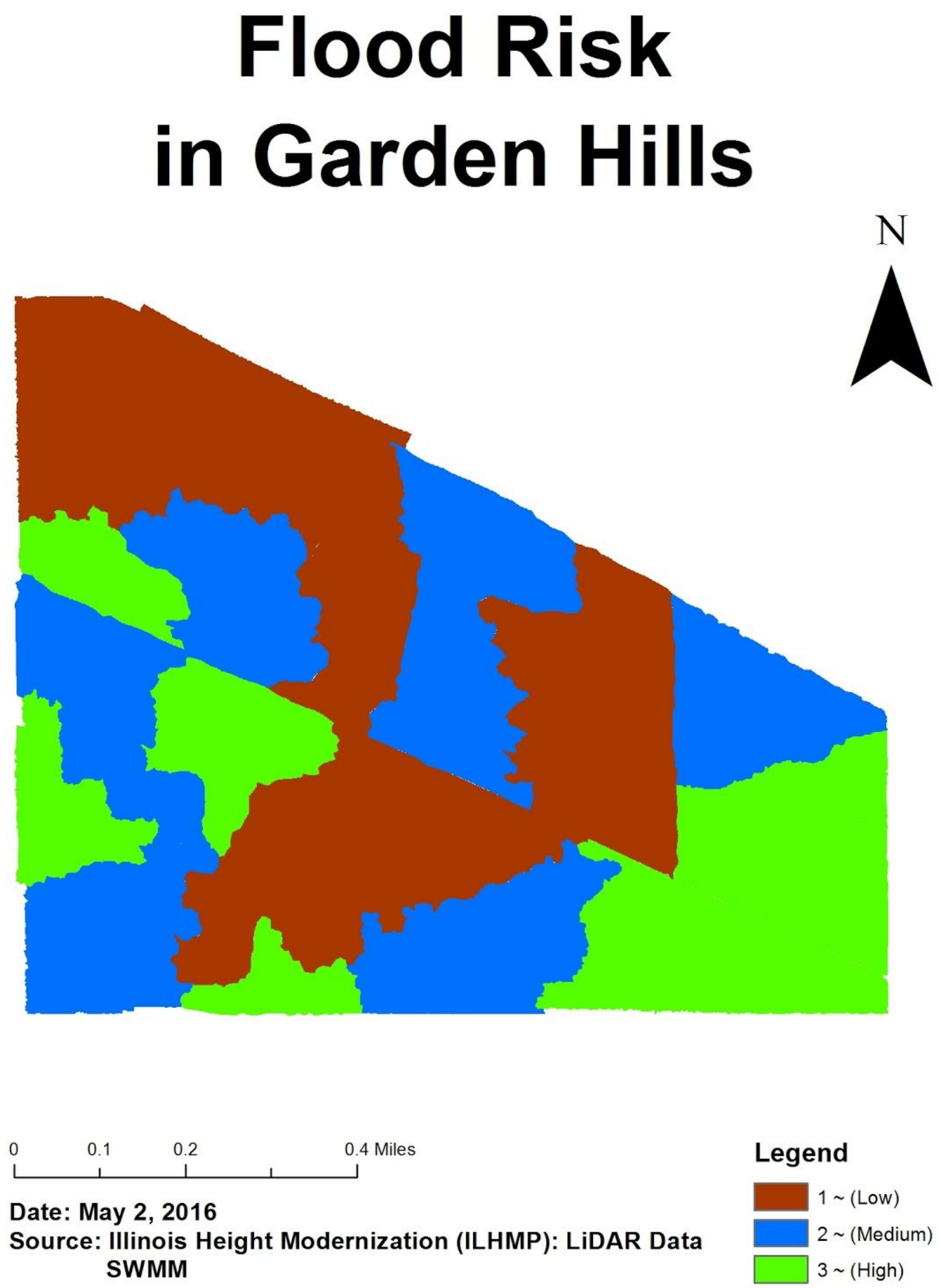


Figure 8 Flood Risk in Garden Hills

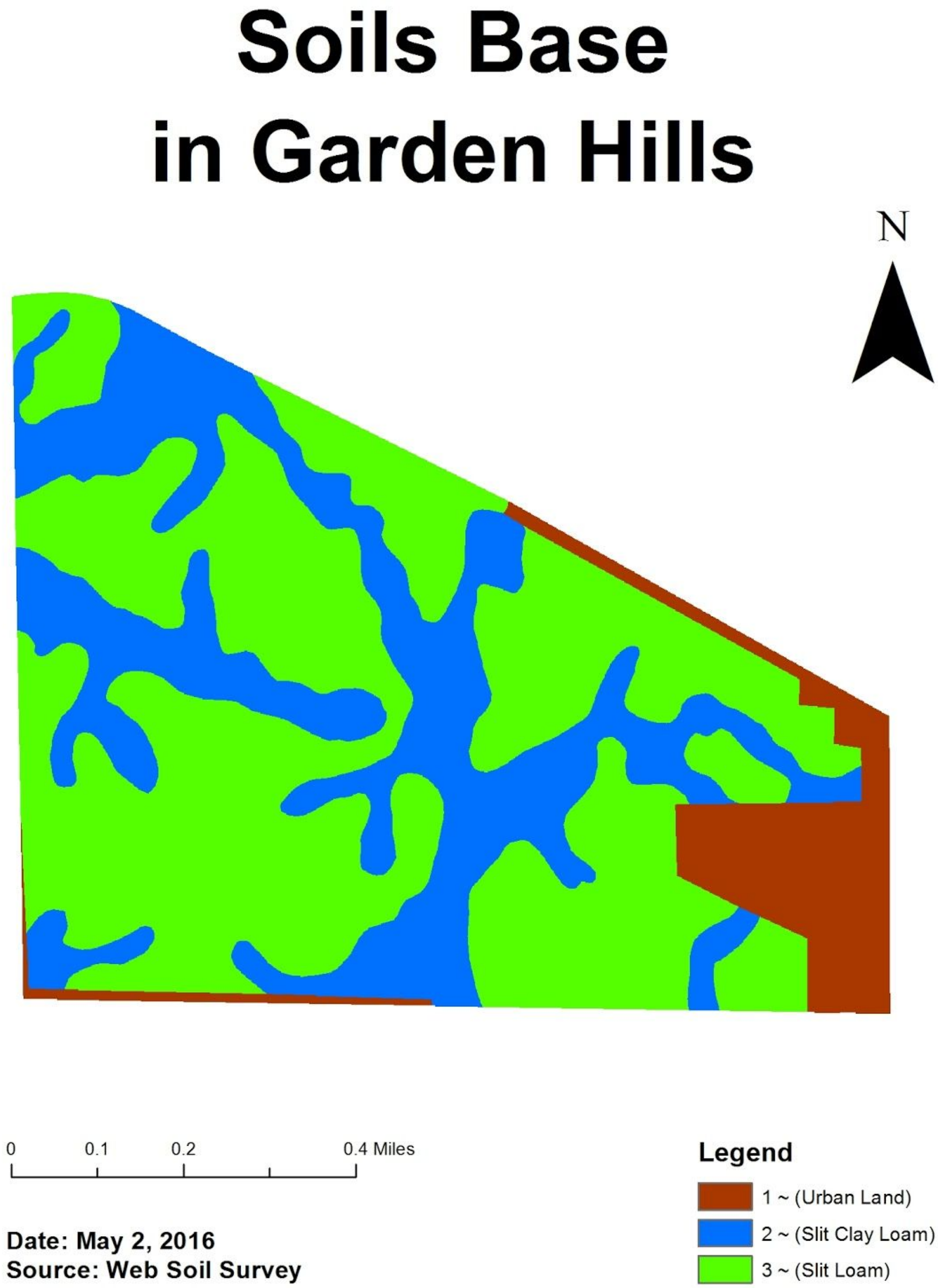


Figure 9 Soil Base in Garden Hills

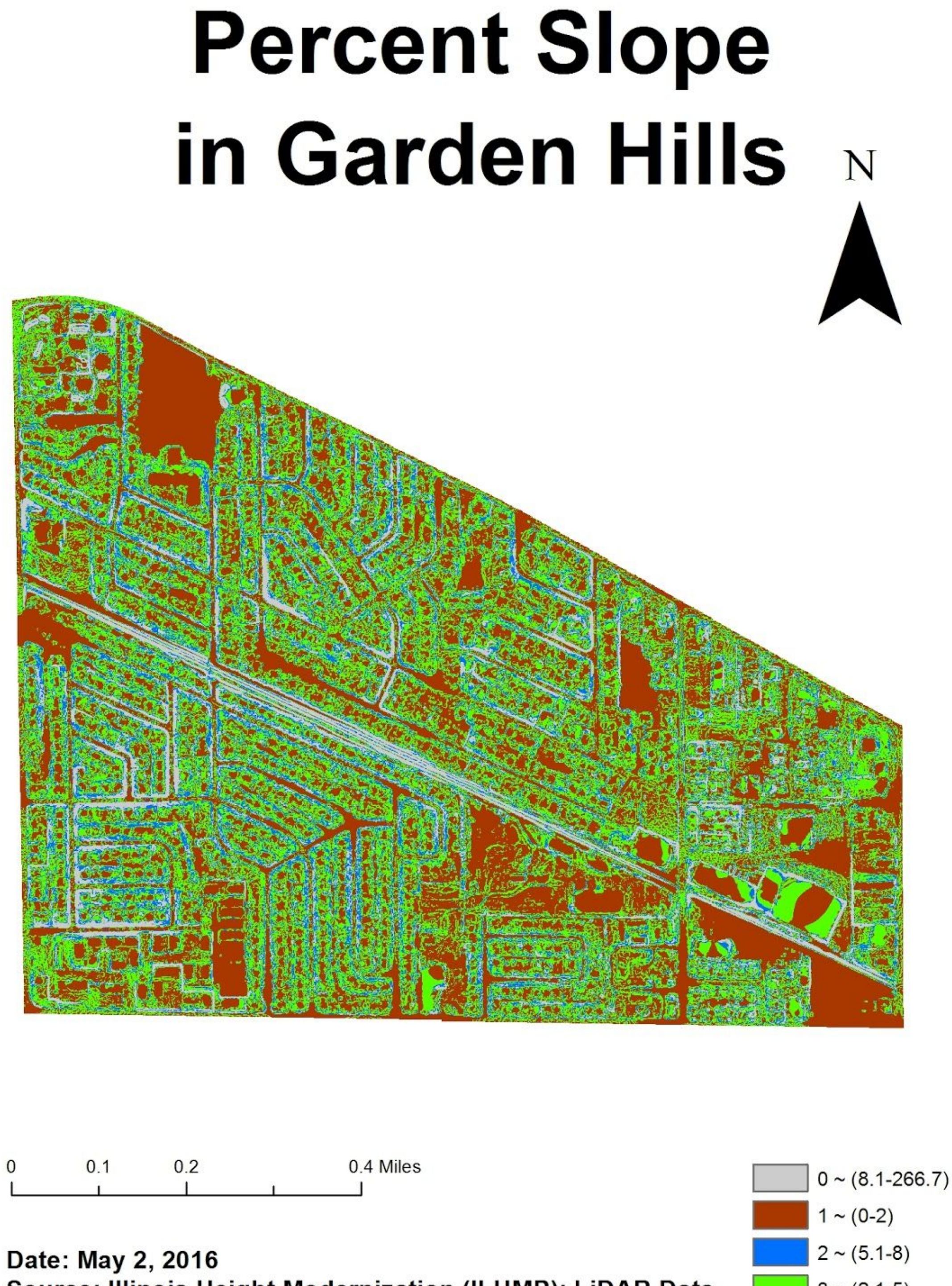


Figure 10 Percent Slope in Garden Hills

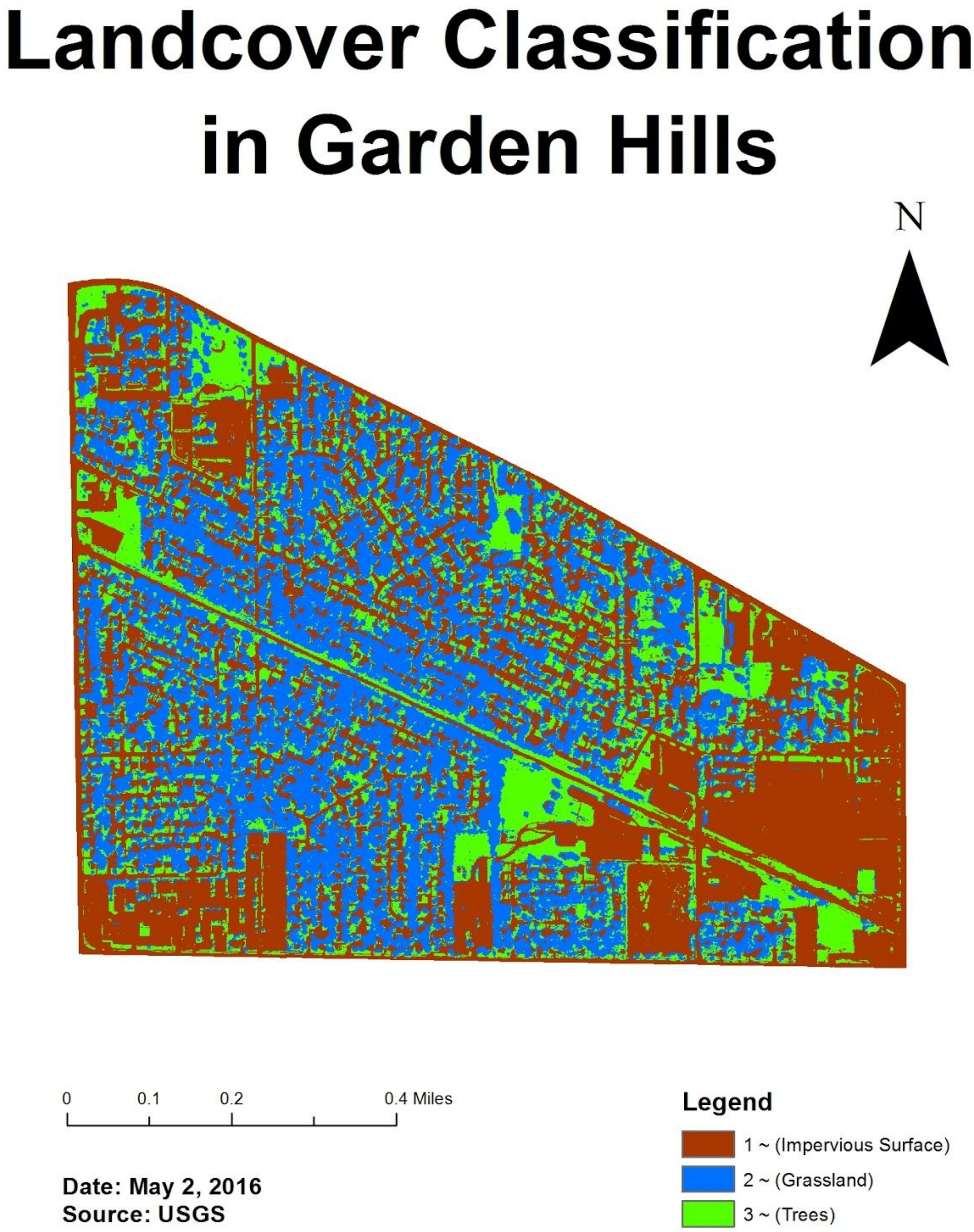


Figure 11 Landcover Classification in Garden Hills

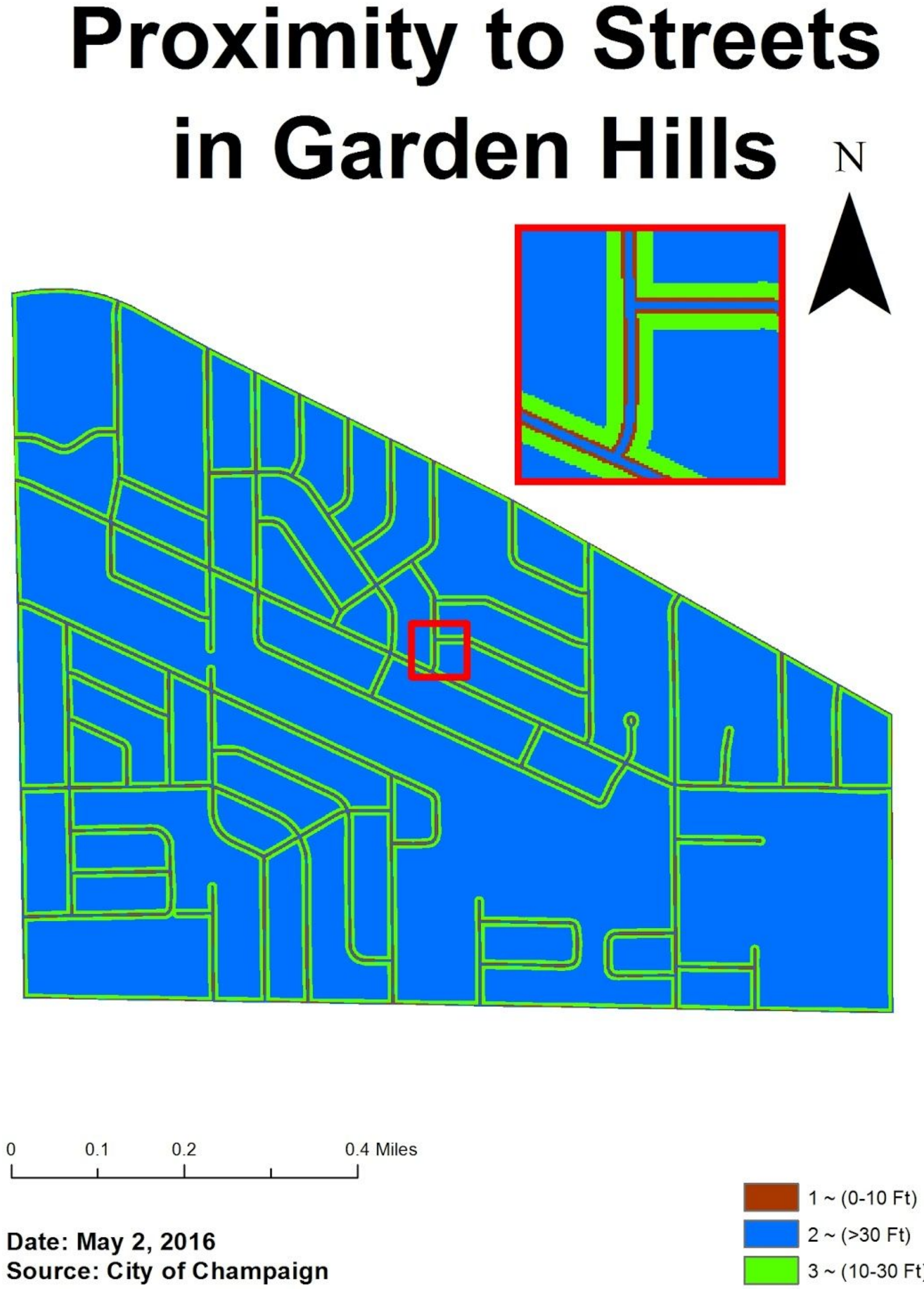


Figure 12 Proximity to Streets in Garden Hills

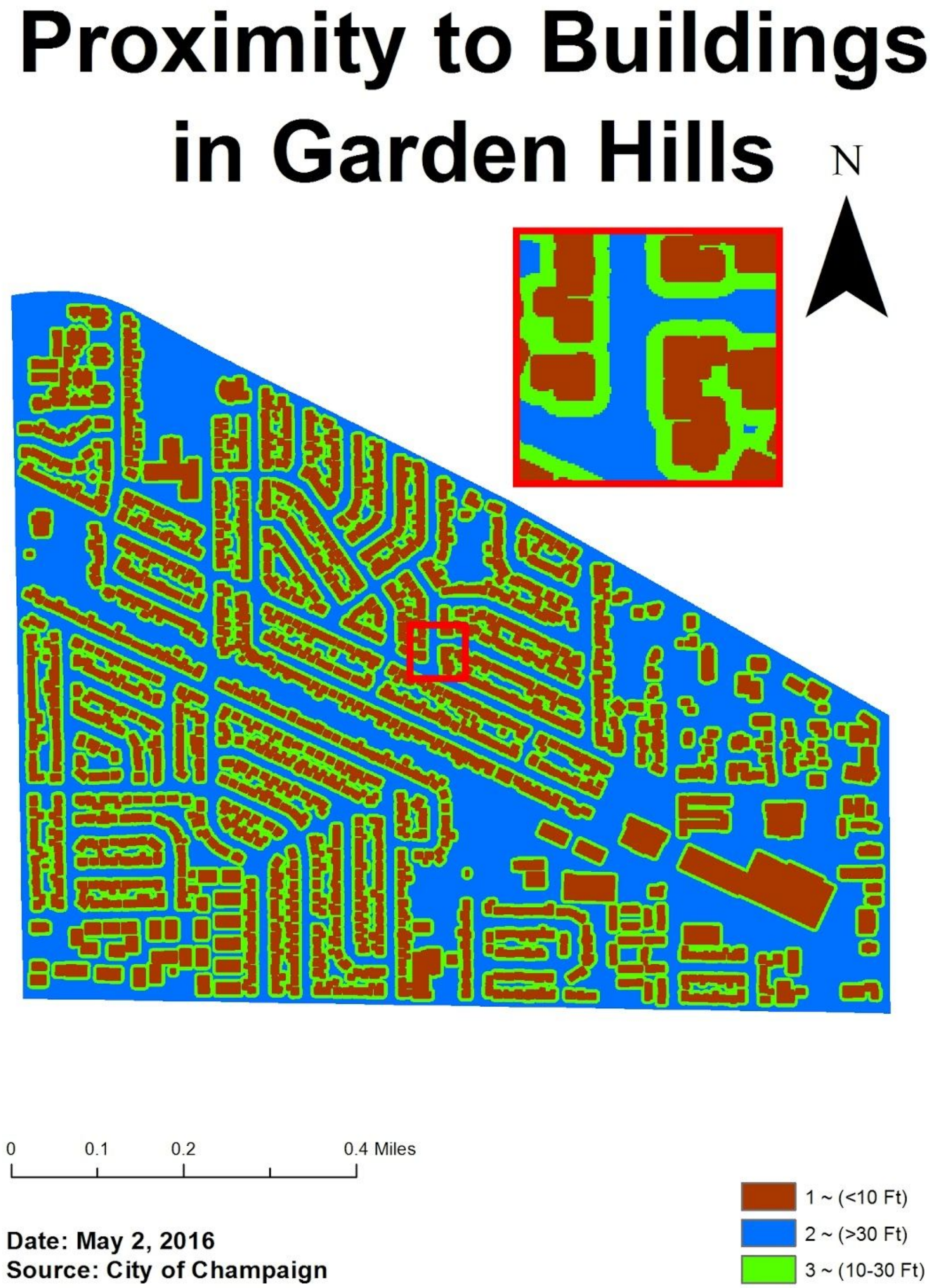


Figure 13 Proximity to Building in Garden Hills

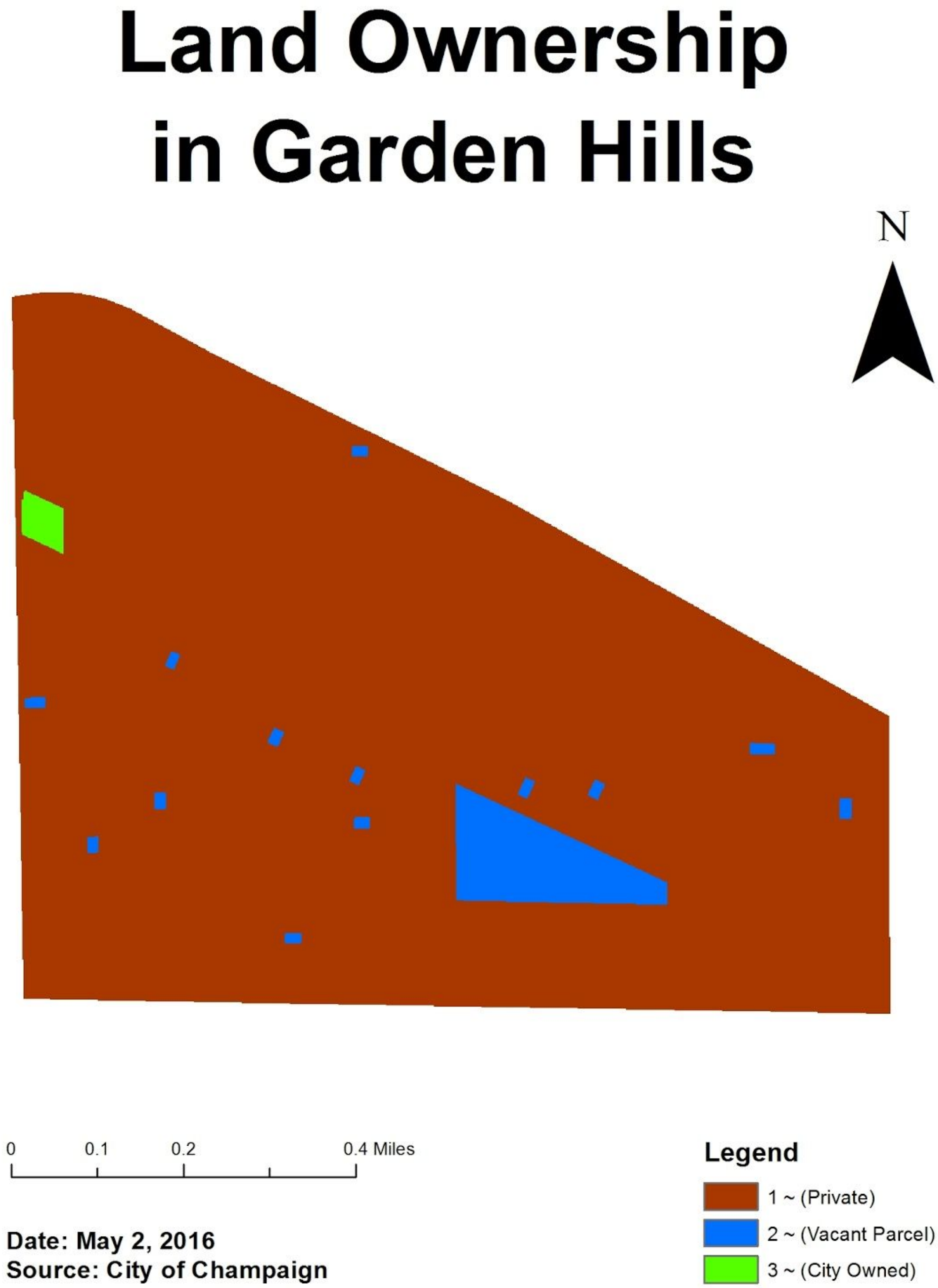


Figure 14 Land Ownership in Garden Hills

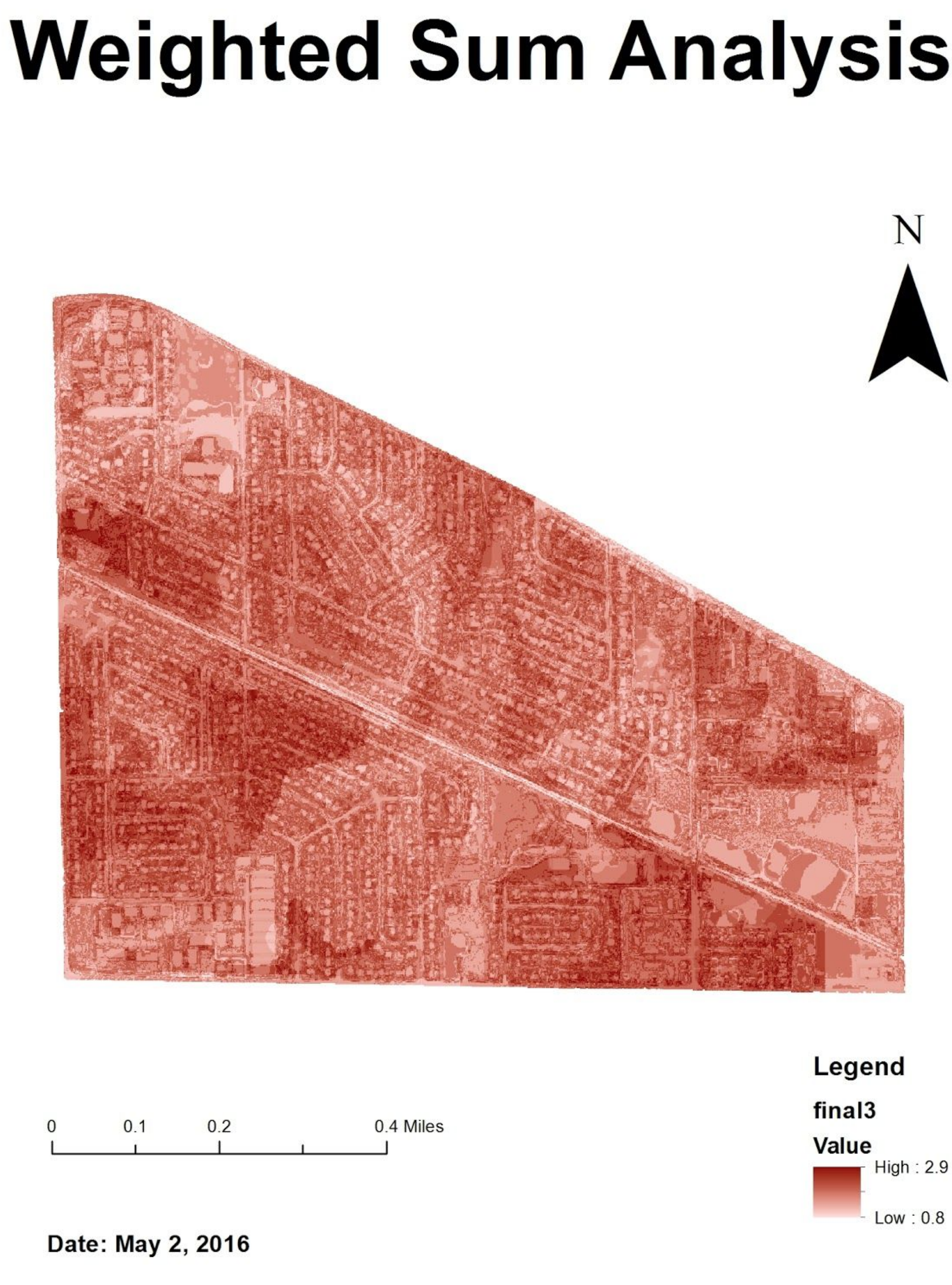
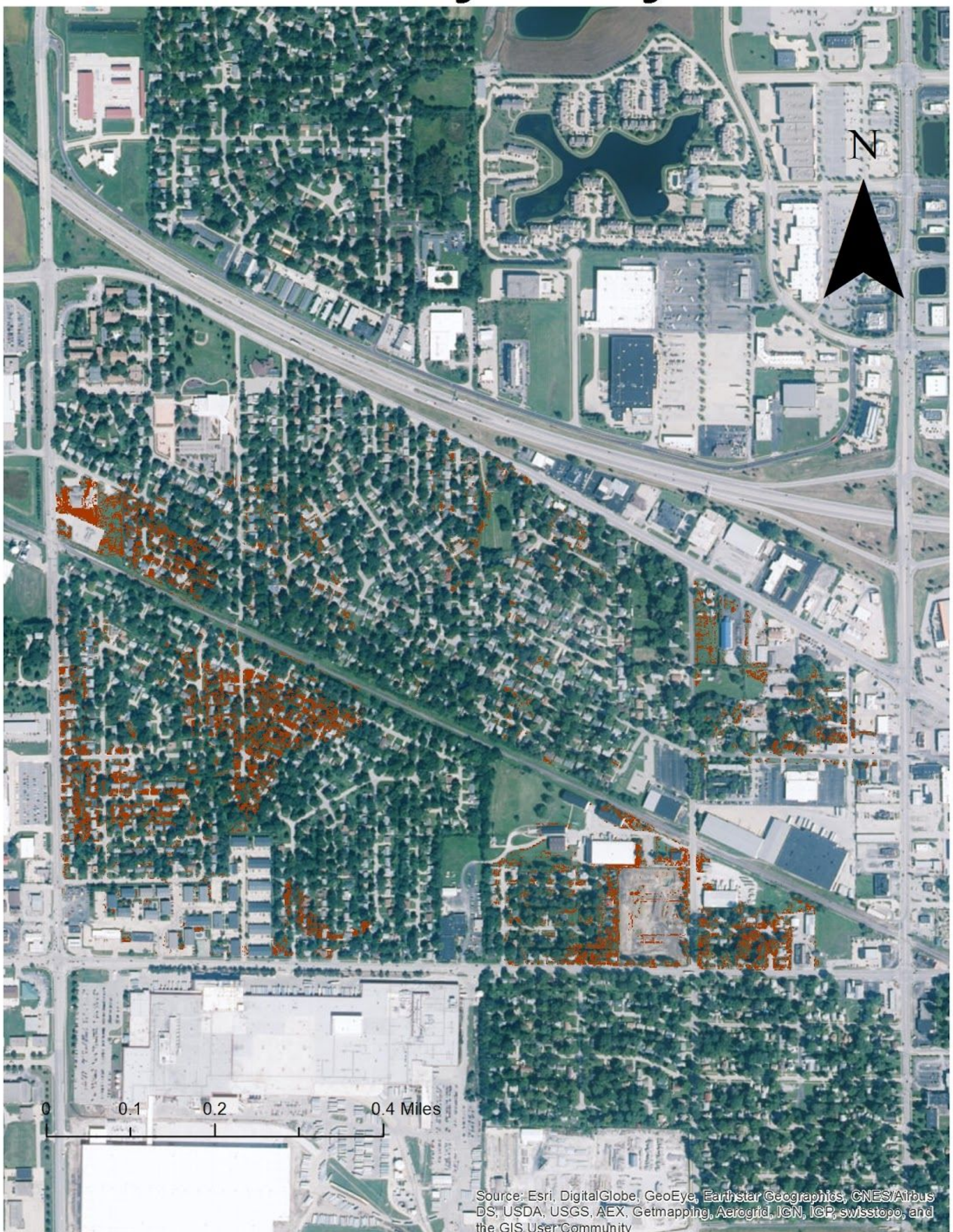


Figure 15 Weighted Sum Analysis

Suitability Analysis



Date: May 2, 2016

Suitable for GI Development

Figure 16 Suitability Analysis

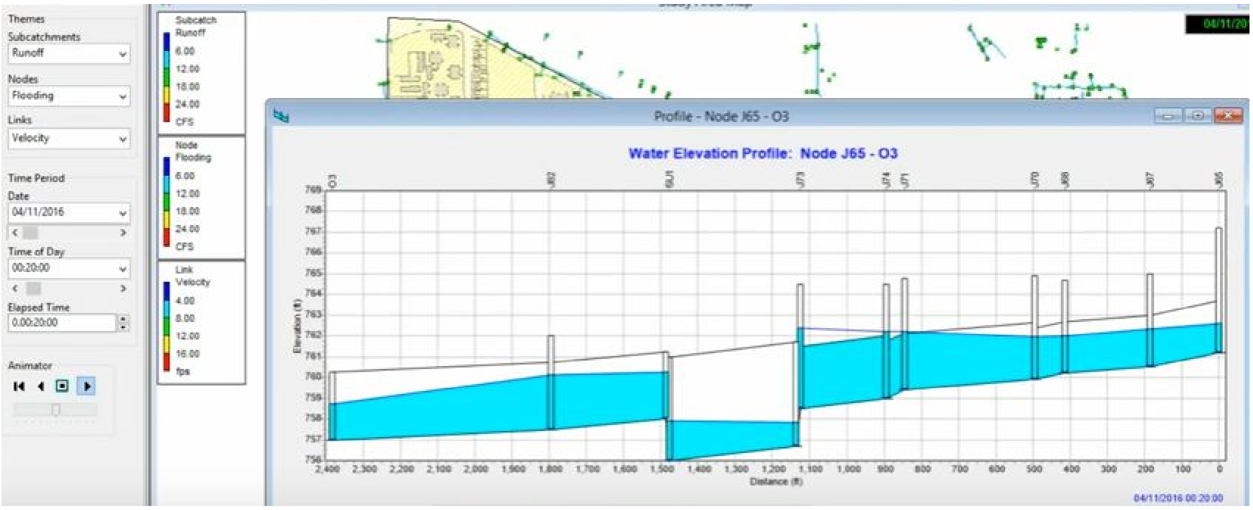


Figure 17: The water profile in green infrastructure after 20 min

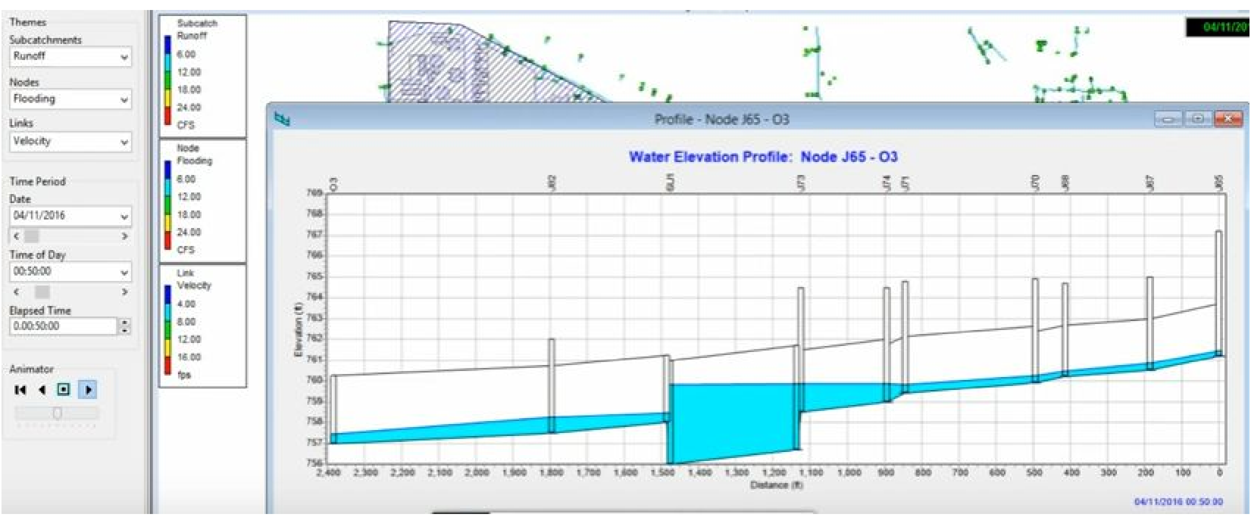


Figure 18: The water profile in green infrastructure after 50 min